Reviewer Comments and Responses

Reviewer 1 comment:

Comment: This was an excellent report on very thorough research. The literature review was thorough, the methodology was painstakingly thorough and incorporated the use of sufficient numbers of samples in dust size analysis and explosion tests. There was clear scientific and practicality to support the recommendation for an 80% incombustible content level in both intake and return airways in underground coal mines. In-mine rock dust sampling data indicated that most mines (66%) are already rock dusting at greater than the 80% level in intake airways.

Response: Thank you for your thorough review and salient observations. It is our sincere hope that this report provides the necessary science and engineering to guide future rock dusting regulations and practice.

Reviewer 2 comments:

Comment: Could it be advisable to look at other International standards? A reference table could be handy?

Response: The authors agree, we have added a table of rock dusting requirements for various countries.

Comment: Work done in South Africa and in Australia confirms >80% dust most of the work undeniably US focused.

Response: South Africa and Australia along with many other coal producing countries have conducted outstanding research to improve coal mine safety. Several countries require incombustible contents ≥ 80 % in the absence of background methane.

Reviewer 3 comments:

Comment: This is an excellent report, and I approve of its publication. It is comprehensive and completely justifies the authors' recommendation that 80% TIC be required for current mine entries based on their measurements that those entries contain finer dusts than those for which the earlier regulations were developed. Their data are only for hvb coals such as Pgh seam coal.

Response: The authors thank the reviewer for his kind words and his approval for publication. This particular study only used high volatile coal such as Pittsburgh seam coal to determine the TIC needed to prevent flame propagation as function of coal particle size.

Comment: They overstepped, however, in accepting the Nagy (1981) recommendation that there be no adjustment for lower volatility coals. This report contains no data for the TIC's of such lower volatility coals. There is ample data to show that lower TIC's are adequate for lower volatility coals (Hertzberg & Cashdollar, 23rd Int. Conf. of Safety in Mines Res. Insts., Washington, D. C., Sept 1989 pp 965-975).

Response: The statement was removed since the authors were only looking at the coal particle size effects. However, the initial recommendation, as summarized by Nagy (1981), regarding rock dusting for low volatile coals was first made by the US Bureau of Mines Mine Safety Board in 1927 (IC 6039) and clarified by decision in 1937 (IC6946). As Nagy summarized in (1981) - "All Federal mine codes and laws since mid 1920s have contained the same requirement. The requirement to have a 65% incombustible content for all coals but anthracite was made to simplify rock-dusting practices. Coals having a volatile ratio of less than 0.2 are provided a greater margin of explosion protection than coals having a volatile ratio higher than 0.2." The NIOSH authors respectfully disagree with the reviewer that the authors overstepped in accepting that there be no adjustment for lower volatility coals. The questions that you raised do not provide compelling technical arguments for the authors to deviate from their proposed criteria. The authors put forth technical and anecdotal arguments to support their position on point by point basis.

1. The authors would like to point out in your referenced report [(Hertzberg & Cashdollar, 23rd Int. Conf. of Safety in Mines Res. Insts., Washington, D. C., Sept 1989 pp 965-975)] Figure 6 that shows that the maximum explosion pressures as a function of coal dust concentrations. Figure 6 shows that coal concentration from ~150 g/m^3 to 600 g/m^3, yield no significant difference in maximum explosion pressure for both low and high volatile coals. Therefore Figure 6 indicates that for the same particle size distribution and coal concentration between 150g/m3 to 600 g/m3 maximum explosion over pressures range from 5 to 6 atmospheres with no significant difference between lower volatile Pocahontas seam coal (18% VM) and higher volatile Pittsburgh seam coal (VM 36.5%).

2. Gibbins and Chi, using a thin coal layer deposited on an electrically heated screen, measured the high heating rate volatile production from several coals. The ratio of the volatility measurement to the ASTM (proximate) volatility (R factor) ranges from 1.1 to 1.4 for the bituminous coals studied with an average of about 1.3. There is no obvious dependence on the ASTM volatility. Results give the highest ratio for Pocahontas with 16% ASTM volatility and the lowest ratio for Byron Creek with 24% volatility.

Gibbins and Chi lists the results for 13 high volatile bituminous coals of international origin. Their proximate VM contents ranged from 32-45% and the volatility ratios (R factor) with rapid heating ranged from 1.2-1.4. The volatile ratio increases with decreasing particle size and coal particle size also has a significant effect on explosibility.

Reference: Jon Gibbins and Chi (also KJ Pendlebury), "Determination of Rapid Heating Volatile Matter Contents as a Routine Test", Combustion Sci. and Technology, 93, 1993, pp. 349-361

3. Hertzberg and Ng (1987) have shown measurements of volatility by the laser pyrolysis method clearly indicate that the volatility increases for smaller particle sizes.

Reference: Hertzberg, M. and Ng, D.L. (1987).: "A Microscopic and Kinetic study of Coal Particle Devolatilization in a Laser Beam," in Fundamentals of the Physical-Chemistry of Pulverized Coal combustion, NATO ASI Series E, p.104, Martinus Nijhoff, 1987.

4. K.L. Cashdollar, M. Hertzberg, and I.A. Zlochower conducted 20 L chamber tests using fine **non volatile** graphite dust and measured strong explosion overpressure ratios of at least 5 with moderate energy igniters. Results indicate that even without volatiles one can have strong explosions.

Reference: K.L. Cashdollar, M. Hertzberg, and I.A. Zlochower. "Effect of Volatility on Dust Flammability Limits for Coals, Gilsonite, and Polyethylene", 22nd Symposium (International) on Combustion/ the Combustion Institute, 1988, pp. 1757-1765,

5. Cashdollar KL, Hertzberg M [1989] show that the particle size distribution of coals can have as much of an effect on the rock dust inerting requirements as the volatility of the coals. The finer the size of coal, the more rock dust is required to inert. However, any single measure of particle size (such as the percent minus 200 mesh) is insufficient to characterize the particle size distribution and rock dust inerting requirement.

Reference: Cashdollar KL, Hertzberg M [1989]. Laboratory study of rock dust inerting requirements: effects of coal volatility, particle size, and methane addition. In: Proceedings of the 23rd International Conference of Safety in Mines Research Institutes (Washington, DC, September 11-15, 1989). Pittsburgh, PA: U.S. Department of the Interior, Bureau of Mines, pp. 965-977.

Comment: The data in Fig. 10 and C-1 are for hvb coals only (Pgh & Sunnyside). The report contains particle size data for lvb Pocahontas and mvb Blue Creek coals, but there is no data for the TIC's required to inert those coals, and hence no justification for the Nagy conclusion.

Response: Authors agree. The data in figure 10 and C-1 are for hvb coals. We have limited data from full-scale exploratory tests conducted the LLEM using lower volatile coals. Additional full-scale experiments should be conducted with lower volatile coals. As the data in Figure 6 indicates that once an explosion starts low volatile coal such as Pocahontas the resulting explosion overpressures will be potentially comparable to those produced by Pittsburgh seam coal ~5 atmospheres.

Without full-scale explosions test data for lower volatile coals, our arguments not to relax the TIC requirements for lower volatile coals are based on laboratory scale explosions and additionally volatility production based on high heating rates. The authors are hesitant, therefore, to recommending lowering the incombustible requirements for lower volatile coals - certainly not without the support of extensive large scale explosion data using coal dust.

Several countries including Australia, South Africa, UK (National Coal Board overseeing private mines) that initially specified lower rock dusting requirements as shown in Table 2 in reference (Sapko MJ, Greninger NB, & Watson RW [1989] have since changed their TIC requirements and now require the same IC to prevent explosion propagation for all bituminous coals. Recently, Dr. Kazimierz Lebecki, former deputy director from the Polish Experimental Mine Barbour, said that about 10 years ago following a major underground explosion that occurred involving coal dust with a confirmed 11% volatility the Polish threshold of volatile matter was changed from >12 to >10% that requires 80% incombustible.

Therefore given 1) the propensity for lower volatile coals to produce more dust containing reactive finer particles, 2) to produce more volatiles under heating high rates that are not correlated with ASTM measurements, 3) the fact that there have been documented strong explosions involving lower volatile coals, and 4) the fact that other major coal producing countries that had relaxed inert standards for lower volatile coals have since essentially eliminated relaxation for lower volatile coals, the authors do not recommend lowering the TIC requirement for lower volatile coals without the support of extensive large experimental mine scale data.

Comment: Also, the reference to the Gates report of the Sago disaster is somewhat misleading since it was a pure methane explosion behind a sealed area and did not involve coal dust.

Response: The authors agree with the reviewer and have removed the reference.

Reviewer 4 comments:

Comment: This is an excellent report dealing with significant technical matters. I find no fault whatsoever with the methods, data analysis, or conclusions. The work, as with all work coming from this particular group, is fundamentally sound. My comments here are concerned solely with the organization of the manuscript. Consideration of these points will, I believe, lead to an improved report that better illustrates the key concepts and conclusions.

Comment: The factors that can influence the amount of admixed rock dust required to inert a coal dust explosion are as follows:

- coal dust particle size distribution,

- coal dust volatile content,

- rock dust particle size distribution, and

- co-presence of methane.

The above points should be discussed clearly and early in the manuscript. It should be emphasized that the manuscript deals only with coal dust particle size effects. Then the manuscript should be reviewed for consistency with respect to this point. For example:

- Page 29; Line 736: Particle size of the rock dust was not part of the current study.

- Page 29; Lines 738-740: I am not sure of the foundation for this endorsement; no data are presented to substantiate this claim. In fact, the use of high volatile coals was actually the basis for the current study.

- Page 40; Line 1105: Rock dust properties are not discussed in this manuscript and do not form part of the current study.

Response: The authors completely agree with reviewers comment that several other factors besides particle coal size can influence the amount of admixed rock dust required to inert a coal dust explosion such as coal dust volatile content, rock dust particle size distribution, and co-presence of methane. We have changed the text following your suggestion by identifying these controlling factors and emphasized that the manuscript deals only with coal particle size effects. The text was changed as follows:

The factors that can influence the amount of admixed rock dust required to inert coal dust explosions include: coal and rock dust particle size distribution, coal dust volatile content and *the co- presence of methane. Much knowledge has been obtained from experimental mine and laboratory dust explosion research during the past three decades. Investigators have examined the effects of rock dust inerting requirements, the minimum explosible coal dust concentrations, the effects of volatile matter on the explosibility of coal dusts, the effect of coal and rock dust particles sizes, and the effect of background methane in full-scale experimental mines and in laboratory test vessels.[Sapko et al. 1987a,b; 1989; 1998; 2000; Sapko and Verakis 2006; Cashdollar 1996; Cashdollar and Hertzberg 1989; Cashdollar and Chatrathi 1993; Cashdollar et al. 1987; 1988; 1992a,b,c; 2007]. Further research evaluated the effects of pulverized versus coarse coal particle size [Weiss et al. 1989], coal volatility, extinguishment, and pyrolysis mechanisms [Hertzberg et al. 1987; 1988a, b; Conti et al. 1991; Greninger et al. 1991]. The clear cumulative consensus of these studies is that dust particle size emerges as the single most influential factor controlling coal dust explosion propagation. Therefore the primary focus of this research was to examine the effect of coal particles size while holding other factors constant.*

Page 29; Line 736: Particle size of the rock dust was not varied during most recent inerting study. All recent experiments were conducted using the 2007 limestone rock dust shown in Table C-2. All previous inerting experiments conducted in LLEM in the 1980's were conducted with high volatile coals using limestone rock dust with particle sizes shown in Table C-2.

Comment: - In general, I think it is important to clarify the historical timeline here (the BEM and LLEM inerting results came first, followed by the recent coal particle size data).

Response: The historical time line is essentially defined by the dates of experiments conducted in the Lake Lynn Experimental Mine shown in Table C-4 starting with Test 49-D on 7/17/85 through Test 522-A on 3/26/08. The early data shown in Figure 1 was from test conducted in the Bruceton Experimental Mine in the mid 1920's as indicated in the body of the report.

Comment: The section on *Limestone Rock Dust Inerting* and *APPENDIX C* are very important components of the manuscript. They need to be reworked to avoid duplication. As presented, I found this material to be somewhat confusing and overlapping. My suggestion is to rewrite these parts and combine into one new section in the main body with only tables and figures in the appendix.

Response: The overall results for the limestone rock dust inerting experiments for higher volatile coals and limestone rock dust are shown on Figure 10 in the main body of the report. The specific data values in Figure 10 are those listed in the Table C-1. The authors chose to use the Appendix C to discuss specific details of the various experiments shown in Table C-1 and minimize including details in the main body of the report.

Comment:

There is an interesting comparison to be made between Figure 1 (earlier BEM data) and Figure 10 (recent LLEM data). One can clearly see an increase in TIC from about 60to 70 % at the coarse coal particle size end of the figures, while TIC remains at about 80% at the fine coal particle size end of both figures. This is a graphic illustration of the main thesis of the manuscript.

Response: Good point the authors included your comparison to the section on "Limestone Rock Dust Inerting"

Comment: Staying with Figure 10, there is considerable overlap with Figure C-1. In fact, Figure C-1 is Figure 10 with one additional datum at about 14 % minus 200-mesh coal dust. This may be confusing to some readers and should be clarified by collapsing the two figures into one, or by providing explanatory text for the two figures.

Response: Figure C-1 has been revised and the 14 % minus 200-mesh coal dust data point was removed.

Comment: Page 41; Line 1159: The rationale for inclusion of the Sunnyside seam data needs to be explained. The vast majority of the data in the paper are for Pittsburgh seam coal.

Response: Agreed, the Sunnyside seam coal data has been removed from the paper.

Comment: Page 46; Lines 1237-1243: There is significant overlap here with the main text (*Limestone Rock Dust Inerting*).

Response: The overall results for the limestone rock dust inerting experiments for higher volatile coals and limestone rock dust are shown on Figure 10 in the main body of the report. The specific data values in Figure 10 are those listed in the Table C-1. The authors chose to use the Appendix C to discuss specific details of the various experiments shown in Table C-1 and minimize including details in the main body of the report.

Comment: Page 20; Lines 720-721: I would advise caution in making this statement. It may be true, but could this statement be used out of context by some people to 'relax' their rock dusting efforts?

Response: Based on the inerting data from the Bruceton and Lake Lynn Experimental Mines, the present size of coal particles in intake airways requires more incombustible content to be rendered inert than the 65% TIC specified in current regulations. Thus for return airways, the current requirement of 80% TIC is still sufficient.

Comment: Page 20; Lines 725-728: The CDEM is undoubtedly an important development, but is it consistent with the study focus to the extent that it should appear in what is essentially the conclusions section of the manuscript?

Response: The authors agree and have removed discussions of the CDEM from this paper since it has been discussed in other NIOSH publications. Mention of the meter here distracts from the main goal of recommending a new requirement of 80% TIC for intake airways.

Reviewer 5 comments:

Comment: No technical errors and approved for publication.

Response: Thank you for your technical review. Your efforts are most appreciated. It is our sincere hope that this report provides the necessary science and engineering to guide future rock dusting regulations and practice.