The Pennsylvania Department of Environmental Protection's Review of the Gas Well Pillar Study Update Completed by the John T. Boyd Company

An internal review of the report "Gas Well Pillar Study Update, PO 4300311202 and 4300400813" by the John T. Boyd Company, March 2016

Office of Active and Abandoned Mine Operations
Office of Oil and Gas Programs

September 6, 2016

5000-RE-DEP4867 12/2016

Contents

Executive Summary 2

Background 2

Approach and Conclusion 3

Workgroup Participants 6

Coal Pillar Study Events Timeline 7

Review of the Boyd Report 9

Editorial/Clarification Comments 9

Proposed Pillar Specifications and Comprehensiveness of Updated Study 10

Mining Around Wells Not Meeting Safeguard Distances 14

Alternative Methods of Casing and Cementing for Wells in Anticipated Gate Road Pillars Not Meeting Safeguard Distances 15

Drilling Through Pillars in Mined-Out and Gob Areas 15

Conclusion 16

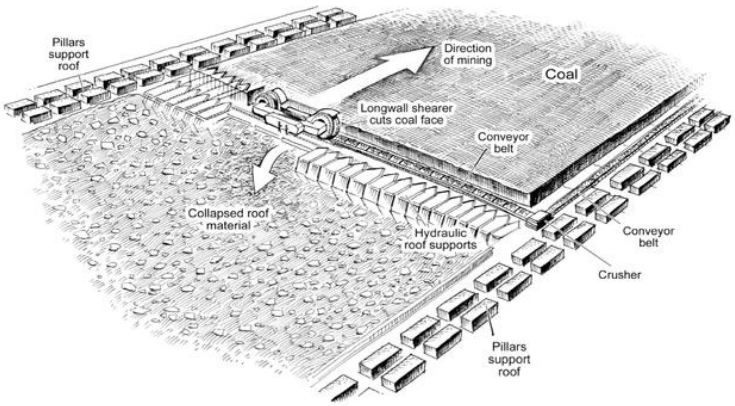
Appendix: MSHA December 3, 2015 Comments 18

Executive Summary

Background

This is a summary of the Department of Environmental Protection's (Department) internal review of the October 2012 Boyd Gas Well Pillar Study Update report (" report") and its subsequent revisions. The Department submitted a letter to the John T. Boyd Company closing out the contract on February 24, 2016.

Currently, coal pillar sizes suitable for ensuring the integrity of gas wells and the safety of coal miners in Pennsylvania are governed by the Joint Coal and Gas Committee report which was published in 1957. Given the considerable extent to which the techniques and processes used by both the coal and gas industries have changed since the study was completed in 1956, an update was deemed to be necessary by both industries and the Department. These changes include modern longwall mining methods as compared to the room-and-pillar method that dominated production in 1956. As shown in the figure below, abutment support pillars typically serve as the location for gas wells and must be sized to resist failure/deformation in order to provide adequate protection of a well's integrity and ensure miner and public safety.



Reference: US Securities and Exchange Commission, accessed 8/21/2016 at https://www.sec.gov/Archives/edgar/data/1037676/000104746914001604/, page 11.

The Boyd report was developed in response to Act 2 of 2011, which was passed on May 13, 2011 and amended the Coal and Gas Resource Coordination Act. Act 2 of 2011 also provided additional requirements for permit applications and the well completion process, introduced the concept of well "clusters" for multi-well pad development, established minimum distances between gas well clusters in areas underlain by workable coal, and granted the Environmental Quality Board the ability to promulgate regulations changing the minimum protective area surrounding a well or well cluster, regardless of a well's status, based on a coal pillar support study (required under section 12.1 of the amended Act).

The pillar support study was required to address these points:

1. The appropriate pillar size around active, inactive, and plugged wells and well clusters to ensure the integrity of the well and to adequately protect the coal seam and coal miners, and

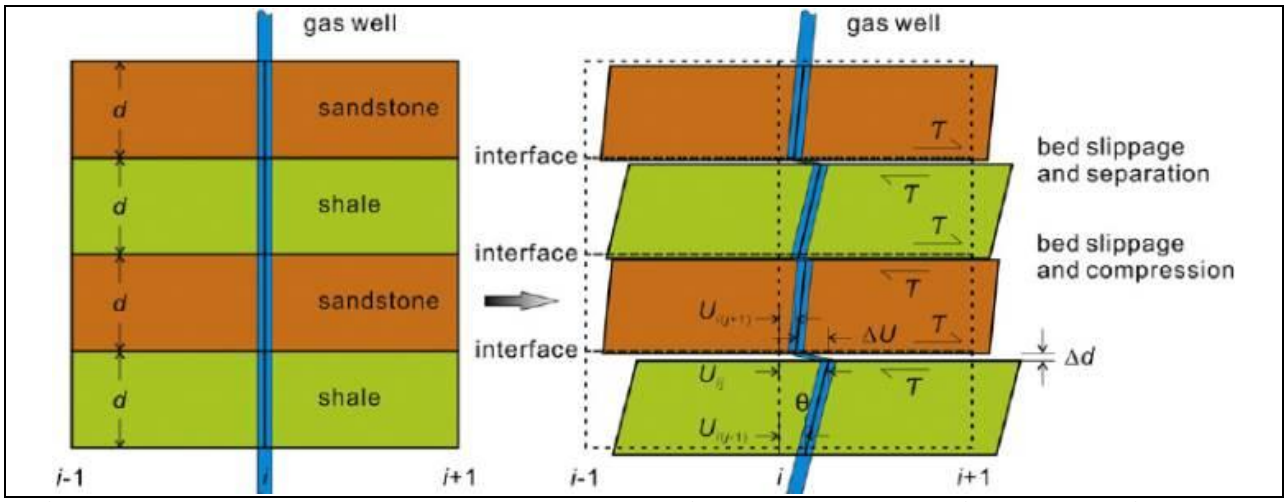
2. additional criteria that should be considered when approving pillars around an oil or gas well that penetrates a workable coal seam.

In total, there were three versions of the report: the initial assessment received in October 2012, an update received in May 2015 that incorporated work completed by CONSOL at their Enlow Fork Mine, and a final version accompanying the close out of the contract dated March 2016.

Approach and Conclusion

Immediately upon receipt of the initial draft report from Boyd on October 17, 2012, staff from the Oil and Gas Program began soliciting comments from the Department staff, including the bureaus of Mine Safety, Mining Programs, and District Mining Operations. An informal workgroup was formed to include staff from the Bureau of Oil and Gas Management and the Bureau of Mine Safety from the Office of Active and Abandoned Mine Operations. As part of this review, outreach was conducted through industry trade groups such as the Marcellus Shale Coalition (MSC) and the Pennsylvania Coal Alliance (PCA).

Industry feedback included a particular concern regarding the feasibility of maintaining Boyd's recommended pillar sizes in conjunction with longwall design configuration. Given this concern, in early 2013 the Department and industry agreed to a field test designed to specifically measure the impacts associated with ground movements related to longwall panel removal and the potential for deformation of constructed shale gas wells. Using field data, a model would be developed to help inform well design. CONSOL agreed to lead this experiment at the Enlow Fork Mine. Field testing was conducted during 2013 and 2014, and subsequent finite-element modeling was completed, which was followed by a review of the results by Boyd. The following figure conceptually depicts subsidence-related deformation that may occur in a support pillar location if the pillar is not suitably sized. In general, where brittle geologic units such as sandstone contact more ductile shales, translational movement along bedding surfaces is enhanced and the potential for well integrity failure is highest.



Reference: Liang, S, Elsworth, D. Li, X, and Yang, D., International Journal of Coal Geology, Topographic influence on stability for gas wells penetrating mining areas, accessed 8/21/2016 at:
https://www.researchgate.net/publication/264827221_Topographic_influence_on_stability_for_gas_wells_penetrating_longwall_mining_areas

On September 16, 2014, a workgroup meeting held at CONSOL offices in Canonsburg at the request of MSC and PCA included presentations by both the coal and gas industries to Department staff. As a follow-up to this meeting, a joint letter dated September 22, 2014, from the PCA and MSC was sent to the Department restating their key issues:

1. Request for Oil and Gas Program to approve an alternative casing method for cementing intermediate casing that would authorize the top of the cement to be left below the base of the workable coal seam; and

2. Department approval of a temporary plugging method protective of miner safety and the environment prior to longwall mining around wells located within a standard longwall gate road pillar.

To further explain the significance of these proposals, it is important to understand how well construction would change in comparison to current industry practices and to discuss the context of "temporary plugging." The alternate method for well construction, when coupled with current regulatory standards, would result in a well design that would only have one cemented casing string through the coal interval – the coal protective casing. Modern shale gas wells are typically equipped with one or two additional cemented casing strings over this interval. The concept of temporary plugging is one that assumes re-entry will be possible. In cases where re-entry is confounded by casing deformation, the long term integrity of the pillar must consider the entire life cycle of the well, including preservation of any vent placed and function at the time of plugging.

With the new information from the Enlow Fork Mine field test, Boyd issued a revised report in May 2015 which was shared with all stakeholders. Industry concerns continued, particularly with temporary well plugging, alternative casing/cementing and safeguard distances, the appropriate application of pillar permits, and minimum pillar size. At the request of Mining Program staff, the Mine Safety and Health Administration (MSHA) met with Department staff in August 2015 to present their assessment of the Boyd report. This was followed by written correspondence outlining MSHA's technical concerns, included as Appendix A.

Given the updated version of the report and recent stakeholder feedback, the workgroup held work sessions and conducted additional research during the fall of 2015, and developed a list of comments spanning five categories:

1. Editorial/clarification-type comments.
2. Concerns regarding the techniques utilized by John T. Boyd Company to arrive at the proposed pillar specifications and references to alternative analyses.
3. Comments regarding mining around wells not meeting safeguard distances.
4. Comments related to alternate methods of casing and cementing for wells in anticipated gate road pillars not meeting safeguard distances.
5. Comments related to drilling through pillars in mined-out areas and in gob.

In 2016, after many years of study and discussion, the Department's Bureau of Mine Safety staff concluded that recommendations in the John T. Boyd Study could not be implemented as a safe alternative to the 1957 Coal Pillar Study. These findings were corroborated by technical experts at MSHA who also reviewed the report and provided formal comments.

Most recently, the Oil and Gas Program's Technical Advisory Board (TAB) requested that a formal TAB Committee consisting of Oil and Gas Program staff, Mining Program staff, TAB members, and other governmental and industry experts be assembled to address additional opportunities for the gas and coal industries to enhance coordination. The Committee first met in New Stanton on March 22, 2016, and the gas industry proposed an alternate method for well construction that includes leaving the cement top down below the coal isolation casing shoe on the intermediate casing and a plan for temporary plugging in advance of longwall panel removal.

In conclusion, technical experts in the Oil and Gas Program determined that the alternate well construction proposals and temporary plugging methodologies developed by the gas industry are inadequate with regard to established regulatory and statutory benchmarks; and concerns are compounded further by the geometry of standard gate road pillars, which have proven to be inadequate relative to the safety factors provided by the 1957 Gas Well Pillar Study. Both Mining Program and Oil and Gas Program staff affirm that departures from the established benchmarks, which are designed to accommodate resource extraction, must meet the highest threshold for miner safety and environmental protection, criteria which have not yet been satisfied in the discussions to date.

Workgroup Participants

Doug Catalano, District Oil and Gas Operations

Brent Stiles, District Oil and Gas Operations

Tom Flaherty, P.G., District Oil and Gas Operations

Tom Donohue, P.G., District Oil and Gas Operations

Sue Ghoweri, P.G., Bureau of Oil and Gas Planning and Program Management

Seth Pelepko, P.G., Bureau of Oil and Gas Planning and Program Management

Tom McKnight, P.E., Bureau of Mine Safety

John Tajc, Bureau of Mine Safety

Colvin Carson, Bureau of Mine Safety

Coal Pillar Study Events Timeline

- November 21, 2011 – Contract with John T. Boyd Company entered into (Purchase Order 4300311202).

- October 17, 2012 – First phase was completed with the issuance of the October 2012 report that focused on recommendations for protective pillar sizes using a formula or reference table.

    - Immediately upon receipt of the draft report from Boyd, staff from the Oil and Gas Program began the process of soliciting comments from appropriate Department staff. This included our staff from the bureaus of Mine Safety, Mining Programs, and District Mining Operations.

    - Outreach was conducted through MCC and PCA.

    - During the review of the first phase by industry, concern was noted with the feasibility of pillar sizes in conjunction with longwall design configurations.

- February 13, 2013 – The Department and industry agreed to a field test aimed at more specifically measuring the impacts associated with ground movements related to longwall panel removal and the resulting potential for deformation on typically constructed shale gas wells. Using field data, a model would be developed to help inform well design. CONSOL agreed to lead this experiment at the Enlow Fork Mine.

- 2013 to 2014 – Field testing was conducted. Boyd review of field testing was done under Purchase Order 4300400813.

- September 16, 2014 – Meeting at CONSOL offices in Canonsburg at the request of MSC and PCA where industry members of the workgroup made a presentation to Department staff based on the field testing.

- September 22, 2014 – As a follow-up to this meeting, a joint letter dated September 22, 2014, from the PCA and MSC was sent to the Department restating their key issues: 1) request for Oil and Gas Program to approve an alternative casing method for cementing intermediate casing that would authorize the top of the cement to be left below the base of the workable coal seam, which when coupled with current well construction standards would only leave one cemented casing string in place over the interval of the coal seam; 2) Department approval of a temporary plugging method protective of miner safety and the environment prior to longwall mining around wells located within a standard longwall gate road pillar.

- May 2015 – Boyd issued their Gas Pillar Study Update, which included the field testing results gathered at the Enlow Fork Mine and finite element modeling completed by CONSOL. The updated report was shared with stakeholders.

- July 23, 2015 – Letter from PCA to the Department, outlining their concerns with the study. Concerns included the need for a method for temporary plugging of wells, methods for alternative casing/cementing and safeguard distances, appropriate application of pillar permits, and increasing the minimum pillar size.

- August 21, 2015 – A meeting with Department and MSHA staff was held at MSHA's Pittsburgh offices where they presented their assessment of the Boyd report.

- December 3, 2015 – A letter from the Department was sent to MSHA as a follow-up to the August 21 meeting and asked for three questions to be answered. 1) In your opinion, can the ALPS and ARMPS stability factors presented in the John T. Boyd gas pillar study update guarantee long term stability for gas well support pillars under all reasonably foreseeable conditions? 2) The report suggests it is acceptable to not centrally locate gas well cases under certain circumstances. Would this provide sufficient support to a gas well's casings? 3) Will the recommendations of this report guarantee long term support pillar stability for gas wells under all reasonably foreseeable conditions?

- December 8, 2015 – MSHA submitted their written response (included in the Appendix) to the Department.

- December 23, 2015 – Department Oil and Gas and Mine Safety staff completed a summary of their review of the Boyd report across five categories. 1) Editorial/clarification-type comments. 2) Concerns regarding the techniques utilized by John T. Boyd Company to arrive at the proposed pillar specifications and references to alternatives analyses. 3) Comments regarding mining around wells not meeting safeguard distances. 4) Comments related to alternate methods of casing and cementing for wells in anticipated gate road pillars not meeting safeguard distances. 5) Comments related to drilling through pillars in mined-out areas and in gob.

- February 24, 2016 – Letter sent from the Department to John T Boyd Company thanking them for their efforts and closing out the contract.

- March 22, 2016 – First Meeting of Coal-Gas Industry-Agency TAB Committee held in New Stanton to work on coal and gas industry coordination matters.

Review of the Boyd Report

Department technical experts from both the Mining and Oil and Gas Programs reviewed the May 2015 version of the John T. Boyd Company updated study and compiled the following commentary on the report, which also incorporates comments and concerns from MSHA (details of which are included in the Appendix). This summary of the analysis was completed on December 23, 2015. The comments in *italics* are provided by Department staff. Comments and concerns are classified using five categories:

(1) Editorial/clarification-type comments.
(2) Concerns regarding the techniques utilized by John T. Boyd Company to arrive at the proposed pillar specifications and references to alternatives analyses.
(3) Comments regarding mining around wells not meeting safeguard distances.
(4) Comments related to alternate methods of casing and cementing for wells in anticipated gate road pillars not meeting safeguard distances.
(5) Comments related to drilling through pillars in mined-out areas and in gob in both abandoned and active mines, with data collected from wellbores in abandoned mines being utilized to study to potential for the application to transition to sealed-off portions of active mines.

Category 1 Comments: The following are editorial/clarification-type comments related to information in the John T. Boyd Company updated study.

1. *It is not clear whether the recommended safeguard dimensions on page 54 represent solid pillars or if the dimensions allow cross-cuts through the pillar, i.e., split pillars. The report does not distinguish between solid and split pillars. Please provide the necessary clarification with regard to these two types of pillar configurations.*

2. *The 2012 Oil and Gas Act (Act 13) does not distinguish between the need for pillars around wells based on status, i.e., active, inactive, or plugged; or well construction variables. The only scenario not requiring a pillar is when a well is plugged in preparation for a mine-through. Wells plugged in accordance with the standard regulatory requirements still require a support pillar. Please make this clear in all applicable sections of the report and indicate if you recommend identical safeguard dimensions for active, inactive, and plugged wells.*

3. *On page 54, it is stated that the minimum pillar width assumes a singular, centrally located well. This indicates that the dimensions must be derived in consideration of the outermost well(s) in a cluster. Additionally, on page 59 it is stated that when a well penetrates a pillar subsequent to mining, available software must be used prior to well placement. It is not clear if there may be situations when wells do not have to meet the prescribed safeguard distances based on such an analysis. Please make sure that these topics are clearly discussed.*

4. *On page 58, under "Recommendations," it is stated that pillars must be sufficiently wide to reduce the "effects of subsidence to a point where stresses are below the allowable*

stress for the casing." It is not clear if this statement applies to all casing strings penetrating the portion of the subsurface affected by mining, or just the production string. In many cases it may be difficult, if not impossible, to understand how outer casing strings could be influenced by mining because they have potentially already been subjected to some level of in-situ deterioration. Please elaborate on the applicability of this recommendation.

Category 2 Comments: The following are specific comments related to components of the John T. Boyd Company updated study directly addressing proposed pillar specifications and concerns related to the comprehensiveness of the updated study.

1. *An updated gas well pillar support study must be inclusive of a methodology that can not only be easily implemented and applied by DEP staff, but it must also reasonably assure support pillar stability under increasing depths of cover and longwall mining scenarios. Further, it must account for multi-seam interaction when multiple coal seams are being mined.*

   The study completed by your firm is based on theoretical analysis and finite element analysis models. Although the merit of applying such tools is not being questioned, it is imperative that commentary relevant to the limitations of such an approach be acknowledged. The updated study ultimately does not provide the same degree of confidence that the original empirical pillar study provided concerning well casing failure because it does not adequately explore all reasonably anticipated failure mechanisms.

   Since the 1956 study, there have been three (3) observed test well cases that serve as the basis for an evaluation gas well casings in longwall gate roads. These test wells were nearly depleted, low production wells where a casing failure would not endanger mine personnel. All three (3) of these wells subsequently failed in the soft floor strata positioned beneath the Pittsburgh coal seam. At the time these test wells were planned, the "beneath-the-coal-pillar" mode of failure was not anticipated by some experts. For tests and models to be valid, they must adequately explore worst-case and previously unrecognized, but nonetheless physically possible, modes of failure.

   The only new test data incorporated into the updated study was obtained from CONSOL's NV–35 pad test wells, where various alternate casing designs were evaluated. This test occurred at one site and at a moderate depth of cover, i.e., 691 feet. Test results were subsequently used to calibrate a finite element analysis model. Although the information derived from these tests was useful, it did not comprehensively examine all reasonably anticipated modes of failure. Aside from the site-specific character of the test mentioned above, further shortcomings include a failure to critically examine failure modes that might occur under deep cover, with clay in the immediate floor or roof, or slips and faults in the vicinity of the coal seam. There is also mounting evidence that there can be adverse effects associated with high horizontal stress and bedding plane slippage at large distances from pulled longwall panels. This mode of failure was not adequately explored.

It should be emphasized that many of the comments provided address potentially significant concerns with the approach used to derive the recommended pillar dimensions. Historically, the Mining Program has approved gas well development in 30-40 pillars that did not meet the original 1957 study, but these were reviewed by Mr. Thomas McKnight using ALPS.[1] Moving forward, it would be hard to approve deeper-seated pillars using this approach, as they would be too big and leave too much coal in the ground.

Page 6, Paragraph 3: "The recommended procedures presented herein, and resulting protection pillar sizes, are intended for use where a more rigorous site-specific design approach, perhaps incorporating alternate techniques, methods, or equipment, has not been conducted."

2. *The purpose of the updated study was to provide a method that can be applied by the oil and gas industry and Department personnel to establish support pillar configurations in such a way as to ensure that the integrity of both support pillar and gas well casing is preserved. There should be no open ended allowance to utilize experts, e.g., consultants, or methods, e.g., finite element analysis models, that are unavailable to the Department.*

Page 6, Paragraph 6: "A field experiment conducted in 2013 and 2014 under active mining conditions with test wells of various alternate casing designs provided results that supported the appropriateness of the pillar sizes recommended in the initial phase of this study."

3. *The study represents one alternate casing design test pad at a moderate cover location where the most likely geologic conditions that could initiate failure (clay in floor or roof, faults and slips, reservoir compaction, mine squeeze initiated by flooded conditions) were not present. This one test does not prove the pillar sizes recommended in the study are appropriate to prevent failures under all reasonably anticipated conditions.*

Page 6, Paragraph 7: "The experiment also showed that 3D finite element modelling provides a reliable approach to evaluate well displacement and casing deformation from nearby mining. Simulations from the modelling showed that alternate casing and cementing designs that accommodate the anticipated movement can maintain well integrity with little deformation and no inelastic strain."

4. *Models are contingent upon the assumptions used to create them. There was one alternate casing design test at a moderate cover location where geologic conditions that would most likely initiate pillar failure were not present. It is difficult, if not impossible, to extrapolate from this one test that the pillar design methods recommended by Boyd's report will prevent pillar failure under all reasonably foreseeable conditions. Finite element analysis programs and the required expertise to use them are not available to*

[1] Analysis of Longwall Pillar Stability (ALPS). ALPS is software for designing pillars for longwall mines. The ALPS method, which is embodied in the program, consists of three basic steps: 1. Estimating the loading that will be applied to the pillars during all the phases of longwall mining; 2. Estimating the load-bearing capacity of the longwall pillar system, and 3. Calculating "stability factors" (SF) by comparing the load to the load-bearing capacity. Since its development, the ALPS method has been verified by back-analysis of more than 100 actual mining case histories. The more recent version of the software includes the Mark-Bieniawski pillar strength formula, which more accurately represent the strength of rectangular pillars, and more flexibility in longwall layout by allowing angled crosscuts and varied crosscut spacing (The National Institute for Occupational Safety and Health).

Department personnel. It is inappropriate to use methods that are unavailable to the Department. The purpose of the updated study was to provide a method for oil and gas industry and Department personnel to establish support pillar configurations that ensure the integrity of both support pillars and gas well casings.

Page 58, Paragraph 6: "A stability factor of 1.5 is to be applied when using ALPS in such cases. This is greater than the NIOSH recommended stability factor of 1.3 for gate road and bleeder pillars because of the long-term stability requirement of a well protection pillar."

5. *Dr. Mark of MSHA recommends an ALPS pillar stability factor of 1.3 based on case histories of entry conditions, not pillar failures. Entry conditions need only remain safe for miners to travel through them until the longwall passes, a short time condition. Stability factors were developed by looking at case histories of successful and unsuccessful designs. Unsuccessful designs were those in which intolerable entry conditions occurred. Gas well support pillars must be stable and provide support for both the life of the mine (up to 35 years) and for the life of the well (50 years). As mining progresses, panels containing gas well casings will eventually be sealed off and pumping of water from these areas will cease. This will allow water to build up in certain instances. Water saturated floor can initiate a mine squeeze where pillars punch into the mine floor if loading conditions are too great. This further increases the need to have a high safety factor design and a well support pillar which will keep average pillar loading low enough to prevent pillar squeezes. A safety factor of 1.5 is not high enough to reasonably ensure gas well support integrity under a worst-case scenario for the life of a mine or the typical production life of a gas well.*

Page 59, Paragraph 1: "For all room and pillar mining, the protective well pillar size determined by ARMPS[2] is to be based on stability factors greater than those suggested by NIOSH because of the long term nature of these pillars. The recommended stability factor is 2.0 at depths shallower than 650 feet and 1.4 for pillars having more than 1,250 feet of overburden. For pillars at depths between 650 feet and 1250 feet, the stability factor is scaled. NIOSH cautions that for panels wider than 425 feet, and where deeper than 1,000 feet, there is a risk of pillar failure when the stability factor is less than 1.5. Thus, for these cases, Boyd recommends a stability factor of 2.0 up to a depth of 650 feet, 1.5 for pillars over 1,250 feet deep, and a scaled stability factor between 650 feet and 1,250 feet of depth."

6. *A back analysis of known mine squeezes associated with Pennsylvania mines showed that numerous mine squeezes occurred when the ARMPS stability factor exceeded 2.5. This strongly implies that the recommended stability factor of 2.0 scaled to 1.5, based on depth of cover, would not prevent a mine squeeze and subsequent pillar settlement under all reasonably anticipated conditions.*

[2] Analysis of Retreat Mining Pillar Stability (ARMPS). ARMPS is software that calculates stability factors based on estimates of the loads applied to, and the load-bearing capacities of, pillars during retreat mining operations. The program can model the significant features of most retreat mining layouts, including angled crosscuts, varied spacing between entries, barrier pillars between the active section and old (side) gobs, and slab cuts in the barriers on retreat. It also features a pillar strength formula that considers the greater strength of rectangular pillars. The program may be used to evaluate bleeder designs as well as active workings (The National Institute for Occupational Safety and Health).

Page 59, Paragraph 4: "A deviation survey of the wellbore from the surface to the base of the coal seam is recommended, with the surveyed location of the well at the level of the coal translated to the mine coordinate system, to verify the well bore at the location of the coal."

7. *A well deviation survey will be required to accurately locate the well bore with reference to the mine coordinate system and to ensure the well casing is properly located within the well support pillar.*

Page 60, Paragraph 3: "2. A site-specific engineering analysis is performed, demonstrating that a well not meeting the safeguard distance would maintain adequate mechanical integrity during and following mining."

8. *The purpose of the updated study was to provide a method that can be applied by the oil and gas industry and Department personnel to establish support pillar configurations in such a way as to ensure that the integrity of both support pillar and gas well casing is preserved. There should be no open ended allowance to utilize experts, e.g., consultants, or methods, e.g., finite element analysis models, that are unavailable to the Department. Such models are cost prohibitive and require a high degree of training: who will review this work? Further, there is no ideal alternate model, although LAMODEL[3] is one commercially available option.*

Page 60, Paragraph 8; and page 61, Paragraph 1: "Further, it is important that the well be located a reasonable distance from the edge of the pillar. The recommended minimum set back distance from a well to the edge of the pillar in these alternate situations is at least one-third of the least pillar width from the rib (edge) of the pillar and at least 2.5 times the pillar height from the rib (edge) of the pillar."

9. *It is important that the well casing be located in the central core, i.e., least stressed, portion of the well support pillar. Even when drilling occurs after both panels have been pulled in a longwall gate-road, the outside edges of pillars will have experienced higher stress levels that may have caused coal pillar spalling, fracturing and a weakening of the coal adjacent to entries.*

Page 6, Paragraph 3: "The Pad NV-35 Experiment (section 5.6) and the Alpha experience (section 5.1) show that stress at coal level and in the underclay can cause considerable yielding in the casings. The use of ALPS and ARMPS in the higher stability factors, as suggested here, will eliminate this concern for typical floor conditions in Pennsylvania. However, for protection pillars with abnormally weak floor conditions, it should be determined that the coal protection and intermediate casing, along with the production pipe will not exceed acceptable total strain (section 6.2) or collapse pressure (section 6.1)."

[3] LAMODEL is software that uses boundary-elements for calculating the stresses and displacements in coal mines or other thin, tabular seams or veins. It can be used to investigate and optimize pillar sizes and layout in relation to pillar stress, multiseam stress, or bump potential (energy release). LAMODEL simulates the overburden as a stack of homogeneous isotropic layers with frictionless interfaces, and with each layer having the identical elastic modulus, Poisson's Ratio, and thickness. This "homogeneous stratification" formulation does not require specific material properties for each individual layer, and yet it still provides a realistic suppleness to the overburden that is not possible with the classic, homogeneous isotropic elastic overburden used in previous boundary element formulations such as MULSIM or BESOL (earlier versions of the methodology) (The National Institute for Occupational Safety and Health).

10. *Typical floor conditions in Pennsylvania often include soft strata composed of clay or clay-stone. The 1957 pillar study's recommended pillar configurations for various depths of cover incorporated geologic anomalies such as a soft floor into its study results. This is the reason why the recommended pillar configurations and associated stability factors are so large at moderate depths of cover in the 1957 pillar study. The updated pillar study should have assumed the worst case conditions such as a soft clay floor when its recommended stability factors were developed. Additionally, oil and gas industry and Department personnel do not have access to finite element analysis software or the expertise to run it. The updated pillar study needs to formulate procedures and methods to evaluate proposed gas wells that utilize the tools we have available (ALPS, ARMPS, LAMODEL) and it should be conservative enough to account for geologic anomalies. The recommended stability factors do not seem to ensure support pillar stability in the presence of worst case geologic anomalies (clay in floor or immediate roof faults and slips).*

Category 3 Comments: The following are comments regarding mining around wells not meeting safeguard distances.

1. *Should wells be "permanently plugged" in advance of mining if they do not meet the safeguard distances?*

2. *Are there any recommended plugging and abandonment procedures or monitoring procedures/engineering analyses that should be implemented in advance of mining around wells installed in pillars that do not meet the safeguard distances? Are there any recommended monitoring procedures/engineering analyses that should be continued following mining around wells installed in pillars?*

3. *"Permanently plugging" in most cases will still require a vent. How would vents (possibly non-functioning/deformed) be addressed?*

4. *On page 60 of the Boyd report, under "Other Considerations," it is stated that plugging the well below the coal seam prior to the advance of mining will mitigate the risks due to potential impacts of subsidence and compression regardless of the well configuration above the coal. Please clarify if this is dependent upon well construction, i.e., cemented or uncemented well casing.*

5. *Should additional measures be taken when annular gas is present prior to abandonment?*

6. *The casing strain analysis in updated study should be clarified: pipe must still be kept at half the minimum elongation required of the steel grade. It appears obvious this measurement would be based upon "new pipe." How would should possible pipe degradation (high sulfate exposure) over time be accounted for? Who would conduct this evaluation in consideration of deformation and degradation influences?*

7. *Based on the industry feedback provided thus far, there will be many instances when the safeguard distances cannot be met. The Department recommends that a process*

flowchart be included in the report to indicate the roles and responsibilities of the agency in such instances.

Category 4 Comments: The following are comments regarding alternate methods of casing and cementing wells in anticipated gate road pillars not meeting safeguard distances.

1. *Although this is not an issue archived in the updated study, the Department does not agree that mining activities can be decoupled from well construction and still result in the conclusion that an alternate method to leave the cement top down on the intermediate string is superior. Any proposed alternate methods must be placed in a site-specific context for an evaluation to be completed. Defining the purposes of the intermediate string is fundamental and demonstrating regulatory equivalency with the alternate design will be necessary.*

2. *Most of the emphasis on alternate well designs have been considerate of Marcellus wells. Moving forward, it will be important to consider Utica wells, where an alternate method might be inclusive of an additional intermediate casing string not cemented in accordance with current regulatory standards.*

3. *The resolution of assertion that cement provides support and protection from chemical attack, but is not necessary for the intermediate string must be addressed in any proposed alternate method.*

4. *Baseline and periodic casing integrity evaluations may need to be considered in any alternate method, e.g., consider storage field well integrity assessments. Ordinarily these logs are limited to a single string evaluation due to well design.*

5. *Due to the functionality of the intermediate casing string, well control details are critical, including where A-section of wellhead will be affixed.*

Category 5 Comments: The following are comments regarding drilling through pillars in mined-out and gob areas.

1. *On page 51 of the updated study, it is stated that "Gas and oil wells are required to be located through protection pillars of an active mine." This is not accurate in consideration of existing statues and regulations. However, the Department's Mining Program has always objected to the permitting of wells in any location but through a support pillar meeting the 1957 Gas Well Pillar Study dimensions in mined portions of an active mine. Please update the report to indicate that the regulatory framework does allow for well placement in the gob of abandoned and sealed-off portions of active mines, provided the wells can be drilled and operated safely.*

2. *How is an evaluation of long-term pillar stability made when additional drilling is proposed in a pillar already exposed to subsidence but not meeting pre-mining safeguard distances?*

Conclusion

The coal mining and unconventional gas industries coordinated to plan unconventional gas well installation in planned coal development areas for many years prior to the establishment of the 2016 Coal-Gas Industry-Agency TAB Committee. The 2011 amendments to the Coal and Gas Resource Coordination Act required updates to the 1957 Coal Pillar Study to account for modern longwall mining techniques. The techniques proposed and the study that ensued as a result of those changes were not able to provide the outcome both industries anticipated. For example, a conclusive technical study confirming the installation of gas wells planned in gate road pillars would enable safe longwall mining passes that neither limited the volume of coal resources that could be extracted nor jeopardized the integrity of unconventional gas wells.

In 2016, after many years of study and discussion, the Department's Bureau of Mine Safety concluded that recommendations in the John T. Boyd Study could not be implemented as a safe alternative to the 1957 Coal Pillar Study. These findings were corroborated by technical experts at MSHA who also reviewed the report and provided formal comments. Amendments to the Coal and Gas Resource Coordination Act that prompted the study and Boyd report envisioned pillar sizes that preserve the integrity of active, inactive, and plugged wells. Additionally, although some of the Boyd report findings suggest it might be prudent to consider a deviation from the current well construction regulations as a means for limiting well deformation during adjacent longwall mining, the Oil and Gas Program cannot accept alternate well construction standards that are potentially less protective in order to continue the planned gate road pillar development that has left hundreds of unconventional wells in the path of longwall mining operations and with an uncertain future.

Proposals to leave the cement top down on the intermediate string below the shoe of the coal isolation casing string in an attempt to accommodate expected deformation during mining passes does not meet the fundamental intent of alternate methods as defined in the regulation as mentioned in the previous paragraph. The Department is fully committed that our state's environmental regulations strike a proper balance that fosters economic growth and protection of public health, safety, and the environment. The proposed alternate method may also extend to scenarios where multiple coal strings and intermediate casings are involved depending on the number of workable seams and the formation being targeted for gas extraction and, thus far, only the simplest derivative has been discussed. Based on analysis, it is concluded that construction techniques such as those introduced may jeopardize well integrity in the long-term in areas underlain by workable coal. This could make proper plugging and abandonment procedures more difficult to implement and potentially elevate the likelihood of uncontrolled gas and fluid migration in large portions of southwestern Pennsylvania.

In summary, there are two fundamental variances that are now being requested by the gas and coal industries:

1. A potentially "less protective" well construction request from the gas industry; and
2. A request to approve less pillar support from the coal industry.

In most situations, well operators seek optimum pillar support to ensure longevity of the production life of the well and also to facilitate proper venting during the well abandonment stage. It is notable that the well operator is provided an opportunity for an "objection" under Section 3224 of the 2012 Oil and Gas Act (Act 13 of 2012) even when the pillar meets applicable standards. In most situations, coal operators seek pillar sizes that optimize well integrity to maximize safety margins when mining around and in the vicinity of the well. This typical scenario ensures long term protection of the wellbore independent of its status. If approvals for either variance are sought, it is strongly recommended that they only be granted on a case-by-case basis until a greater understanding of the technical issues and risks can be gleaned. Further, "temporary plugging," as proposed by both industries as a means for addressing the hundreds of wells that have already been constructed in anticipated gate road pillar locations, requires authorizations that fall outside of any existing laws and regulations. In such a scenario, mechanisms for facilitating inspections by the Oil and Gas Inspector during review of submitted pillar permits and before any "temporary plugging" activities take place in advance of each mining pass are critically necessary.

The Oil and Gas Program has determined that the alternate well construction proposals and temporary plugging methodologies developed by the gas industry are inadequate with regard to established regulatory and statutory benchmarks. Additionally, the geometry of standard gate road pillars, have proven to be inadequate relative to the safety factors required by the 1957 Gas Well Pillar Study. For these reasons, the Department determined that a departure from the established practices designed to accommodate resource extraction cannot be accepted, unless there is a demonstration that the protections envisioned by existing laws and regulations can be consistently maintained.

Appendix

Detail of Letter from MSHA, December 3, 2015

1. *In your opinion, can the ALPS and ARMPS stability factors presented in the John T Boyd gas well pillar study update guarantee long term stability for gas well support pillars under all reasonably foreseeable conditions?*

MSHA Technical Support Response: The Boyd report discusses pillar design to prevent strength failure on pages 14-15 and 55-59. Boyd's recommendations rely heavily on the NIOSH pillar design software packages ALPS and ARMPS. Unfortunately, there are errors in the application of the ALPS and ARMPS stability factors (SF). In particular:

- The Boyd report states that NIOSH recommends an ALPS SF of 1.3 for all depths. However, that recommendation applies to maintaining *roof stability in the tailgate entry* of an active longwall panel. **For *pillar stability,* the traditional SF recommendations have been 1.5 for short-term applications and 2.0 for long-term applications.** (It should also be noted that (a) ALPS is best suited for evaluating pillar stability in *isolated loading conditions,* where the pillar system is between two worked out longwall panels, and (b) The ALPS(R) SF should be used, not the "Classic" ALPS SF).
- The Boyd report states that the NIOSH recommended SF for ARMPS is "1.5 for mines less than 650 feet deep and 0.9 for pillars deeper than 1250 feet deep." However, those NIOSH recommendations applied to ARMPS version 5, which was superseded by ARMPS version 6 in 2010 (footnote 10, on page 14 of the Boyd report, refers to ARMPS version 6, which is still the current version). **When using ARMPS version 6, NIOSH recommends an SF of 1.5 regardless of depth for typical room and pillar applications. For long-term applications, an ARMPS SF of 2.0 is more appropriate** (as the Boyd report correctly points out.)

In addition, the report consistently refers to "*the* protective pillar," but both ALPS and ARMPS calculate the SF for a pillar *system*, not individual pillars. For example, with a typical three-entry longwall gate, ALPS will sum the load-bearing capacities of both rows of pillars when calculating the SF. The Boyd report does not make clear how the SF of the protective pillar should be determined in a multi- pillar system. (Note that the original 1957 Gas Well Pillar Study took care to define both the "solid pillar area" of the pillar that contains the gas well, and the "additional pillar area" required in the pillars that surround the central pillar (see pages A-14 and A-20 in the Boyd report)).

Finally, it is also important that a pillar's *deformation* may be just as significant as its strength when evaluating the stability and integrity of a gas well cased through it. Unfortunately, the mechanics of squat pillars (pillars whose width is more than ten times their height) are only poorly understood. On the one hand, it seems that significant deformations may take place in the core of such pillars even when they are "stable," as occurred in the Consol Pad NV-35 studies described in the Boyd report (see page 40 and page B-19). On the other hand, squat pillars are expected to be "strain hardening," which means that even if they "fail" due to excessive loading, they will not collapse.

2. *The report suggests it is acceptable to not centrally locate gas well casings under certain circumstances. Would this provide sufficient support to a gas well's casing?*

MSHA Technical Support Response: The Boyd report states that the design of a protective pillar surrounding a gas or oil well should address two concerns:

- The pillar has to wide enough to reduce the effects of subsidence to a point where stresses are below the allowable stress for the casing. The distance from the pillar rib to this point is called the "safeguard distance."
- The pillar has to be strong enough for long-term stability.

The Boyd report suggests that there are two circumstances in which the wellbore need not be located in the center of the pillar:

- On page 58, it suggests that when the protective pillar's width exceeds twice the minimum safeguard distance, the well's location can deviate from the pillar center so long as its distance from the nearest rib exceeds the safeguard distance.
- On pages 59-61, several "alternate situations" are described in which the safeguard distances recommended by Boyd are not obtained, but certain other criteria are met. In these "alternative situations" it is also assumed that the pillars involved "meet the minimum size required for pillar stability." In such "alternative situations," Boyd suggests that the wellbore location need only meet a recommended minimum setback distance from the rib.

In principle, these are both sensible exceptions to the requirement that the well be located in the pillar center. However, these exceptions require accurate determinations of both the safeguard distance and the stable pillar size. MSHA Technical Support's concerns regarding the calculation of the stable pillar size were outlined in our response to question (1) above. MSHA Technical Support also has concerns about the calculation of the safeguard distance.

Boyd calculated the minimum safeguard distance in two steps. First, the maximum allowable shear stress in a single-wall, H-40 steel casing with outside diameter of 13.375 inches and an inside diameter 13.045 inches was determined (pages 41-49). Then this value was compared to the maximum subsidence shear strain determined using standard subsidence prediction programs (pages 50-53). The Boyd approach would be valid if the maximum shear strain could be predicted using conventional subsidence theory, as discussed on pages 12-14 of the report. However, the field studies described in the report, including the Alpha W-510 well and the four Consol Pad NV-35 wells, clearly showed that the most significant shear strains applied to the test well bores resulted from *non-conventional subsidence.* Non-conventional subsidence involves large horizontal ground movements that occur on the bedding plane contacts between weak and strong rock layers. In the Alpha and Consol well studies, several inches of slip developed either below the coal seam (in the Alpha well) or approximately 200 feet above the seam (the four Consol wells). These ground movements exceeded by an order of magnitude the strains predicted by conventional subsidence theory.

The Boyd report points out that "Geologic analysis for the identification of weak/strong rock contacts is key in determining the mining effects on well strings" (page 41). Yet the Boyd report does not consider such geologic analysis, or the shear strains resulting from non-conventional subsidence, in its determination of the maximum expected shear strain and the safeguard distance. **MSHA Technical Support believes that, even though it is difficult to predict, the potential shear strain due to non-conventional subsidence must be considered in the evaluation of the stability and integrity of a gas well drilled through a longwall coal pillar.**

3. *Will the recommendations of this report guarantee long term support pillar stability for gas wells under all reasonably foreseeable conditions?*

MSHA Technical Support Response: MSHA Technical Support's concerns regarding the calculation of the safeguard distance and the stable pillar size were outlined in our responses to the first two questions. In addition, there are some specific mining conditions which we believe it would be inadvisable to drill gas wells within active mines:

- *Soft floor:* The Boyd report states that "the use of ALPS and ARMPS at the higher SF, as suggested here, will eliminate this concern for typical floor conditions in PA" (page 61). However, there is still cause for concern when *atypical* floor conditions are encountered. There are many historical examples of pillar failure in underground coal mines in the Commonwealth caused by unusually soft floor, and the Alpha W-510 well test provided an example of the ground strains such an event could apply to a well casing. **MSHA Technical Support believes that a thorough evaluation of floor stability should be conducted before a gas well is drilled in active mine.**
- *Pillar retreat:* The Boyd report contains recommendations for designing protective pillars within room and pillar retreat panels prior to conducting pillar recovery (p. 59). **MSHA Technical Support recommends that gas wells not be drilled within panels that will be pillared, but rather be restricted to locations within barrier pillars or panels where mining will be limited to development only.** Since there are only a handful of mines in the Commonwealth that practice pillar recovery, and since those mines have much more flexibility with their mine layouts than longwall mines, such a restriction will not impose an undue hardship.
- *Multiple seam mining:* On page 10, the Boyd report states that one reason for the study update is that "multiple seam operations are now common and will increase in frequency." It also states that "multiple seam mining and other complicated mine environments may require numerical analysis" (page 15). **MSHA Technical Support concurs, and suggests that gas well pillars not be drilled in any active multiple seam situation without an extensive geotechnical evaluation.**