U.S. Department of Labor

Mine Safety and Health Administration
1100 Wilson Boulevard
Arlington, Virginia 22209-3939

MAR 13 2007

Dr. Guner Guturnca
Director
Pittsburgh Research Laboratory
National Institute for Occupational Safety and Health
P.O. Box 18070
Cochran Mills Road
Pittsburgh, PA 15236

Dear Dr. Guturnca:

Enclosed are our comments on the NIOSH draft report, "Explosion Pressure Design Criteria for New Seals in U.S. Coal Mines". We appreciate your inclusion of Terry Hoch and Technical Support in the peer review process of your report.

I look forward to working with you in the future on this important project.

Sincerely,

Mark E. Skiles
Director of Technical Support

Enclosure

General Comments by Technical Support, PS&HTC, on the NIOSH draft report "Explosion Pressure Design Criteria for New Seals in U.S. Coal Mines"

The readers should be made aware of the atmospheric conditions that must exist to attain the pressures that are presented; that is, 10% CH_4 and 90% air (which is ~21% O_2 and 79% Nitrogen). As stated, physics reveals that these 640 and 120 psi overpressures are attainable, given ideal or worst case scenarios. In gobs and sealed areas, however, these worst case scenarios, involving that uniform, homogeneous concentration, would never occur. The NIOSH proposed design criteria for unmonitored seals are based on a worst-case scenario. For example, it is not practical or economical to design a civil structure for the maximum blast loading from a terrorist attack. The report should address the fact that it may be practical from a risk-based approach to design seals to a lower criteria than that presented in the report. NIOSH should assess the practical risk and provide a rational basis by using research and actual experiences from around the world for establishing overpressures and pressure-time curves.

NIOSH personnel have traveled to many countries throughout the world to obtain data on seals and their design requirements. The physics is the same and high attainable explosion pressures have been known for several decades by researchers and blasting experts throughout the world. Many of the references cited by the report state these high explosion pressures. However, no country in the world has adopted a law requiring a seal to resist an overpressure greater than 72 psi; with a safety factor of 2, the pressure would not exceed 144 psi. Could NIOSH explain this? Could it be that the atmospheric conditions that must exist to attain levels such as 640 psi (as suggested by NIOSH) are rarely found? In general, it is noted in the report that authorities in Poland and Australia recognized that higher pressures were possible but did not think it was practical to design to those standards. An explanation should be provided, perhaps in Section 5, to justify why the full 640 psi is being recommended for the United States.

The Introduction, Section 1.2, 3rd paragraph, states that; "When an area of an underground coal mine is mined out, operators will frequently choose to isolate the abandoned area with simple dam-like structures called seals rather than continue to ventilate the area." It should be stated here, that the reason for this trend was not solely economical. It was to reduce miners' exposure to fire and explosions. Accident history shows that there has been a significant reduction in fires and explosions as operators progressed to sealing techniques. Other risks of exposure for miners to bad roof conditions and poor air quality have been reduced or eliminated through sealing. The term "dam-like" is used to describe seals. MSHA treats underground water-retention structures differently than explosion-control structures. For this reason, MSHA would prefer that "seals" are not referred to as "dam-like." A suggestion is to use the term "barrier," as in: "Seals are barriers constructed in underground coal mines..." The term "dam-like" is also used on page 3.

The report indicates that in sealed areas, CH_4 increases, and oxidation creates more CO_2. This will in turn lower the O_2 in the atmosphere. When these conditions exist, the explosive ranges that are presented in this paper can be drastically reduced. See, Section 1.4 page 6. Figure 6 shows comparisons of theoretical pressures (NASA) and "experimental pressures". Other than at the 10% CH_4 range the discrepancy is significant. The experimental pressures are significantly lower than the theoretical pressures. At a percent or two above or below the optimum 10% CH_4 range, the experimental pressures are 20 to 30% lower then theoretical.

We disagree with the inclusion of design charts as presented. Based on comparison with MSHA approved alternative seals, the NIOSH recommendations are not conservative. If the charts in the final report do not consider all failure modes and incorporate structural code, they should not be included. If this is the case, the title of the report should be changed to "Explosion Pressure Design Considerations for New Seals in U.S. Coal Mines".

NIOSH lists eleven mine explosions that have occurred in sealed areas from 1993 – 2006. NIOSH does not give any information about the explosive pressures that would have been generated by these explosions. The reader may incorrectly assume that the pressures were high and similar to those described in their report, however, MSHA records show that the pressures associated with these explosions are much lower than those being presented in this report.

If NIOSH is to focus in on the worst case scenario, then maybe the title should state "worst case scenario".

Specific Comments on Draft NIOSH Report "Explosion Pressure design Criteria for New Seals in U.S. Coal Mines"

1. Executive Summary:
   a. 1st paragraph: The term "dam-like" is used to describe seals. MSHA treats underground water-retention structures differently than explosion-control structures. For this reason, MSHA would prefer that "seals" are not referred to as "dam-like." A suggestion is to use the term "barrier," as in: "Seals are barriers constructed in underground coal mines…" The term "dam-like" is also used on page 3.

   b. 1st paragraph, 2nd Sentence: The report refers to the mine regulations requiring seals to withstand an "explosion" pressure. The 30CFR §75.335(a)(2) actually states a static horizontal pressure of 20 psi, not a 20-psi explosion pressure.

   c. 2nd Paragraph, 3rd Sentence: Terminology in the field of explosives and blast design is inconsistent at times and may lead to confusion. The recommendation is made to provide a glossary of terms so that the audience is fully cognizant of the use and meaning of the terms (4, pp. B-1 – B-4)[1]. The recommendation is made to use the term "pressure-time curve(s)" instead of "pressure pulse(s)" in this section and throughout the document. The term "pressure-time curve" is more commonly used in the structural design of blast-resistant structures (1, fig. 1-6; 4, p. 3-15; 5, p. 291). Pressure-time curves provided for structural design are always relative to the ambient pressure. A design total (absolute) pressure-time curve is provided in Figure 22 and is not consistent with the term total pressure, since the plot falls below ambient pressure. In addition, the subtitle of Figure 22 states overpressure, meaning pressures relative to the ambient pressure.

   d. 3rd Paragraph: One of the assumptions made during the NIOSH analyses is that the seals are infinitely rigid and may be decoupled from the CFD analyses. A flexible structure (one that deforms) will not create the ideal reflected pressures provided in the report; the reflected pressures will be less due to the interaction between the structure and blast wave (2, p. 222). A coupled code is required to properly address this interaction and determine the actual reflected pressures (this was discussed at the MSHA-NIOSH meeting on 18 January and the underwater explosion on a miter gate was presented as an example). In addition, the FLACS and AutoReaGas CFD codes are not capable of modeling the transition from deflagration to detonation (DDT). Other codes such a SAGE have this capability, and for a detonation, the reflected pressures on an

[1] See list of references at end of document.

infinitely rigid seal may be significantly higher due to reflected wave reinforcement.

e. 3rd Paragraph: The 50- and 120-psi pulses noted in the report are not reflected pressures. NIOSH should address the case where the methane gas is ignited at the boundary of the assumed gas cloud (the farthest distance) rather than at the face of the seal.

f. 4th Paragraph: The comment should be provided that seal thicknesses computed from arching action in WAC are based on the assumption of non-yielding support conditions and as a result, the seal thicknesses provided in the design charts may or may not be conservative, depending on the actual mine support conditions and the material and construction quality control measures employed, even with a safety factor equal to 2. Only a more rigorous analysis may determine the degree of conservativeness or un-conservativeness of the propose designs. In addition, WAC only considers failure in terms of user defined limits on support rotation and does not address other modes of failure, which may occur prior to the limit established for support rotation.

2. Section 1.1, 2nd Sentence: See comment No. 1a.

3. Section 1.2:

a. 1st Paragraph: The report may also discuss other hazards faced by the mining industry if mined-out areas are not sealed and abandoned, such as spontaneous combustion, exposure to roof falls during inspections, and methane explosions due to deteriorated ventilation controls and/or restricted ventilation.

b. 3rd Paragraph, 3rd Sentence: The number of existing seals is approximately 14,000.

c. 3rd Paragraph: There is a reference to seals constructed of materials such as concrete, brick, or cinder block. Since brick and cinder block are not currently used in seal construction, a suggestion is to delete the reference to these materials.

d. 5th Paragraph, 1st Sentence: Mining companies may also only develop panels with three entries from the submains to minimize the number of seals. This may create a pressure focusing condition (converging blast waves), where multiple entries converge to three entries.

4. Section 1.3

a. In general, is the focus of this work purely on explosions occurring in the worked out area? Since seals are supposed to be capable of withstanding an explosion from either direction, how would the potential for an explosion in the active portion of the mine affect the seal design recommendations in this report?

b. 2nd Paragraph, 1st Sentence: The explosion loading potential should include the initial blast pressure and the C-V pressure.

c. 2nd Paragraph, 4th Sentence: the statement may lead to the opinion that the larger the sealed area, the greater the blast pressures, and this is not necessarily true. The pressures will not exceed those for a detonation unless the blast wave is reinforced by additional reflected waves.

5. Section 1.4

a. 3rd Paragraph: For figure 3A, the explanation may be provided that the seals will be subjected to an initial short-duration blast pressure followed by a long-term constant-volume pressure caused by the air heated to a high temperature as a result of the burning of the methane-air mixture. The C-V pressure is a long-term load and dissipates by the surrounding strata in the sealed area acting as a heat sink and gradually cools the temperature of the air and subsequently decreases the pressure until ambient pressure is re-established

b. 5th paragraph: It is stated that sealed areas continue to present explosion hazards even after inertization, oxygen depletion, etc. because air leakage around seals can create an explosive atmosphere around the perimeter of the sealed area. Do they mean to say around the area of the seal rather than the entire sealed area?

6. Section 1.5.

a. 1st paragraph: It is indicated that ten explosions have occurred in sealed areas since 1993, but Table 5 lists 11 cases. Also, Table 5 indicates that "more seals were destroyed" in the June 1996 explosion at Oasis Mine. Is this based on the MSHA accident report, or other information? (I didn't think the MSHA accident report indicated what damage was caused by the June '96 explosion…)

b. The report should mention the likely detonation in the Blacksville mine shaft that killed several workers doing maintenance on the shaft cap.

7. Section 2.1

a. On the origin and evolution of the 20 psi seal design criterion in the US, no mention is made of the possibility that Mitchell's recommended 20 psi "static" pressure was intended as a static loading in the structural engineering sense of the term rather than in the ventilation engineering sense of the term.

b. Mitchell believed that a seal that was designed to withstand an explosion of 20 psi static could withstand an explosion pressure of 50 psi, which was the previous 1921 Dept. of Commerce standard.

8. Section 2.2:

a. In general, it is noted in this section that authorities in Poland and Australia recognized that higher pressures were possible but did not think it was practical to design to those standards. An explanation should be provided, perhaps in Section 5, to justify why the full 640-psi is being recommended for the United States.

b. Paragraph 2: The strength of the gypsum was 1,700 to 2,000 psi after 24 hrs (6, p. 23). In addition, it should be noted that the minimum seal length permitted is 3 m. The failure of the unreinforced gypsum seal was quite violent and was completely blown out of the test site and into a nearby field.

Safety factor should be based on the maximum load-carry capacity (peak reflected pressure and impulse) of a structure and should not be based on a material property, such as shear strength. The reason is that for a pressure-time curve, the safety factor computed for shear may be 2; however, if the peak reflected overpressure is increased by only 40 percent, the seal will fail. This has been revealed through numerical analysis using FLAC3D and LS-Dyna 3D. Safety factor for a reinforced structure or steel structure may be reliably based on ductility.

c. Paragraph 10: In the discussion of the Australian seals design requirements, one would expect that the standards would also require the design strength of the seals to achieved when the sealed area transitions through the explosive range, where the transition time period would be based on a methane liberation study. This is an important consideration in the design of the seals.

9. Section 3.1

a. 1st Paragraph: The stoichiometric methane-air mixture is 9.5 percent. The definition for term stoichiometric fuel-air mix should be provided in the section or in the glossary for reference.

10. Section 3.3:

a. 1st Paragraph: The C-V pressure is the same for a deflagration versus a detonation. The resultant blast pressures (side-on and reflected) will be significantly different in magnitude, but the C-V pressures will be the same.

b. 2nd Paragraph: The mine entry roughness and debris causes significant turbulence during the combustion wave propagation. This in turn will be a significant factor on flame speed, the resultant pressures, and possible DDT.

11. Section 3.4:
    a. 1st Paragraph: This section needs to be carefully presented and it is recommended that the terminology be clarified for internal explosions. Internal explosions are characterized by two phases of loading – the blast loading phase (pressure wave for deflagration or shock wave for detonation) and the gas or quasi-static loading phase. A seal may initially be subjected to the side-on pressure or reflected pressure, depending on its orientation with respect to the direction of the blast load. Following the blast pressure (side-on overpressure or reflected pressure), the structure would then be subject to the gas or quasi-static pressure.

    b. 7th Paragraph: The 20 psi static pressure specified in 30CFR §75.335 is a time-independent pressure; it is not the quasi-static (side-on) pressure implied in this paragraph.

    c. The second equation on page 18 is missing parentheses. In general, equations should be given reference numbers.

12. Section 3.5: Chapman-Jouguet is never defined or explained.

13. Section 3.8. 3rd paragraph. In Cybulski's research, please clarify if the 290 psi pressure was side-on or reflected.

14. Section 4.1:
    a. Dr. Ingel may have conducted the first CFD study of the methane explosion tests conducted in the Kloppersbos 20 m and 200 m tunnels using FLACS and AutoReaGas.

       In addition, the U.S. Army Corps of Engineers under contract with MSHA is currently conducting a CFD study using SAGE (SAIC) of the Sago Mine accident. SAGE will handle DDT and detonations and may also be used to model methane-air-coal dust explosions.

    b. 6th paragraph: It is stated that the models used are not correct but they will "indicate" the pressure build up. There is no explanation given why the models are not correct. Further, it seems that more information is necessary before difficult decisions can be made on "indications" rather than facts.

c. General comment. The report should fully explain the modeled methane/air mixture makeup (i.e., percentages of oxygen, methane, nitrogen, etc.). If an oxygen content of 20.6 percent was used, is this realistic? What would the effects of lower oxygen content be on the resultant maximum pressures?

15. Section 4.3: Similar to comment 11b. It is stated that the models used are not accurate, but the models are correct in "indicating that very high pressures have developed." Can the pressures presented in the document be trusted?

16. Section 5:

a. 1st Paragraph: The term "pressure-time curves" is more consistent with the terminology used in the design of structures for blast loads. This isn't to imply the use of "pulse" is incorrect, but "pressure-time curve" and "pressure-time history" is predominantly used.

b. 2nd Paragraph: The recommendation is made to label the y-axes for figures 20 through 22 "Reflected Overpressure and Quasi-Static Pressure".

c. 3rd Paragraph: Figure 21 should provide the ignition source location. This figure appears to be an ignition at the face of the seal and not 41 m away from the seal. For a blast wave propagating to the seal, one would expect to observe a reflected wave, not a gradual buildup to the C-V pressure. The pressure wave shown in figure 21 does not resemble the pressure waves propagating in C-drift for the LLEM tests, especially the rise time to peak pressure.

d. The section presents the design pulses that should be used for seal design. However, it seems that Figure 22 is overstating the design pressure when compared to Figures 20 and 21. The plateau shown on the first two figures is plus and minus the model prediction while the Figure 22 plateau is about 25 percent greater than the peak shown. The basis for the 50 psi design criteria should be clarified.

e. Some consideration should be given to determine if it is possible to develop a method for minimizing the run-up distance that would allow the lower pressure seal criteria to be applied. Some thoughts include breaching parts of an entry, placing gob plugs, placing stoppings, etc. This may be more economical than designing all seals for 640 psi.

f. In the designation of the limit of the size of the zone in which an explosive mixture can be allowed to develop adjacent to a seal, Table 5 and page 30 cite 5 meters as the distance to be monitored. The basis for this distance should be better explained – with reference to the pressures shown in Figure 18.

Presumably, the 5-meter value is based on consideration of the reflected wave pressure. Does it also include a factor of safety?

17. Section 6:
    a. In general, please clarify if a seal needs to be designed for pressures from both directions. If an inby explosion is 640 psi, what should the seal be able to take from the other direction? That is, on the outby (active) side? This is an important point when selecting the locations for flexural reinforcement in concrete.

    b. 3rd Paragraph: It should be stated that the proposed conceptual design may or may not be conservative, since all failure modes are not considered. In addition, one-way arching action may not be appropriate without proper consideration of the stiffness of the strata in comparison to the stiffness of the structure.

    c. 4th Paragraph:
        i. Comment similar to comment 1b. 30CFR §75.335 is a 20-psi horizontal static pressure, not an explosion pressure as stated in the report.

        ii. WAC is an analysis tool for predicting structural response. Although unreinforced structures may be analyzed for blast loads, the program is really not meant to design these types of structures for blast loads. There are a number of other design checks that must be made to assure structural integrity and this has not been done from a structural engineering point of view.

    d. 4th Paragraph: This document should not refer to the design charts as "recommended design charts" as in the last sentence of this paragraph. Unless, of course, NIOSH is recommending use of the charts alone for design.

    e. 4th paragraph: It is stated that a quasi-static approximation is used for the plug and arching analysis. The authors should detail why no dynamic magnification factor is applied. In particular, a discussion should be made of the period of vibration of the structure verses the time of load. This same comment would apply to Section 6.2.

    f. 5th Paragraph: In the referenced Table 6, the shear strength values appear to be a higher percentage of the compressive strength than is typically expected or assumed. Can the basis for these shear strength values be given?

    g. 7th Paragraph: Seal designs should be based on a pressure-time curve, not a "quasi-static pressure." The loading and reactions are not the same, since the designer needs to evaluate the support reactions at peak response for the SDOF approach, and this is dependent on structural resistance and the pressure time curve (5, p. 213-214). For example, the WAC reaction results for the reinforced concrete seal (2-way or 1-way slab) would not correspond to the reactions obtained by assuming a uniformly distributed load about the perimeter of the seal using a static pressure equal to 300 psi.

h. 8th paragraph: Since a detonation basically has no rise time and the assumed decay time is approximately 100 milliseconds, the ratio of load duration to period of the structure is large. This would imply that the affect on the structure is double, not cut in half as stated by the authors who are using 300 psi.

18. Section 6.1:
    a. 2nd Paragraph: WAC should not be used for structures where the thickness to span (height) ratio is greater than 1/5 to 1/4. Thickness to span greater than these ratios should be verified with FEM. The magnitude of the mobilized in-plane thrust forces for the force-couple will also depend on the compressive strengths and stiffnesses of the floor and roof rock. In addition, the unconservative assumption is made that the seal, following construction, will be in perfect contact with the mine roof. This assumption and many others are not justified, considering the mine conditions and the construction methods employed.

    b. 5th Paragraph:
        i. The guidelines referencing proposed ductility and support rotation limits for various types of structures were developed for the Facility and Component Explosive Damage Assessment Program (FACEDAP) and may be used in the analysis and design (TM 5-1300) of structures.

        ii. Safety Factor: Safety factor is blast design may be used differently, depending on the circumstance and type of structure. For reinforced structures, the safety factor may be based on the reserve of strength in terms of ductility or support rotation. For an unreinforced structure (plug), the safety factor in reference to the maximum load-carry capacity (energy) should be evaluated using FEM or other appropriate analytical methods. It would seem more appropriate to raise the peak pressure of the pressure-time curve by a factor of two to determine the required thickness.

19. Section 6.2:
    a. 1st and 2nd Paragraph: The plug equation and the safety factor only evaluates shear strength or interlock strength and is not representative of the true

strength of the seal in terms of peak reflected pressure and impulse. The plug equation used to size the seals for dynamic loading may not be appropriate for plug design and its use needs to be validated through numerical analysis. NIOSH, in introducing this equation, is validating its use and will make it extremely difficult for MSHA to refute its use in the future. NIOSH should refrain from using this equation until it is validated for dynamic loading.

b. 1st and 2nd Paragraph: The safety factor equal to two is misleading, since the seal will most likely not be able to carry twice the peak reflected pressure. This concept was introduced to a design engineer and the engineer verified the concept using FLAC 3D. For cellular concrete structures, shear strength is not the only factor that needs to be considered.

c. The internal shear strength of 100 psi for the lightweight cement foam presented in table 6 and used in the quasi-static plug formula may be reasonable for material with a compressive strength of 400 psi; however, the design should also consider the shear strength at the boundary between the seal and host rock. In materials with higher internal shear strengths such as concrete, the possibility of shear failure through the coal ribs, floor, or roof become an increasing concern. In limited direct shear strength test data from Minova, an interface shear strength (between the Tekseal and coal samples) of 36 psi was found for Tekseal material with a compressive strength of 400 psi.

d. 4th Paragraph: A word of caution needs to be expressed concerning the NIOSH tests. The seals were subjected to a pressure wave (side-on pressure) traveling at roughly 1,850 ft/sec. The seals were not subjected to a direct blast pressure (reflected pressure). As a result, the magnitude of the leading and trailing peak pressures are different and the response of the structure will be different for the traveling pressure wave (side-on) versus a reflected pressure wave.

20. Section 6.3:
   a. General Comment: A comparison of seal thicknesses found using the charts in the report to the thickness of seals approved by MSHA indicates that the charts are unconservative. See table 1.

Table 1. Comparison of NIOSH Recommended Thickness Versus MSHA Approved

Type of Seal (20 feet wide unless noted)	Height (inches)	Approximate NIOSH Thickness Recommendation (inches)	MSHA Thickness Approval (inches)	Additional details from MSHA Plan
Concrete	96	12	20	6,000 psi concrete 2 row dowels flexural reinforcement stirrups for shear
Minova Tekseal	96	35	78 *	
Minova Tekseal (22 feet wide) (design pres. 100 psi)	120	95 (chart for 120 psi, 20 feet wide)	96 – 120	2 row dowels all sides
Minova Tekseal	90	31	109	
Minova Tekseal	120	41	112	
Minova Tekseal	156	55	131	
Minova Tekseal	48	19	55 to 67	Lower value for gob isolation seal; Upper value for main seal.
Minova Tekseal	72	26	77 to 92	Lower value for gob isolation seal; Upper value for main seal.
Minova Tekseal	96	35	95 * to 114	Lower value for gob isolation seal; Upper value for main seal.
Minova Tekseal	144	50	125 to 150	Lower value for gob isolation seal; Upper value for main seal.

* Reason MSHA approvals may differ for same height: For the seal with a 78-inch thickness, a more in-depth structural analysis was conducted by the designer. The 95-inch thickness was simply taken off Minova's design charts for plug-type seal.

   b. 1st paragraph: the criteria for using the wall analysis versus the plug analysis is stated. Then the last sentence states that this was determined based on a factor of safety of one, not two. If there are ramifications for not considering a factor of safety of two, they should be stated.

c. 1st Paragraph: The safety factors may really not be realized considering the assumptions made in the analyses. The minimum seal thicknesses may not be conservative and this should be discussed in the report. Using WAC for a t/h ratio greater than 1/4 may be unconservative and potentially violates the basic assumption of arch-action and the kinematics that are required to occur. Again, when the safety factor equal to two is emphasized throughout the report, it portrays a degree of safety and confidence that may not be realized and justified, considering the assumptions made.

d. 2nd paragraph: A 48-inch-thick masonry wall probably would not be able to withstand 640 psi. There isn't any shear resistance at the roof line if only the ribs and floor are hitched.

e. 2nd Paragraph: The 300-psi static pressure for the 640-psi reflected pressure (fig. 20) is not justified.

f. This section presents design charts for minimum seal thickness. These charts are very misleading. Here are five points that demonstrate this.

   i. The second paragraph in Section 6.5 states that convergence and water pressure must also be considered in the structural analysis. The charts have not considered all loads that will be acting on the seal.

   ii. The seal material shear strengths listed in Table 6 are high. Table 6 shows the shear strength to be 25 percent of the compressive strength. While shear strength can only be accurately determined with testing, the accepted rule-of-thumb for estimating the shear strength for standard concrete is 20 percent [ASTM STP 169C, 1994]. It is difficult to say if this relationship is appropriate for low density and low strength material since this property is not typically used in design. In any event, the estimated shear strengths of the seal materials appear to be high.

   iii. There are two curves on the design charts for unreinforced standard and high-early-strength concrete. The charts assume that the concrete will act as a monolithic structure with the strength as designed. The use of concrete requires that steel reinforcement be used. As a minimum, reinforcement is necessary to control shrinkage and thermal cracking. Concrete will crack and the reinforcement is necessary to control the cracking and maintain the concrete as a monolithic structure. The reinforcement also has to be adequate to take any flexural and shear loads since concrete is only strong in compression.

   iv. The design charts show concrete block and specify that the strength is 2,500 psi. The charts and the report need to clarify that this is the masonry compressive strength and not the compressive strength of the concrete block. A masonry strength of 2,500 psi will require that the block be a higher strength and will require the use of an appropriate mortar to achieve that strength.

v. The design charts show low strength and low density materials being analyzed as walls and not plugs. This is inappropriate. The low density and low strength materials are only appropriate for use as plug material and should not be treated as a structural material. The Corps of Engineers may be able to provide guidance on this, but the limit should be at least 1200 psi. Any material with a compressive strength of 1200 psi or less should only be analyzed as a plug.

g. The plug seal design curves presented in figure 25 (640 psi design pulse) were based on shear strengths for lightweight foam cement, 1 day fly ash/cement, and sprayed gypsum presented in table 6. The shear strengths used to create the design curves may not represent more critical shear design conditions at the seal-boundary interface or through the host rock itself. Using a relatively conservative boundary interface shear strength of 36 psi (which is used by Minova in the design of their Tekseal plugs) in the plug formula presented in the draft, a seal would need to be 31.6 feet thick for an opening 2 meters in height and 20 feet in width. The corresponding thickness presented in the NIOSH draft document for a seal of equal dimensions is 14.8 feet. This thickness is considerably less than what the material manufacturer is using.

h. There appears to be discrepancies between calculated thicknesses for plug seals constructed of fly ash/cement and sprayed gypsum and the design curves presented on figure 25. For example, using the plug formula with the shear strength presented in table 6 for the fly ash/cement mix, a required thickness of 16.8 feet was calculated for a seal height of 2 meters. The corresponding thickness using the design curve is only 7.9 feet. Similarly, when analyzing a 2-meter-high seal constructed of sprayed gypsum with the plug formula, a required thickness of 25.3 feet was calculated. The corresponding thickness from the design curve yields a thickness of 11.5 feet. The appropriate corrections to the design curves need to be made. The calculations for figures 26 and 27 appeared to be consistent with the design curves.

i. For the design curves presented in figures 25 through 27, it should be indicated if the curves can be extended for seal heights exceeding those on the diagram and required thicknesses extrapolated.

21. Section 6.4:

a. 1st paragraph: Clarification should be provided regarding the installation of steel reinforcing bars within the seal. Would a continuous (spliced) section of rebar anchored to the roof and floor constitute 2 points of reinforcement? Additionally, the use of continuous rebar through the seal would greatly increase the flexural capacity of the seal.

b. In the equation for the number of reinforcing bars, should the strength of the bars used in the equation be the shear strength of the bars instead of the yield strength?

c. 1st Paragraph: The structural design of reinforced concrete seals requires the use of yield-line theory, ACI 318, and TM 5-1300.

d. 2nd Paragraph: The anchorage requirements for the seals cannot be resolved. For instance, assuming the anchorage acts as shear-friction steel and using the maximum coefficient permitted for concrete cast against hardened concrete intentionally roughened (ACI 318-02, Sec 11.7.4.3), the total number of dowels required for a seal 20 ft by 6.6 ft high subjected to a 300-psi static pressure is 190 for No. 6 dowels with 40-ksi yield strength (300 psi x 20 ft x 6.6 ft x 144 in^2/ft^2 / [0.75 in^2 x 40,000 psi]). Note that this does not include a "safety factor". It is not clear how a total number of No. 6 dowels equal to 160 was derived. Shear of the concrete and punching shear due to the dowels also needs to be addressed. Shear, not flexure may dominate the design of the reinforced concrete seals and this needs to be a consideration in the design of proposed seal thicknesses.

e. 2nd paragraph: Rebar shear strength using LRFD is = .9 x .6 x Fy (i.e. = .54Fy). Generally the bars should be at least 60 psi for yield strength in order to cut down on the amount required.

f. 2nd paragraph: The floor hitch should be into competent floor. If the 4 inches is all fireclay and the mine makes water, then the floor material will turn to soft mud. The mines may not be able to rely on the hitches due to long-term weathering and water effects if the mine makes water, therefore the bars should be sized to take all of the shear loading.

g. 2nd paragraph: The report should clarify the intention for how far the reinforcing bars need to extend into the seal.

h. 3rd Paragraph: An electrical engineer would need to address the hazards associated with a pump connected to piping extending through a seal, but this does not appear to be a safe recommendation for dewatering. There may be valves (blow-out prevention) to eliminate this hazard.

i. 3rd paragraph: Would it be acceptable to put a drain pipe in a 50 psi seal since the loading is less severe than 640 psi? What about the 120 psi?

j. 3rd paragraph: Unless the sump is accessible through a borehole to the surface, the system would not be serviceable. More consideration is required for controlling water accumulation.

22. Section 6.5:

a. 1st Paragraph: The first paragraph implies that the proposed seal dimensions and reinforcement is conservative and safe and this may not be true, considering the assumptions made, the limited number of failure modes considered, and the lack of quality control in construction employed in the mines.

b. 2nd Paragraph: A safety factor equal to 2.0 is not warranted for reinforced concrete and steel structures, due to ductility.

c. 2nd Paragraph: It is stated that structural analyses should consider all likely failure modes including flexural, compressive or shear failure through the seal material along with the shear failure through the rock or at the rock-seal interface. The presentation of design curves based solely on the use of approximated internal shear strength of the seal material may be misleading since a shear failure along the interface or through the host rock may actually govern the plug seal design. The shear strength in the latter scenarios may be considerably less than the internal shear strength of the material. As such, companies should be strongly cautioned when using the presented design curves.

23. Section 7.

a. The document should discuss that the monitoring of a mine atmosphere may be inconclusive for the reasons below:

   i. The interpretation of gob gases requires expertise be available.

   ii. Effective monitoring may require that the complete atmosphere of the sealed area be monitored. Monitoring of methane content only can be misleading if ethane, butane, and other hydrocarbons are present in the atmosphere.

   iii. A monitoring system needs to consider the gases that will be present. Heavy hydrocarbons will be at the bottom and methane will be at the roof. Monitoring can be inconclusive because of the layering of the gases.

24. Section 7.1. In the 4th paragraph, Scenario 2, Part F (from figure 19) is explicitly outlined, but Parts D and E are not summarized. Design summaries should also be provided for Parts D and E.

25. Section 7.2.
    a. In general, it is important to include that the professional engineer must stamp the information, design, and construction record. This should be included as a bullet item under Items 1, 2 and 3.

    b. Second bullet item under Item 4, it should be clarified that the repairs must be "structural repairs". It is important to emphasize the difference between a structural repair versus eliminating air leakage.

26. Section 7.3. It would be beneficial if NIOSH could research explosion barriers in front of seals, such as stacked sand bags, etc..

References:

1. Structures to Resist the Effects of Accidental Explosions, DOD, TM 5-1300, 1990.
2. Baker, W.E., P.A. Cox, P.S. Westine, J.J. Kulesz, and R.A. Strehlow. Explosion Hazards and Evaluation, Elsevier, 1983.
3. Structural Design for Security – State of the Practice, ASCE, 1999.
4. Design of Blast Resistant Buildings in Petrochemical Facilities, ASCE, 1997.
5. Biggs, J.M. Introduction to Structural Dynamics, McGraw-Hill, 1964.
6. Sealing-off Fires Underground, The Institution of Mining Engineers, 1985.
7. Gledhill, I.M.A. Computer Simulation of methane Explosions at the Kloppersbos Experimental Facility, CSIR, Report AERO 97/299, Oct. 1997.