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Office of Miners Health Safety and Training Coal-Dust Practices Survey Program

On March 6, 2012 the West Virginia Legislature modified the W.Va. Code §22A-2-24 standards for the application of rock-dust in underground coal mines. The attached document provides extended guidance and references for the program to implement those standards described in Emergency Rule §56-17.

The objective of the Legislature's action and the Coal-Dust Practices Survey Program is to reduce the probability of the initiation of a coal-dust explosion in West Virginia underground coal mines by supplementing visual examinations by miners and inspectors with quantitative surveys of the effectiveness of a mine's rock-dusting practices in meeting regulatory requirements.

While this document outlines the procedures to be utilized by the agency, mine operators are encouraged to institute their own process for quantitatively validating that their practices are effective in minimizing coal-dust accumulation and that adequate rock-dust is being applied to inert any that does. Based upon experience in an individual mine, quantitative sampling of areas of likely accumulation should be monitored not less than once per month. Accumulation of coal-dust may be less rapid outby active sections, however, identifying areas of concern and initiating a not less than quarterly quantitative survey of those as well is advised. The sampling and analytical procedures described herein should prove useful in such programs.

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Coal-Dust Practices Survey Program

West Virginia Office of Miners Health Safety and Training

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HIGHLIGHTS OF OMHST COAL DUST ENFORCEMENT PROGRAM

The West Virginia Office of Miners Health Safety and Training (OMHST) began investigating the feasibility of creating an internal coal-dust analysis capability in January 2010. The Upper Big Branch accident and the resultant Executive Order 1-10 dated April 14, 2010 accelerated the process. It was found that the current process taught by the US Mine Safety and Health Administration (MSHA) lacked the consistency and transparency that West Virginia sought for in its programs. Rather than simply adopt the MSHA process OMHST set out to determine the best-in-class solution.

OMHST spent considerable time understanding the practice and origins of the MSHA procedures for sampling and analysis. An in-depth literature review was undertaken which lead to follow-on discussions with the researchers and authors of mine safety reports across the US and internationally. In addition, significant lessons were learned in the over six months of practice the agency's staff has gained in collecting samples and doing analysis. The result is that the procedures OMHST is now instituting represent the state-of-the-art across the mine safety community.

OMHST in-mine dust surveys implement a statistically based sampling procedure focused on historically the portion of the mine where a minor ignition is likely to initiate a major explosion, the area one thousand feet (1,000') from the point where coal is being cut. The exact sampling locations will be determined utilizing a random process that produces an unbiased sample representative of this critical area. The portion of the accumulated dust collected for analysis will be that which the National Institutes of Occupational Safety and Health (NIOSH) and others have found to be most likely involved in an explosion, the top one-eight inch (1/8"), and the dust on the roof and ribs will be collected separately from that on floor. This approach follows the most recent recommendation from NIOSH and international mines safety organizations and corrects for infrequent, inadequate and non-representative sampling that result from that taught by MSHA.

The OMHST analysis process is based upon the MSHA Mount Hope Laboratory procedure #102. That procedure differs from the analogous NIOSH procedure which in turns differs from those utilized by other combustible content testing standards within government and industry. The MSHA procedure is available upon request from the Mount Hope Laboratory, but no published peer review of its effectiveness was found. OMHST worked with the Sandia Livermore National Laboratory's combustion chemistry group to verify the validity of the MSHA procedure and consulted with NIOSH to expand the definition of the various steps and processes. Currently MSHA equivalent rock-dust tests are not part of the standard suite of commercially available procedures available to the industry. OMHST will work with commercial laboratories that provide services to West Virginia coal mines to ensure that they can provide the same compliance test to their customers. The OMHST procedures and the chain-of-custody procedures are based upon those

used by WV State Police Forensic Laboratory and the FBI. OMHST will accept an offer from the MSHA Mount Hope Laboratory to do joint quality control testing in addition to working with commercial laboratories that have expressed interest in participating in an inter-lab QA program with OMHST. These steps plus the ability of mines to do independent testing will greatly improve the validity of the process and increase awareness of the issue.

This document is the first installment of guidance for staff and the industry providing detailed procedures and coal-dust explosion background that will:

- Focus on the 'practice of rock-dusting' rather than a percentage at a specific location;
- Provide procedures for statistical determining the locations that are sampled;
- Describe sampling only top one-eighth inch (1/8") of dust deposited;
- Show how to separate rib-roof and floor samples;
- Provide procedures for sampling in wet and dry conditions;
- Define qualitative methods of determining too-wet to sample;
- Provide guidance for limiting exposure to the respirable portion of rock-dust [1];
- Standardize laboratory analysis procedures for combustible and moisture content;
- Standardize sample handing and quality control procedures; and
- Provide guidelines for violation and abatement.

Educational outreach will be required to explain the rule and the procedures. This will be conducted through OMHST's existing corps of trainers and rock-dust surveyors by attending as many individual mine and joint mine events as possible.

INTRODUCTION

In the course of normal mining it has been estimated that one to three percent (in some thin, friable[2] seams up to ten percent) of the total coal mined is reduced to dust able to pass through a US Standard 20-mesh sieve.[3] Large quantities of this float dust are carried on the air currents which settle on the floor and the "rib-roof surfaces". The dust settling on the rib-roof surfaces is generally of finer particle sizes than the floor dust; this, coupled with its more advantageous position for dispersion, makes the rib-roof dust a greater explosion hazard.[4]

[1] That portion of airborne dust in coal mines that is capable of entering the gas-exchange regions of the lungs if inhaled; by convention, a particle-size-selective fraction of the total airborne dust; includes particles with aerodynamic diameters less than approximately 10 microns – "Occupational exposure to respirable coal mine dust" NIOSH (1995) Standards - OSHA Permissible Exposure Limit: 15 mppcf (million particles per cubic foot); American Conference of Industrial Hygienists (ACGIH) Threshold Limit Value: 2 mg/m^3; NIOSH Recommended Exposure Limit: 2.5 mg/m^3 TWA; MSHA Permissible Exposure Limit 2 mg/m^3

[2] Friability (or friable) is the ability of a solid substance to be reduced to smaller pieces with little effort.

[3] Hartmann, et al, "Incombustible Required on floor and rib-roof surfaces of coal mines to prevent propagation of explosions", USBM RI-5053 (1954)

[4] Two primary forces act against the lifting of individual particles of dust into the air stream 1) Cohesion is the intrinsic property of like molecules caused by their shape and structure creating an attraction, 2) Gravity is the force that attracts a particle toward the center of the earth. To lift a particle into the air stream both need to be overcome, however, for particles on the rib-roof surface only the force of cohesion must be surpassed as gravity will then pull the particle toward the floor and into the air stream. Because coal-dust is less dense than rock-dust

Under conditions prevailing in underground coal mines coal-dust accumulates on the surfaces of the mine as dust in the air settles.[5] During normal operations the quantity of coal-dust in the air is insufficient to develop an explosion; in other words it is below its lower explosive limit.

Two factors must act in concert to initiate a coal-dust explosion: a factor which causes the raising of a dangerous cloud of coal-dust and the appearance, at the same time, a thermal factor capable of initiating this cloud.

Such conditions are created in underground coal-mines most easily by a localized ignition of methane. The methane explosion causes a strong blast of turbulent air as the result of the rapid expansion of hot combustion gases. At the same time the burning methane can easily ignite the coal-dust cloud.

The combustion of the coal-dust in the cloud causes the sudden liberation of additional thermal energy. The even more rapid temperature rise of gasses from the coal-dust combustion expands turbulently in turn raising the next cloud of coal-dust. If the coal-dust is sufficiently dispersed throughout the mine and no means of suppression are provided the explosion will propagate with increasing force until it consumes all the fuel available.

STANDARDS

The standard for the maximum combustible portion of accumulated coal-rock-dust is set in West Virginia rules at:

W.Va. Code §22A-2-24 Control of coal-dust; rock-dusting

(a) In all mines, dangerous accumulations of fine, dry coal and coal-dust shall be removed from the mine, and all dry and dusty operating sections and haulageways and conveyors and back entries shall be rock-dusted or dust allayed by such other methods as may be approved by the director.

(b) All mines or locations in mines that are too wet or too high in incombustible content for a coal-dust explosion to initiate or propagate are not required to be rock-dusted during the time any of these conditions prevail. Coal-dust and other dust in suspension in unusual quantities shall be allayed by sprinkling or other dust allaying devices.

(c) In all dry and dusty mines or sections thereof, rock-dust shall be applied and maintained upon the roof, floor and sides of all operating sections, haulageways and

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coal will be lifted at approximately at 5 meters per second while rock at 8 meters per second. Thus a week explosion is more likely to preferentially lift the coal only. Dawes JG "Dispersion of dust deposits by blast air" SMRE RI-36 (1956) and Singer "Some aspects of the aerodynamics of formation of float dust clouds" USBM RI-7252 (1969)

[5] An eight entry mine producing 12,000 tons per day by continuous miners will produce approximately 20% dust that will pass a number 20 sieve, 150 tons daily, of that about 1% will be fine enough to be transported through the ventilation air before it all settles. If only 0.1% of this were float-dust it would accumulate 0.1 ounces per square foot in the entries per day or layer 0.003 inches almost enough for the 0.005 inch propagation minimum. Hartman I "Rockdusting and sampling" USBM IC-7755 (1956) While hypothetical this demonstrates the importance of regular rock-dusting practice.

parallel entries connected thereto by open crosscuts. Back entries shall be rock-dusted. Rock-dust shall be so applied to include the last open crosscut of rooms and entries, and to within forty feet of faces. Rock-dust shall be maintained in such quantity that the incombustible content of the mine dust that could initiate or propagate an explosion shall not be less than eighty percent. The incombustible content of mine dust in return entries shall also be equal to or greater than eighty percent.

(d) Rock-dust shall not contain more than five percent by volume of quartz or free silica particles and shall be pulverized so that one hundred percent will pass through a twenty mesh screen and seventy percent or more will pass through a two hundred mesh screen.

(e) If requested by the director, an operator shall provide records establishing the quantity of bulk and bag rock-dust purchased for period not to exceed the immediately preceding six months.

Guidance for understanding and applying W. Va. Code § 22A-2-24 and Emergency Rule 56CSR17:

a) **"Coal-dust"** – the name for the fraction of very fine coal particles deposited throughout the underground mine by air currents and transport that can change even a minor methane ignition into an explosion. Coal-dust passes a US Standard No. 20 sieve as differentiated from "loose coal" that refers to fragments larger in size than those passing a US Standard No. 20 sieve. Particles passing a US Standard No. 200 sieve constitute an even greater explosion hazard as they are more easily lifted into the air stream. [6] Coal-dust is not easily wetted and less than fully saturated accumulations, thirty percent (30%) moisture, will participate in an explosion.[7,8,9]

b) **"Rock-dust"** – a pulverized stone used to cover coal-dust and render accumulations of it inert. Rock-dust shall be composed of calcite[10] or dolomite[11] or an equivalent mineral, preferably light colored, one-hundred percent (100%) of which will pass through a US Standard No. 20 sieve and seventy percent (70%) or more of which will pass through a US Standard No. 200 sieve; rock-dust particles when wetted and dried will not cohere to form a cake which may not disperse into separate particles by a blast of air and do not contain more than five percent (5%) free and combined silica (SiO_2) and do not exceed regulatory respirable dust levels when applied.[12,13,14]

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[6] Hartmann I, "Studies on the development and control of coal-dust explosions in mines", USBM IC-7785 (1957)
[7] Cashdollar K, et al, " Recommendations for a new rock-dusting standard to prevent coal-dust explosions in intake airways", NIOSH RI-9679 (2010)
[8] Rice G, et al, " Effective rock-dusting of coal mines", IC-639 USBM (1927)
[9] Nagy J, "The explosion hazard in mining", MSHA IR-1119 (1981)
[10] Calcite constitutes a significant part of all three major rock classification types; oolitic, fossiliferous and limestone. Limestone becomes marble from the heat and pressure of metamorphic events.
[11] Dolomite or dolomitic limestone although common is one of the few sedimentary rocks that undergoes a significant mineralogical change after it is deposited though the incorporation of magnesium rich ground waters. Except in its pink form, dolomite is hard to distinguish from calcite.
[12] Rock Dusters have the highest exposure measured to respirable dust of all underground coal mining occupations "Occupational Exposure to Respirable Coal Mine Dust", NIOSH (1995) Table 5A pp 251

c) **"Dangerous Accumulations of Fine, Dry Coal and Coal-dust"** – more than twenty percent (20%) combustible content in the top one-eighth (1/8) inch of dust on the surface of floor and/or rib-roof or structures.[15,16]

d) **"Dry and Dusty Operating Sections and Haulageways and Conveyors and Back Entries"** – areas so described that are not sufficiently wet to prevent the spread of coal dust in an explosion, the condition where total moisture is less than thirty percent (30%) as indicated when a ball of dust from the top one-eighth inch (1/8") is squeezed reasonably in a hand yields no liquid flowing between fingers or leaving no wet residue in the hand; visual observations are not sufficient.[17,18,19,20]

e) **"All Mines or Locations in Mines that are Too Wet or Too High in Incombustible Content for a Coal-dust Explosion to Initiate or Propagate**" – a location would be "too wet" when accumulated dust has a moisture content of thirty percent (30%) or greater which can be observed in the mine if a ball of dust from the top one-eighth inch (1/8") is squeezed reasonably in a hand that liquid flows with between fingers leaving a wet residue in the hand; visual observations are not sufficient. Coal-dust laying on standing water will participate in an explosion. If the location of the mining activity is

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[13] Rock-dust should not contain particles that would result in exceeding regulatory respirable dust levels in 30 CFR 56 - 57.5002 when applied as coal miners who are exposed to respirable crystalline silica are at risk of developing silicosis or mixed-dust pneumoconiosis. During dry rock-dusting in 6,000 cubic feet per minute air 25 feet down wind particle counts as high as 5,000 million per cubic foot have been measured dropping to only 2,000 million 100 down wind. Hartmann I "Rock dusting and sampling", USBM IC-7755 (1956) Note - OSHA Dust Permissible Exposure Limit: 15 million particles per cubic foot

[14] "These incombustible concentrations [65% and 80%] are not magical values which cause flame to quench instantaneously, but are sufficient to prevent ignitions of the dust by an electric arc, spark, open flame, or other weak ignition source and limit the travel through the dust mixture when it is ignited by a stronger source." John Nagy, MSHA Report 1119 "The Explosion Hazard in Mining" (1981) pp26

[15] Explosibility of coal-dust is related to the quantity available, known as the minimum explosive concentration (MEC), the minimum quantity of dust in suspension that will propagate a coal-dust explosion. The MEC for bituminous coal is approximately 0.10 ounce per cubic foot or 100 grams per cubic meter. Tests have demonstrated that the MEC quantity of coal-dust created a layer averaging 0.005-inch thick in a mine entry**.**

[16] Homogeneous mixtures of rock and coal-dust seldom occur in a mine, rather coal-dust is deposited continuously and rock-dust periodically resulting in layers of different material.

[17] Cybulski W, "Coal-dust explosions and their suppression", translated by USBM from Polish (1973)

[18] Mitchell D & Nagy J, "Water as an inert for neutralizing the coal-dust explosion hazards", USBM (1962)

[19] Cybulski W, "Research on the effect of water on the Explosibility of coal-dust", Research Reports of Mining Central Institute Quarterly (Prace GIG) Ser. A, No. 231 (1959) translated from Polish by USBM (1965)

[20] The British Coal Mines Regulation Act of 1887 introduced the term "dry and dusty" in its discussion of conditions in which blasting was dangerous. It was incorporated into subsequent regulations across the British Empire and was utilized by USBM reports on coal-dust in 1911. While it has never been defined in regulation it was noted by Mitchell & Nagy in USBM (1962) that previously held approximations of "too wet" were incorrect and that "visual observation is a poor method for estimating the moisture content of mine dusts", this was confirmed by studies issued in the same period in England, Germany and Poland. The phrase is not actually used in Federal Law rather the Congressional Report 91-563 that accompanied the 1969 Mine Safety Act said "… rock dusting is not necessary in those underground areas of a mine that are, in fact, too wet or too high in incombustible content to propagate an explosion." The inverse of this "dry and dusty" was used in media reports at the time and was incorporated into the 1985 WV rule on rock dust. Case law has defined the phrase by differentiation between "dry and dusty" and "sufficiently wet to prevent the spread of coal dust" (Secretary of Labor (MSHA) V. Consolidation Coal, 03/03/1989, Docket No WEVA 88-197).

advancing through other than coal, the dust may be found to be incombustible upon testing.[21,22]

f) **"Dry and Dusty Mines or Sections Thereof**" – areas as defined above that are not sufficiently wet to prevent the spread of coal dust in an explosion, the condition where total moisture is less than thirty percent (30%) as indicated when a ball of dust from the top one-eighth inch (1/8") is squeezed reasonably in a hand yields no liquid flowing between fingers or leaving no wet residue in the hand; visual observations are not sufficient

g) **"Coal-dust and Other Dust in Suspension in Unusual Quantities**" – a coal-dust explosion is the fast combustion of dust particles suspended in the air, a dust cloud. When pulverized coal-dust at the MEC[23] was dispersed in an entry, a cap lamp ten feet (10') within the cloud was not visible to observers standing in front of the dispersed dust.[24]

h) **"Sprinkling or Other Dust Allaying Devices"** – application of rock-dust on floor and rib-roof surfaces by either manual or mechanical means is sufficient to allay or alleviate the hazards posed by coal-dust being lifted into the dust cloud during an explosion if it accounts for at least eighty percent (80%) of the combined dust.[25,26]

i) **"Rock-dust Shall Be so Applied to Include the Last Open Crosscut of Rooms and Entries, and to Within Forty Feet of Faces"** – up to a point forty feet (40') from the face or the last open crosscut in a room and pillar mine or up to a point forty feet (40') from the maingate [27]and tailgate in a longwall mine.

SAMPLING LOCATIONS

An Authorized Representative of the Director[28], Inspector or Dust Surveyor, will conduct a coal-dust survey by collecting samples at a location(s) that are representative of the conditions found in the mine.

Each survey shall include, at a minimum, a random sample location no more than one-thousand feet (1,000') from the last open crosscut in a room-and-pillar mine or no more than one-thousand

[21] Mitchell D & Nagy J, "Water as an inert for neutralizing the coal-dust explosion hazards" USBM (1962).
[22] Cybulski W, "Research on the effect of water on the Explosibility of coal-dust", Research Reports of Mining Central Institute Quarterly (Prace GIG) Ser. A, No. 231 (1959) translated from Polish by USBM (1965)
[23] The minimum quantity of fine size dust in suspension that will propagate a coal-dust explosion – the MEC for bituminous coal is approximately 0.10 ounce per cubic foot or 100 grams per cubic meter. It has been reported that the greater the percentage of finer dust the lower the MEC, with very fine coal-dusts exploding at 65 grams per cubic meter. Stephan C "Coal dust explosion hazards" MSHA Pittsburgh Safety And Health Technology Center (2010)
[24] Stephan C, "Coal-dust explosion hazards", MSHA Pittsburgh Safety And Health Technology Center (2010)
[25] 80 percent rock-dust to 20 percent coal-dust is a 4 to 1 ratio
[26] Cashdollar K, et al, " Recommendations for a new rock-dusting standard to prevent coal-dust explosions in intake airways", NIOSH RI-9679 (2010)
[27] Maingate and tailgate: Underground roadways formed on either side of longwall block. Maingate refers to the roadway(s) containing the conveyor belt, stage loader and other services to the face area. Tailgate refers to the roadway on the return side of the longwall face.
[28] WV§22A-1-4(b)(2) and WV§22A-1-14 herein referred to as Inspectors or Coal-Dust Surveyors

feet (1,000') from the tailgate or maingate in a longwall mine.[29,30] Based upon the observations by the Inspector or Dust Surveyor, other locations maybe sampled based upon proximity to a potential ignition source or that appear to represent conditions substantially inferior to requirements.

During an OMHST Coal-Dust Survey, sampling locations will be determined using probability-based random sampling techniques. The approach requires that an area of concern be identified and the location selected for sampling within that area has an equal chance with every other location of being selected.[31]

The primary area of concern for a typical OMHST Coal-Dust Survey will be all entries outby one-thousand feet (1,000') from either the last open crosscut in a room-and-pillar mine or one-thousand feet (1,000') from the tailgate and maingate in a longwall mine. The surveyor, upon arriving at the one-thousand foot (1,000') point will use a table of random numbers to select the sampling location (example attached). The procedure to be utilized is an adaptation of that used by the West Virginia Department of Transportation.[32] The OMHST table contains one-thousand (1,000) numbers in a random order. To use the table, the surveyor will select a random point on the table by tossing a pebble or similar object upon the page. The number under the object will be the distance outby the last open crosscut or maingate and tailgate at which the sample will be taken. If when arriving at that location it is in a crosscut the surveyor will move fifty feet (50') inby if an even numbered day or fifty feet (50') outby if an odd numbered day.

All entries in the section shall be sampled in a line roughly perpendicular to the mains at the random location selected, but no more than three crosscuts inby[33] or outby[34] said deviations based upon accessibility. Limitations to access might be roof conditions, man-door locations, belt structures, etc. In those cases alternative sampling locations within the three crosscut range maybe selected but shall be the same distance from the inby edge of the pillar as the primary location.

Wet portions of the survey area should receive the same rock-dust treatment as dry areas. Pure coal-dust adsorbs water with difficulty and retains water poorly; water adsorption and retention is increased with the addition of rock-dust to the coal-dust; the rock-dust acts as glue for wetted

[29] Since most ignition sources occur at and near active coal faces, rock-dusting outby the face is critical. Studies have shown that coal-dust explosions can be quenched most successfully near their point of origin; however, a coal-dust explosion that originates in a non-rock-dusted area cannot be quenched immediately but will propagate from one to several hundred feet through the rock-dusted zone before the flame is extinguished. Starting rigorous rock dusting near the face and continuing outby is the most effective means of ensuring that an ignition will be stopped quickly.

[30] If a methane explosion flame were to not extend beyond 350-feet it is defined as not having been propagated by coal dust – Rice G & Greenwald H, "Coal-dust explosibility factors indicated by experimental mine investigations, 1911-1929" USBM IC 464 (1929)

[31] Cochran W, "Sampling Techniques-Edition 3", Wiley Series in Probability and Mathematical Statistics (1977)

[32] WVDOT, "Procedure for determining the random location of compaction tests", MP 712.21.26 (1999)

[33] Pertaining to the direction towards the coal face

[34] Pertaining to the direction away from the coal face

coal and assures that incombustible material is present should drying occur.[35] Therefore, it is advantageous to rock-dust wet areas in coal mines. "Too wet to sample", is defined as the condition when the total moisture content equals or exceeds thirty percent (30%) which in the mine can be determined qualitatively when a ball of dust from the top one-eighth inch (1/8") is squeezed reasonably in a hand that liquid flows between the fingers leaving a wet residue in the hand; visual observations are not sufficient. Even in wet areas, dry coal-dust deposited on the surface of wet dusts or standing water will become lifted in an explosion thus requiring periodic rock-dusting. Saturated coal <u>not</u> standing pools of water is effective in inerting an explosion.[36,37,38,39] In these areas the wet alternative sample collection procedure described below will be used.

SAMPLING FREQUENCY

Each underground mine shall be surveyed by the OMHST at least twice annually, preferentially during late fall and winter months when the humidity is low for long periods of time.[40,41,42,43] It is recommended that in addition to visual inspections, mines should conduct their own quantitative

[35] Rock-dust that meets the definition given herein, after partial or complete drying regains most of its dispersibility. Results have varied in explosion tests of the effectiveness of wetted coal-rock-dust mixtures that subsequently are dried. While they have been shown to be effective when combined with a dry blanket of rock-dust on the floor the results are dependent upon the force generated by the initial explosion and the amount of dry float dust that has settled since the application. In mines where the face advances so rapidly that dry dusting creates potential inhalation hazards for face workers wet-rock-dusting combined with a fresh blanket of dry floor dust may be preferable to waiting to the maintenance shift. Work has been done and is being done on additives that would enhance the ability of wet-dusting. Advances in this area are hopeful. Hartman I "Rock dusting and sampling", USBM IC 7755 (1956) and Amyotte PR, et al, "Suppression of coal-dust explosions by wet rock dusting" Technical University of Nova Scotia (1994)

[36] Herzberg M & Cashdollar K, "Introduction to dust explosions", Industrial Dust Explosions, ASTM pp.5-32 (1986)

[37] Hartman I, "Studies on the development and control of coal-dust explosions in mines", USBM (1956)

[38] Mitchell D & Nagy J, "Water as an inert for neutralizing the coal-dust explosion hazard", USBM IC 8111 (1962)

[39] Dian-Bang Z, et al "Research on the suppression of coal-dust explosions by water barriers", Industrial Dust Explosions, ASTM pp. 152- 157 (1986)

[40] The dryer the coal-rock-dust the more available it is to be lifted in the event of an explosion. An outside temperature of 0^{o}F at 70% humidity will carry one half gallon of water per 100,000 cubic feet of ventilation air. The same amount of air in the summer at 80^{o}F and 70% humidity carries 13.1 gallons. Assuming 100,000 cubic per minute that is 750 gallons per day in the winter verse 19,000 gallons per day in the summer. Since the average mine temperature is 60^{o}F and the humidity 90%, air exiting the mine carries 8.9 gallons per 100,000 cubic feet or 11,952 gallons per day. The difference is deposited in the mine during the summer and removed from the mine in the winter.

[41] Scholz C, "Effect of humidity on mine-explosions", Transactions of the American Institute of Mining Engineers, 9 pp. (1908)

[42] Kissell F, "Handbook for methane control in mining", U.S. Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2006-127, Information Circular 9486 (2006)

[43] Mannakee N, "The barometric and temperature conditions at the time of dust-explosions in the Appalachian coal-mine", Transactions of the American Institute of Mining Engineers, 13 pp. (1910)

surveys throughout the year to determine if rock-dust practices have been successful and identifying any modification to the rock-dusting practices that are required.[44]

SAMPLING PROCEDURES

SAMPLE COLLECTION

In practice the conditions of dustiness are far from uniform, however, the composition of the dust cloud lifted in an explosion will correspond to the composition of the dusts available. The necessity for care in sampling cannot be over emphasized. The composition of a sample must represent truly the composition of a mass of material many times its own weight. With materials as variable as coal-mine dusts accurate samples are not obtained by grab sampling or by careless use of good sampling methods.[45] All sample collection procedures assumes they result in a homogeneous mixture of coal, rock, and other dust on all surfaces.[46] For these reasons deviations from standard operating procedures should be rare and their causes documented with any affected samples.

The use of a random selection of the sampling location within the area of concern along with the collection of all material within a band at that location provides a statistically representative unbiased sample. Other techniques, such as multiple random spot samples have been tested against this approach and found to provide equivalent results, however, they require more time to conduct.[47]

In a break from the traditional MSHA approach, OMHST will revert to the original approach proposed by the US Bureau of Mines (USBM) to separate the sample collected on the floor from that taken on the rib-roof. This is justified from multiple researchers who have found that coal-dust deposited on the rib-roof are preferentially lifted in an explosion which begins as a methane ignition contributing more to explosion propagation than do floor dusts. The lower pressure wave of the methane ignition is sufficient to cause the coal dust to drop from the upper portion of the entry but not to raise significant quantities from the floor. Over the course of tests it was found that eighty-five percent (85%) of float dust, the portion most likely to be raised into a dust cloud, is deposited on the rib-roof.[48,49,50]

[44] In addition to those required agency Coal-Dust Surveyors will conduct quantitative surveys at mines identified by the Inspector at Large throughout the year as well as providing outreach to miners, operators and safety trainers on the issues and lessons learned during coal-dust surveys.
[45] Owings C, et al, " Methods of sampling and analyzing coal-mine dusts for incombustible content", USBM IC 7113 (1970)
[46] Owings C, et al, "Methods of sampling and analyzing coal-mine dusts for incombustible content" USBM IC 7113 (1970)
[47] Cybulski W, "Coal-dust explosions and their suppression", translated by USBM from Polish (1973)
[48] Hartman I & Westfield J, "Rock dusting and sampling", USBM IC-7755 (1956)
[49] Cybulski W, "Research on coal dust explosibility as a function of the distribution of coal and stone dusts", Research Reports of Mining Central Institute Quarterly (Prace GIG) Ser. A, No. 198 (1957) translated from Polish by USBM (1965)
[50] Hartmann I & Nagy J "Incombustible required on floor and on rib-roof surfaces of coal mines to prevent propagation of explosions", USBM RI 5053 (1954)

SAMPLE COLLECTION TOOLS

The best method of collecting samples is by use of the special tools described herein. While other methods, such as vacuum cleaners, have been advocated and used to some extent; however, tests have shown no advantage.

Sampling tools consist of a:

- random number sheets,
- stainless steel scoop with an opening approximately two inches by six inches (2" x 6") with a square tube handle and a slot for accepting a brush or spatula holder,
- four inch (4") brush, a four inch (4") putty knife with a rubber blade attached,
- section of fiberglass roof bolt machined to fit in the handle of the scoop,
- chain of custody sample bags; and a
- US standard 20 mesh sieve, pan and cover.

Drawings and specifications for the custom tools or assembled tools can be obtained from OMHST.

FLOOR SAMPLE COLLECTION

MSHA inspectors have been taught to collect dust samples in a band or perimeter method from the roof, ribs, and floor creating one "band" sample.[51] This band sample includes a one inch (1") deep material from the floor. Once collected, the sample is thoroughly mixed, coned, and quartered to take a portion for analysis.

Test results describing the relative contribution of differing amounts of dusts on the rib-roof versus that on the floor have been published. Explosion tests were made with blanket rock-dust on the floor and none on the roof and ribs, some with as much as twelve pounds (12 lb) of rock-dust per linear foot, however, none were successful in stopping an explosion.[52,53, 54]

The ease of dispersion and initiation of coal-dust in air is markedly influenced by its original position in the mine entry. Coal-dust deposited on rib-roof surfaces and on overhead structures is generally of finer size, is more readily dispersible and ignitable, and constitutes a greater explosion hazard than coal-dust on the floor.[55,56,57] Since many of the studies upon which rules are based were conducted, coal mining has become more mechanized, and this has resulted in the

[51] United States Mine Safety and Health Administration, http://www.msha.gov/readroom/handbook/handbook.htm MSHA Handbook Series, Handbook Number: PH-08-V-1, General coal mine inspection procedures and inspection tracking system, pp. 45, and 60-66 (2008)
[52] Hartman I, et al, "Recent rock-dusting experiments for arresting coal mine explosions", USBM RI-4688 (1950)
[53] Hartman I, et al, "Summary of Coal Mine Explosion Research by the Bureau of Mines 1954-1955", RI-5264 (1956)
[54] Amyyotte P, et al, "Suppression of coal-dust explosions by wet rock-dusting", Technical University of Nova Scotia (1994)
[55] The USBM took over 1000 samples in a reference mine and found that dust below a No 20 sieve was 25 percent higher on the rib-roof than the floor. Hartmann I, "Lessons from intensive dust sampling of a coal mine" RI-5054 (1954)
[56] Hartman I, "Studies on the development and control of coal-dust explosions in mines", USBM (1956)
[57] Hartmann I & Nagy J "Incombustible required on floor and on rib-roof surfaces of coal mines to prevent propagation of explosions", USMM RI 5053 (1954)

generation of higher quantities of smaller particles available for deposition on rib-roof. NIOSH researchers report that a minimum five one-thousandths of an inch (5/l,000") thick layer (about the thickness of a sheet of paper) of pulverized float coal-dust deposited on top of a three-eighths inch (3/8") thick uniform concentration of eighty percent (80%) rock-dust and twenty percent (20%) float coal-dust would propagate an explosion.[58] This equates to one pound (1 lb) per linear foot of entry, about one-fifth ounce (1/5 oz) per cubic foot of space.[59]

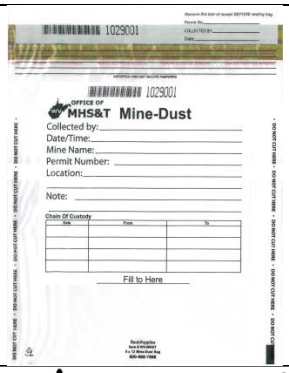
In multiple mine explosion tests conducted by USBM and other researchers it has been reported that only a small portion of the dust on the floor was raised during explosions, although pressures waves as high as 40 psi were recorded during the testing.[60] This was recently quantified as a part of large-scale dust explosion testing conducted by NIOSH[61] in which floor dust scouring measurements were collected.[62] The depth of floor dust scoured is indicative of dust entrained in the blast wave and thus participating in an explosion.

The amount of dust on the floor scoured during an explosion ranged from 0.03 inch to 0.1 inch (1/32 to 3/32-inch) with an average of 0.06 inch (~ 1/16 inch). This is much less than the one inch (1") that has been taught in the band sampling procedures. The current one inch (1") sampling depth of dust does not represent the dust that actually contributes to initial explosion propagation. An explosive layer on the rib-roof can be combined with thick layers of excess rock-dust by sampling to a full depth of one inch (1") on the floor, thereby giving a false sense of safety. NIOSH concluded a sample depth of 0.125 inches (1/8 inch) was a better representation of the potential deficiencies in rock-dust on mine floors.[63, 64]

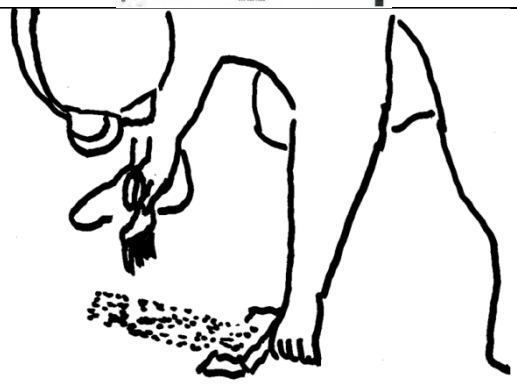
These studies indicate that rock-dust on the floor alone, even in excessive quantities, cannot compensate for deficiencies of rock-dust on the roof and ribs. Therefore, West Virginia dust sampling procedures have been developed to conform to these findings.

[58] Sapko M, "Float Coal-dust Explosion Hazards", National Institute for Occupational Safety and Health (2006)
[59] Rice G, "Notes on the prevention of explosions in coal mines", USBM - Coal Age article Vol. 3. No 4 (1914)
[60] Hartman I, et al, "Summary of coal mine explosion research by the Bureau of Mines 1954-1955", RI-5264 (1956)
[61] The Pittsburgh Research Center was part of the U.S. Bureau of Mines until 1996, when it was transferred to the National Institute for Occupational Safety and Health (NIOSH) and became known as the Pittsburgh Research Laboratory
[62] Harris M, "Rock-dusting considerations in underground coal mines", National Institute for Occupational Safety and Health (2010)
[63] Sapko M, et al, "Explosibility of float coal-dust distributed over a coal-rock-dust substratum", Proc. 22nd International Conference of Safety in Mines Research Institutes (1987)
[64] Harris M, et al, "Mitigating coal-dust explosions in modern underground coal mines", Proc. of the 9th International Mine Ventilation Congress (2009)

Floor Sample Collection

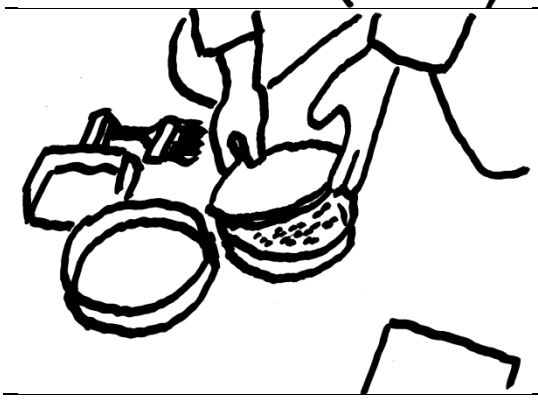


Floor Step 0 – Select location based upon the random number procedure or a location identified for other reasons. Complete the information on the sample bag and make an entry in the personnel logbook.

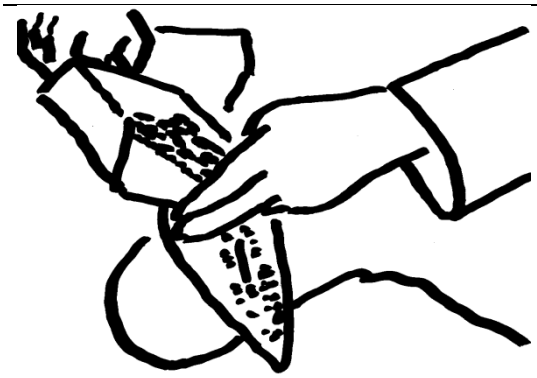


Floor Step 1 – Starting at the point where the rib meets the floor on one side of the sampling location use the brush and the scoop to gently remove the top one-eighth inch (1/8") in a strip approximately four inches (4") wide at right angle to the rib until you reach the opposite rib. As ripples in the floor are encountered be careful to not over sample the ridges or troughs. (If floor appears too wet go to Wet Sampling Procedures below)

Floor Step 2 – Place the materials collected into the sieve with the pan section below and the lid on and shake gently. Use a rocking motion always keeping the lid upright. Check periodically until all the material capable has passed through the sieve.



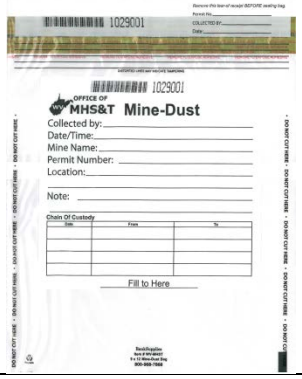
Floor Step 3 – Remove the sieve section and discard the oversized material. Place the lid on the pan and shake gently to ensure the contents are adequately mixed.



Floor Step 4 – Ensure that scoop is free of any material then transfer the mixed sample back to the scoop taking care to prevent air currents from blowing the dust away. Using the scoop, pour approximately an eight ounce (8 oz) volume into the sample bag and seal – this is approximately the amount that will fit in small coffee cup. If there is insufficient sample repeat the procedure creating another sampling line immediately adjacent to the first. Any excess can be discarded.

Floor Step 5 – Clean the sampling tools.

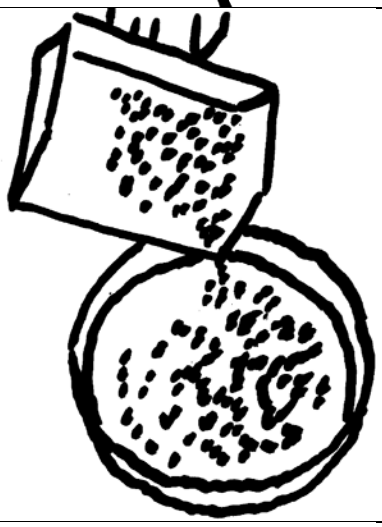
Rib and Roof Sample Collection



Rib/Roof Step 0 – Select location based upon the random number procedure or a location identified for other reasons. Complete the information on the sample bag and make an entry in the personnel logbook.

Rib/Roof Step 1 – Starting at the point of the rib where the floor sample ended, use the brush to gently remove one-eighth inch (1/8") of dust from the rib to the point where the vertical four inch (4") line reaches the roof. (If Rib/Roof appears too wet go to Wet Sampling Procedures below) Take care to prevent air currents from blowing the dust away while sampling by placing yourself upwind. The result should be a continuous vertical four inch (4") line from floor to roof.

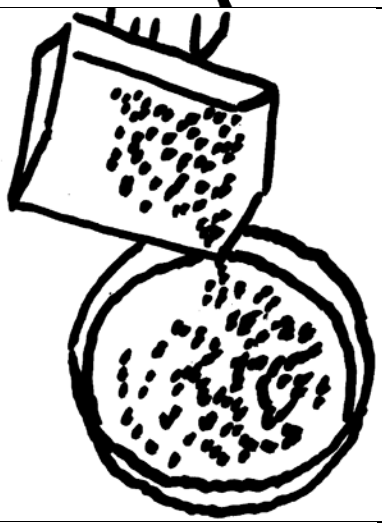
Rib/Roof Step 1a – If the rib is too high to reach the roof utilize the rib brush adapter for the scoop and an extension rod. Starting at the point that could be reached without an extension, place the brush with the adapter against the rib and raise upward to where the rib meets the roof collecting the surface one-eighth inch (1/8") of dust. Care should be taken to ensure the scoop does not scrape the rib. The result should be a continuous vertical four inch (4") line from floor to roof.



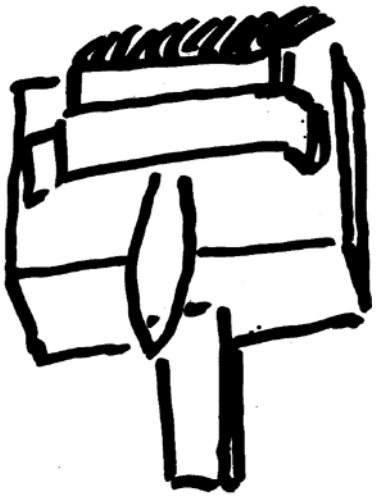
Rib/Roof Step 2 – Place the collected sample in the sieve with the pan attached below then place the lid on.

Rib/Roof Step 3 – Starting at the point of the rib where the floor sample ended, use the brush to gently remove one-eighth inch (1/8") of dust from the rib to the point where the vertical four inch (4") line reaches the roof. (If Rib/Roof appears too wet go to Wet Sampling Procedures below) Take care to prevent air currents from blowing the dust away while sampling by placing yourself upwind. The result should be a continuous vertical four inch (4") line from floor to roof.

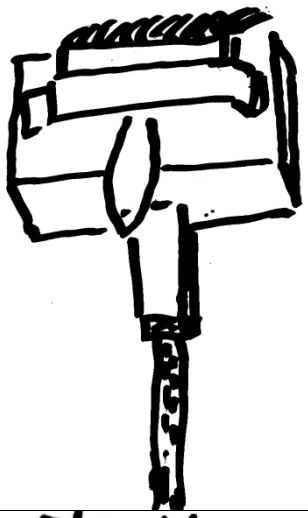
Rib/Roof Step 3a – If the rib is too high to reach the roof utilize the rib brush adapter for the scoop and an extension rod. Starting at the point that could be reached without an extension, place the brush with the adapter against the rib and raise upward to where the rib meets the roof collecting the surface one-eighth inch (1/8") of dust. Care should be taken to ensure the scoop does not scrape the rib. The result should be a continuous vertical four inch (4") line from floor to roof.



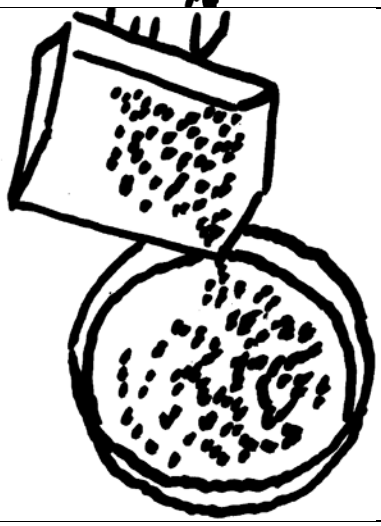
Rib/Roof Step 4 - Place the collected sample in the sieve with the pan attached below then place the lid on.



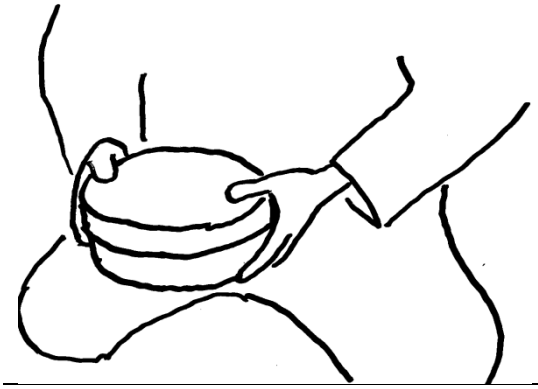
Rib/Roof Step 5 – Place the brush in the slot provided on the scoop such that approximately 1 inch (1") of bristles extends beyond the scoop edge. Pull the brush across the roof from the point where one vertical rib collection line meets the roof to the same point on the opposite side. Gently collect the surface one-eighth inch (1/8") of dust from the roof in a line approximately four inches (4") wide. Take care to prevent air currents from blowing the dust away while sampling by placing yourself upwind and if necessary angling the scoop.



Rib/Roof Step 5a – If the roof is too high to reach utilize an extension pole for the scoop. Place the brush in the slot provided on the scoop such that approximately 1 inch (1") of bristles extends beyond the scoop edge and the extension rod in the scoop handle. Pull the brush across the roof from the point where one vertical rib collection line meets the roof to the same point on the opposite side. Gently collect the surface one-eighth inch (1/8") of dust from the roof in a line approximately four inches (4") wide. Take care to prevent air currents from blowing the dust away while sampling by placing yourself upwind and if necessary angling the scoop.



Rib/Roof Step 7 – Place the collected sample in the sieve with the pan attached below then place the lid on.



Rib/Roof Step 8 –With the collected material from each rib and the roof now placed into the sieve with the pan section below and the lid on shake gently. Use a rocking motion always keeping the lid upright. Check periodically until all the material capable has passed through the sieve.

Rib/Roof Step 9 – Remove the sieve section and discard the oversized material. Place the lid on the pan and shake gently to ensure the contents are adequately mixed.

Rib/Roof Step 10 – Transfer the material back to the scoop then pour approximately an eight ounce (8 oz) volume into the sample bag. This is approximately the amount that will fit in small coffee cup. Any excess can be discarded. If there is insufficient sample repeat the entire rib/roof procedure creating another sampling line immediately adjacent to the first.

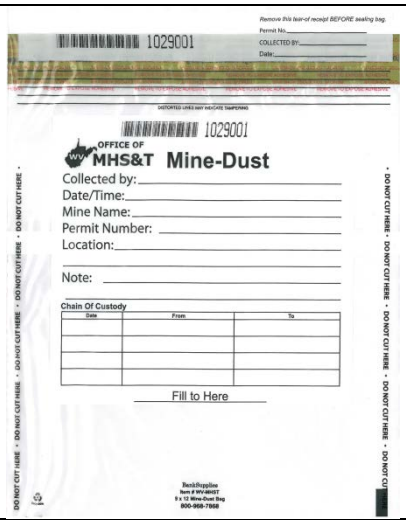
Rib/Roof Step 11 – Clean the sampling tools.

Wet Sample Collection Method

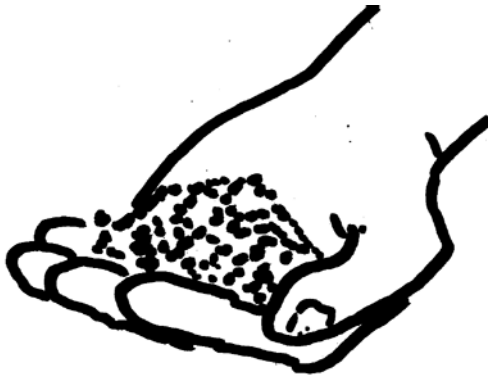
Research shows that water neutralizes the explosion hazard of coal-dust only when present in sufficient quantity and when intimately mixed with the dust. The quantity of water required to neutralize coal dust and coal-rock-dust mixtures is equal to the maximum adsorptive capacity of the dust; the adsorptive capacity increases with increase in the fineness and volatile content of the coal. Pools of water or high atmospheric humidity do not reduce the explosion hazard. Although wetted dust is less dispersible than dry dust, poor dispersibility cannot be relied on as a safeguard against explosion. Even dust mixtures that contain water in excess of their limiting adsorptive capacity are dispersed and ignited by severe initiation sources.[65,66]

[65] Mitchell D & Nagy J, "Water as an inert for neutralizing the coal dust explosion hazard", USBM IC-8111 (1962)
[66] Cybulski W, "Coal-dust explosions and their suppression", translated by USBM from Polish (1973)

The water content of the loose material in a mine is not the factor that controls explosions, it is the water content of the explosive dusts fraction.[67] Dust can be wetted in two ways – by absorption of water within the dust particles and by adsorption or coating the surface of the dust particles. Bituminous coal-dust neither absorbs nor adsorbs water readily. Depending on the amount of water blended, dusts pass from a dry to a plastic and then to a fluid state which depending on the ratio of rock to coal approximately thirty percent (30%) is.[68] The boundary between the plastic and fluid states defines the limiting adsorptive capacity of a dust – the maximum amount of water that can be retained. The determination that a sample is "too wet" may be approximated by the condition where when a ball of dust from the top one-eighth inch (1/8") is squeezed reasonably in a hand that liquid flows with between fingers leaving a wet residue in the hand. If in doubt the sample needs to be collected in its entirety, submitted to the laboratory and processed as described in the laboratory procedures below.



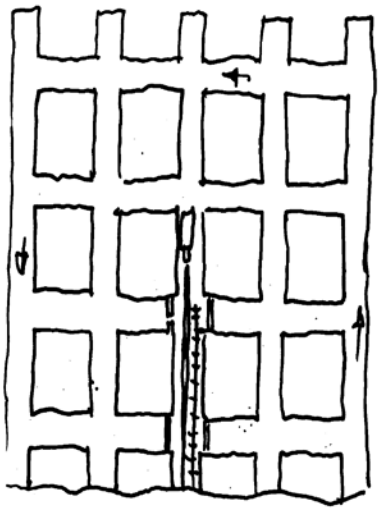
Wet Step 0 – Select location based upon the random number procedure or a location identified for other reasons. Complete the information on the sample bag and make an entry in the personnel logbook.



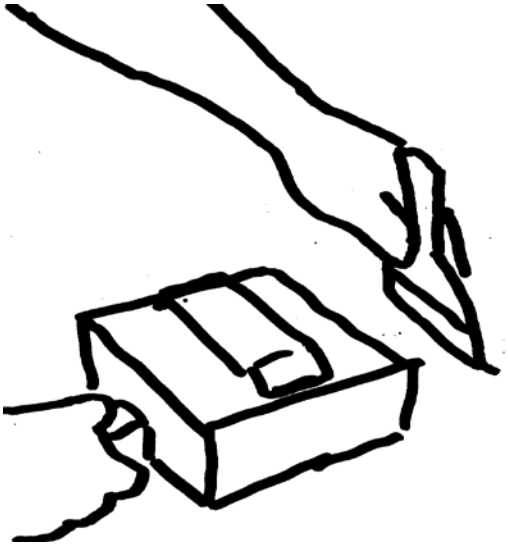
Wet Step 1 – If it is suspected that either the floor or rib/roof sampling location may be too wet use the rubber trowel to remove enough material to make a dust ball in the palm of the hand from the top one-eighth inch (1/8"). If when squeezed reasonably in a hand liquid flows with between fingers leaving a wet residue in the hand it can be concluded that the dust may be too wet. Visual observation is not sufficient for determining too wet.

A sample that is not too wet to sample but is sufficiently wet that it will not pass through the sieve should be bagged without sieving to be dried at the laboratory.

[67] Nagy J, "Control of the dust explosion hazard on coal mine shuttle-car runways", USBM RI-7446 (1970)
[68] Mitchell D & Nagy J, "Water as an inert for neutralizing the coal dust explosion hazard", USBM IC-8111 (1962) and Cybulski W, "Coal-dust explosions and their suppression", translated by USBM from Polish (1973) and Nagy J, "Control of the dust explosion hazard on coal mine shuttle-car runways", USBM RI-7446 (1970)



Wet Step 2 – If the above step results in an area that is too wet then the surveyor should move to another location as follows: a) If the original footage is 500 feet or greater then move inby one break ensuring that it is the same distance from the inby edge of the pillar as the primary location. b) If the original footage is less than 500 feet then move outby one break ensuring that it is the same distance from the inby edge of the pillar as the primary location. If the second location is still too wet, move the same direction in the same fashion until a location is found that is not too wet. The locations of sampling locations in adjacent entries remains based upon the original selected location.



Wet Step 3 – If all are part of the rib/roof location is determined to be "wet" but not "too wet" the sample should be taken using the rubber sampling tool.

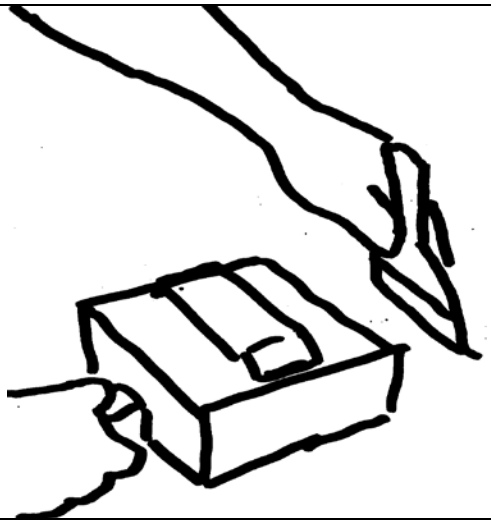
Starting at the point of the rib where the floor sample ended, use the rubber sampling tool to gently remove one-eighth inch (1/8") of dust from the rib to the point where the vertical four inch (4") line reaches the roof. Take care to prevent air currents from blowing dust into the sample while sampling by placing yourself upwind. The result should be a continuous vertical four inch (4") line from floor to roof.

If the rib is only partly wet, use the rubber tool for the wet portion and switch to the brush for the dry portion with all material collected going into the sample bag.

Wet Step 4 – If the rib is too high to reach the roof, utilize the rib brush adapter for the scoop and an extension rod. Starting at the point where the rib reaches the roof place the rubber sampling tool with the adapter against the rib and pull downward to the last point that could be reached by hand collecting the surface one-eighth inch (1/8") of wet dust. Care should be taken to ensure the scoop does not scrape the rib. The result should be a continuous vertical four inch (4") line from floor to roof.

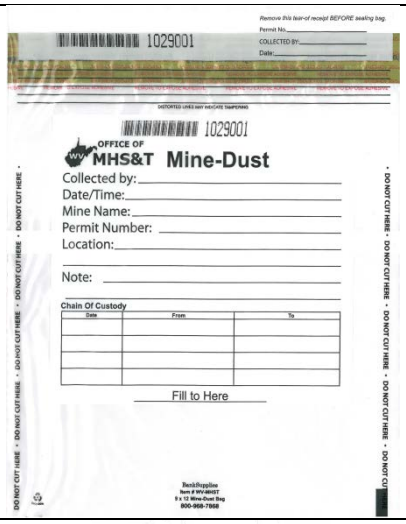
Wet Step 5 – If the wet collection procedure is used the roof sample should also be placed in the same sample bag as the rib sample.

Placing the rubber sampling tool into the brush slot provided on the scoop such that approximately 1 inch (1") of rubber extends beyond the scoop edge. Pull the tool across the roof such that the wet dust falls into the collection bag of the scoop. Proceed from the point where one vertical rib collection line meets the roof to the same point on the opposite side. Gently collect the surface one-eighth inch (1/8") of dust from the roof in a line approximately four inches (4") wide. Take care to prevent air currents from blowing dust into the scoop while sampling by placing yourself upwind and if necessary angling the scoop.



Step 6 – If the wet collection procedure is needed for the floor; label and insert a separate sampling bag into the scoop.

Starting at the point where the rib meets the floor on one side of the sampling location use the rubber sampling tool and the scoop to gently remove the top one-eighth inch (1/8") in a strip approximately four inches (4") wide at right angle to the rib until you reach the opposite rib. As ripples in the floor are encountered be careful to not over sample the ridges or troughs.



Step 7 – No sieving is required for wet samples, the sample bag should be sealed once the entire sample has been collected.

Step 8 – Clean the sampling tools.

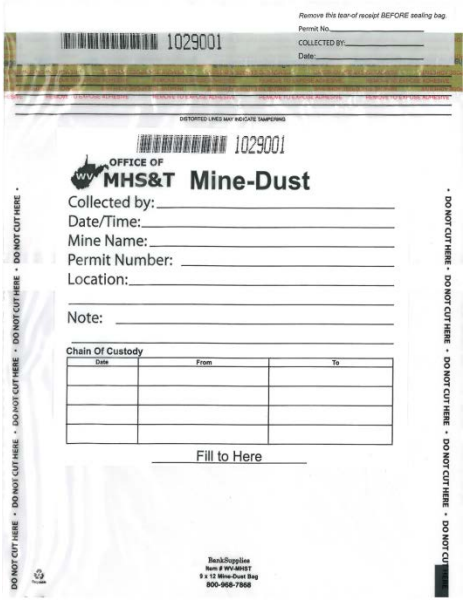
DOCUMENTATION

Forensic investigation experts stress the importance of thoroughly recording field notes.[69] While information required on the sample bag is important; organized, meaningful notes may be the only way to preserve key observations as well as comments required to be recalled months in the future.

All samples submitted to the laboratory must be placed into a mine-dust bag that is properly sealed. The definition of a "proper seal" is a container that is secured to prevent access to the contents. If and when access is made, then the sealing mechanism should be obviously broken. Do not place any notes or other paper in the sealed evidence container as it will absorb moisture. Once evidence is placed into individually sealed bags, these must be placed into a USPS Priority Mail Box for mailing and properly sealed. Priority Mail Boxes can be deposited in the closest Post Office.

Using an appropriate marker, enter the required information which includes:

[69] Lyman M, "Criminal Investigation: The Art and the Science", Prentice Hall (2010) pp. 33-40



Collected by: your name

Date/Time

Mine Name (from most recent master list)

WV Permit Number (from most current master list)

Location (entry, break along with the distance and direction to nearest spade)

Notes (any information relevant to understanding the sample) additional information should be recorded on the carbonless sample note pad and the original placed in the pouch on the rear of the bag and sealed with the copy remaining in the field book.

Chain-of-custody is essential for maintaining control of the sample from the moment it is collected. The Inspector or Dust Surveyor should minimize the number of people in the chain-of-custody. Do not send mine-dust bags to the laboratory via a third person.

Samples should be sent by Certified US Mail using Priority Mail boxes, certified mail requires a return receipt to be signed by the individual receiving the mine-dust bags. Not only does the receipt provide a permanent record of the transaction, certified mail can be tracked much easier should a package become lost while in the custody of the postal service.

A Sample Submission Form must be placed in the properly addressed Priority Mail Box.

WV Office of Miners Health Safety and Training - Coal-dust Sample Submission		
Sample #	Date Collected	WV Permit Number

The shipping box should be addressed in the following manner:

West Virginia Office of Miners Health Safety and Training
Coal-Dust Laboratory
Building 740
Room 2326
1740 Union Carbide Dr.
South Charleston, WV 25303

Thermogravimetric Analysis Procedures

While progress has been made in developing in-mine screening tools, none have been adopted for enforcement by Federal or State agencies. Those in use are primarily seen as aids for enhancing rock-dust practices.[70] Therefore, in validating compliance with West Virginia rock-dust rules only thermogravimetric analysis (TGA) will be utilized.

Thermogravimetric analysis is the process used to determine the moisture, combustible and incombustible content of Coal-Dust Survey samples. TGA is a laboratory technique to determine changes in sample's weight in relation to changes in its temperature.

The OMHST Coal-dust Laboratory test procedure is based upon ASTM[71] standard method for determining the combustible/incombustible content of coal, D 3174-11, modified to conform to the analytical procedures used by the MSHA's Mount Hope Laboratory[72]. In particular the final temperature is changed from the D 3174-11 value of 950˚C to 515˚C [73]with a 1.5 hour ramp-up period and 2.5 hours at the final temperature.

The goal of the MSHA variation is to avoid thermally decomposing rock-dust ($CaCO_3$ and $MgCO_3$)[74,75,76,77] which reacts with air above 600˚C to produce CO_2 thus reducing the mass of the sample. Since the objective is to calculate the weight percentage of the rock-dust this would produce a variance that could only be accounted for by capturing and weighing the CO_2 gas, a procedure that would negatively impact the ability to do timely analysis.

The complete decomposition of the coal is reported by MSHA staff;[78] however, those results have not been published in a peer reviewed journal. A literature search revealed that NIOSH had compared their process to the MSHA's and found that the 24 hour heating period utilized by NIOSH was better at determining the combustible content of dust sample with low rock-dust percentages but in the 60-80 percent rock-dust range the difference were less.[79] Since there was not a published study of the MSHA process and noting the discrepancies identified by NIOSH, OMHST undertook a computational verification of the process.

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[70] US Department of Labor, "Discussion of Final Rule", Federal Register/ Vol.76, No. 119, page 35973 (June 21, 2011)

[71] ASTM International, known until 2001 as the American Society for Testing and Materials (ASTM), is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services.

[72] Dust Section of MSHA's National Mine Air and Dust Laboratory, located in Mount Hope, West Virginia

[73] ^{o}C [degrees Celsius] = (°F – 32) × 5/9

[74] CaCO3 and MgCO3 are both carbonates all of which undergo thermal decomposition producing a metal oxide and carbon dioxide gas. Thermal decomposition is the term given to splitting up a compound by heating it.

[75] Rodriguez-Navarro C, et al, "Thermal decomposition of calcite", American Mineralogist, Volume 94 (2009) pp. 578–593

[76] Zhao Y, "The Thermal Decomposition of Calcium Carbonate", Chinese Chemical Letters Vol. 12, No. 8 (2001) pp 745 – 746

[77] Cheng C, "Kinetics in limestone decomposition", Otto-von-Guericke University of Magdeburg, Germany

[78] Conversations with Mark Wesolowski of MSHA Tech Support

[79] Cashdollar K, et al, "Post-explosion observations of experimental mine and laboratory coal-dust explosions", NIOSH Pittsburg Research Laboratory

Coal decomposition begins at 400˚C [80] at which point it becomes plastic with the shape and size of the particle changing dramatically; continued heating devolatilizes the coal producing carbon monoxide, carbon dioxide, methane and hydrogen along with other trace gases while reducing its mass by up to 70 percent ending with a char particle.[81] In the 500-750˚C range the char-air reaction rate is endothermically controlled by the application of heat.[82] To calculate at reaction time for the coal char particle it was necessary to use published activation energies (130-150 kJ/mol) and the reaction order (O_2 exponent of 0.65) along with their reactivity at 515°C. Using a conservative log(R) value of -4, which is a slightly lower reactivity than published for medium-volatile and high-volatile bituminous coals[83], it was found that a characteristic total burnout time would be approximately 108 min at 515˚C (ignoring the conversion during the ramp-up period)[84]. This is less than the specified 150 min baking time given in the MSHA procedure. Providing that adequate air is provided to allow the reactions to reach completion the MSHA process is in line with published literature, thus supporting the MSHA observations.

LABORATORY PROCEDURES

Sample Receipt

The Coal Dust Laboratory Technician will place received samples in the evidence room until ready to process. Only OMHST Coal-Dust Laboratory staff will have access to the evidence room or samples. All visitors to the actual lab will sign in and be accompanied by a member of the OMHST staff.

Sample analysis shall be conducted in a batch process with all due hast taken. Abatement samples will be provided priority and the results reported upon completion.

Laboratory Description

The OMHST TGA Laboratory is located in a secure research building in South Charleston, West Virginia. The space consists of three laboratory bays with benches and six vent hoods, an evidence room and an office.

Laboratory equipment includes of multiple networked electronic scales integrated with barcode readers and a database that allows for the tracking of samples and calculation of results. A customized variable speed shaker table is provided capable of processing 16 three inch sieves simultaneously. There are two low temperature drying cabinets capable of accepting 16 custom built stainless steel trays each holding 12 sample crucibles. The unique barcodes on the ceramic crucibles are capable of withstanding temperatures twice that utilized in the process. Each

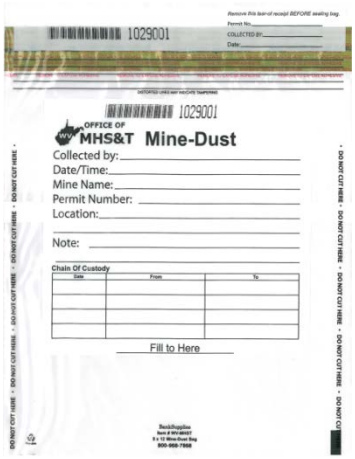
[80] Van Heek K, et al, “Recent results on the kinetics of coal pyrolysis”, American Chemical Society – Fuel, Volume 29 No 2 (preprint collection on ANL web site)
[81] Solomom P, et al, “General model of coal devolatilization”. Energy & Fuels, 2:405-422
[82] Tomeczel J, “Coal Combustion”, Silesian Technical University (1994)
[83] Lang T & Hurt R, “Char combustion reactivities for a suite of diverse solid fuels and char-forming organic model compounds”, Proceedings of the Combustion Institute, Volume 29 (2002) pp. 423–431
[84] Calculations and assumptions peer reviewed by Christopher Shaddix, PhD , Sandia National Labs, Livermore, CA on January 26, 2011

crucible's tar weight is recorded and maintained in the database. There are three descant cabinets for holdings samples such that ambient moisture will not affect the calculations. There are four programmable muffle ovens each capable of processing 75 crucible per day for a total capacity of 300 samples per day.

Additionally the facility is equipped with a lab-scale fluid dryer is used for handling samples too wet to pass manually through the sieves and a sonic sifter for determining particle size distribution.

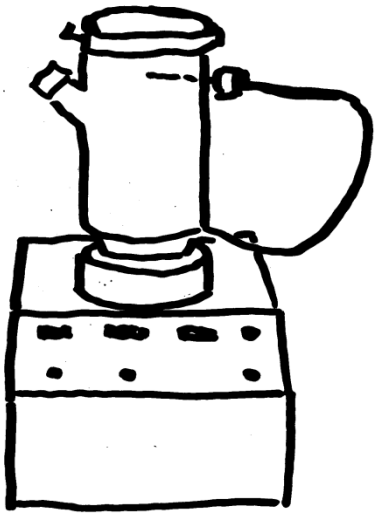
While the facility is capable of chemistry based analysis of samples these are not covered in this manual.

Rock-Dust Analysis Procedure



TGA Step 1 - Scan the barcode on the sample bag into the data base to open a new record.

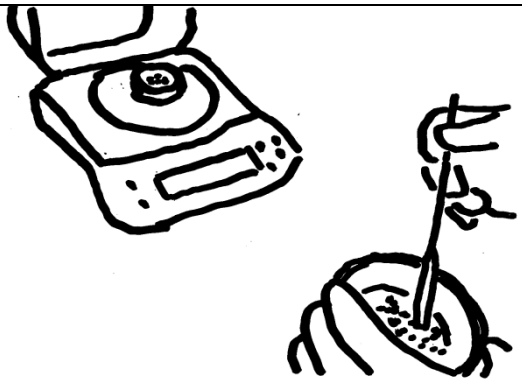
TGA Step 2 – Cut the bag with scissors above the barcode without completely removing the top of the bag. Prepare sample for analysis by passing through a US Standard No. 20 sieve. In sieving, the entire sample should be shaken until it is evident that no more of the course particles will pass through into the pan beneath.



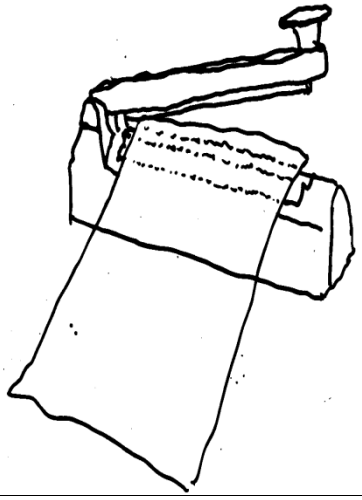
TGA Step 3 - If a sample is too wet to place through the sieve go to alternative wet sample preparation procedure. To determine if a sample is "too wet" to process the following procedure shall be used to determine if the 30% limiting absorptive capacity of a sample has been reached:

i. Weigh the entire sample
ii. Place the sample in the fluidized bed dryer for approximately 15 minutes
iii. Weigh the entire sample
iv. Calculate the moisture content. (1- Initial weight/final weight)

If greater than 0.3 the sample was too wet. Do not process and notify the Inspector or Surveyor, if less than 0.3 process the sample per below.[85]



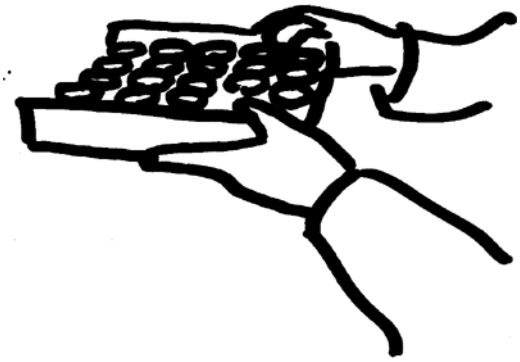
TGA Step 4 – Scan the porcelain crucible's barcode place it on the scale and add approximately 0.5 grams of the sample pressing the print button to enter the data into the database.



TGA Step 5 - Place the remainder of the sample in the original sample bag and place that in a clear poly sleeve such that the labels and notes can be seen without opening. Use the impulse sealer to secure the bag, transferring it to the evidence room after the batch is processed.

*Note: If the sample fails the ploy sleeve will have to reopened for reanalysis.

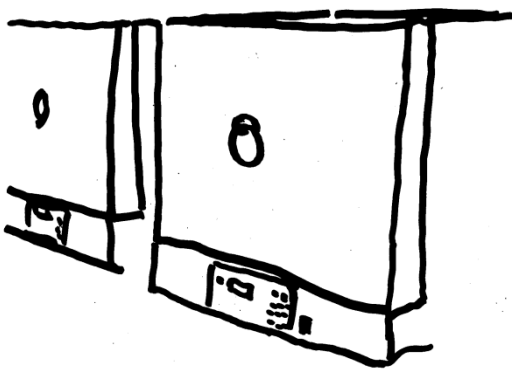
[85] Small batch fluid-bed dryers are commonly used for pharmaceutical powder drying processes. Due to better air-solid contact, drying in fluid-bed dryers is faster than in tray ovens and because of good mixing, drying uniformity is much improved.



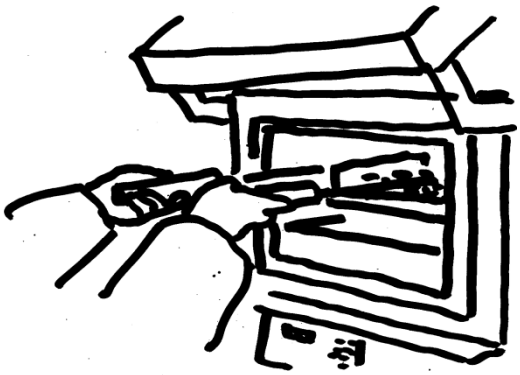
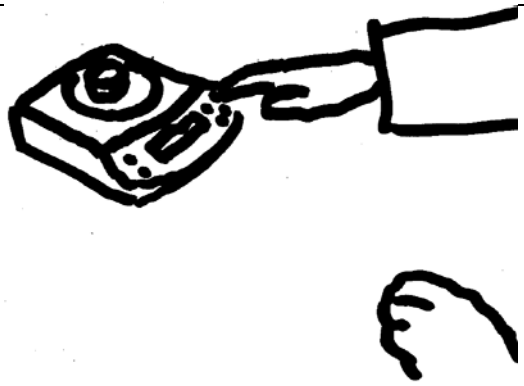
TGA Step 6 - Place weighted crucibles in a tray and place the tray in a drying oven, set to 105°C for a period of one hour.

TGA Step 7 - Remove the tray from the drying oven. Rapidly scan and weigh each crucible.

TGA Step 8 - Place the tray of samples in a desiccant holding cabinet until a full batch of samples is ready to place in the Muffle Furnace.



TGA Step 9 - Place the batch of crucibles in a Muffle Oven programmed for a 90 minute ramp up to 515°C then hold for 150 minutes.

	TGA Step 10 – Allow to muffle oven to cool to approximately 100°C then remove the trays using the rods to avoid burns. Place the tray into the desiccant holding cabinet until cool enough to handle.
	TGA Step 11 - Remove each crucible place on the scale then scan its barcode and press the print button to enter the weight into the correct database field.
	TGA Step 12 - The data base will automatically compute the difference in weight and the percentage incombustible. If the sample is below the legal limit he record will be highlighted. The Laboratory Technician will generate a report at the end of each batch or as needed that will then to emailed to the appropriate Region with a copy to the Director.

Sample Retention

Samples that met the legal requirements will be held for 180 day then disposed.

Samples that were found not to have met the legal requirements will be held until notification from the Attorney General's Office that they are no longer needed.

Quality Control

1. **Laboratory organization and responsibility**
   a. Coal Dust Program organization and lines of responsibility:

Director OMHST	Overall responsibility for the direction and implementation of the program
Coal Dust Program Supervisor	Responsible to the Director for effective implementation of the program and supervisor of the Coal Dust Surveyors and the Coal Dust Laboratory Technicians
Inspectors at Large	Responsible to the Director for the coordination of Coal Dust Surveyors and Inspectors within their Regions
Coal Dust Surveyor(s)	Responsible to the Coal Dust Program Supervisor for coordinating with the Inspectors at Large in the conduct of surveys and the collection of dust samples as an Authorized Representative of the Director
Coal Dust Laboratory Technician(s)	Responsible to the Coal Dust Program Supervisor for the effective operation of the laboratory, the conduct on quality procedures and reporting samples which are out of compliance as an Authorized Representative of the Director

   b. The Coal Dust Laboratory Technician assigned the responsibility by the Coal Dust Program Supervisor will be responsible for ensuring the production of valid measurements and the routine assessment of measurement systems for precision and accuracy (e.g., the persons responsible for internal audits and reviews of the implementation of the plan and its requirements);
   c. Coal Dust Surveyors must have completed the 80 hour underground miners training and have passed the apprentice miners test or have a current WV underground miner's certificate. Each Surveyor will have completed an on-the-job of no less than 90 days if a certified miner or 180 days if an apprentice miner. Coal Dust Laboratory Technicians must have completed the 80 hour underground miners training and passed the apprentice miners test or have held a WV underground miners certificate and have completed at least 90 days of on-the-job training in the Coal Dust Laboratory.
   d. Records of the qualifications of individuals in the Coal Dust Program are maintained by the Coal Dust Program Supervisor.

2. **Calibration procedures**
   a. Each scale shall be calibrated with a reference weight at the beginning of each day.
   b. The temperatures of each oven will be verified at least once per month.

3. **Process Quality Control**
   a. A sample of laboratory grade limestone will be processed as if it were a sample. If variance of more than three percent is found corrective action will be taken to correct the cause.

b. A sample of bituminous coal from the Argon National Laboratory will be processed as if it were a sample. If variance of more than three percent of the certified ash content is found corrective action will be taken to correct the cause.
c. Each sample that results in less than 80% rock dust will be retested if result varies by more than three percent the sample will be reprocessed and the average the three results used.
d. Once per month a sample will be chosen at random and split into multiple samples with each sent to a different cooperating laboratory for independent analyses the results will be compared. If variance of more than three percent is found corrective action will be taken to correct the cause.

4. **Schedule of Internal Audits**
   a. An audit of compliance with procedures in the laboratory and among the surveyors will be conducted at least twice per year by an independent organization.

5. Record Keeping Procedures
   a. A binder with procedures shall be maintained at the laboratory and in the vehicles of coal-dust surveyors. All amendments and addendums will be included.
   b. The database associated with the laboratory will be on a closed-system not connected to other computers or the accessible from the internet. It will have an emergency power supply and possess external removable data storage that will periodically backup the data several times per day. At the end of each day the removable storage device will be placed in the evidence room and locked in cabinet.

154	153	18	640	707	518	83	849	748	373	239	217	652	877	596	221	315	280	207	205
20	234	830	708	918	328	797	530	427	540	978	195	473	888	786	813	386	407	567	762
839	751	534	436	806	199	119	626	949	89	928	86	875	53	4	729	812	998	318	879
241	133	6	443	853	420	570	351	589	874	623	108	187	886	835	858	501	165	533	650
51	891	277	617	356	416	832	532	630	973	487	131	545	134	47	281	125	579	785	688
709	145	95	357	191	735	547	591	687	929	903	257	950	548	613	503	444	236	844	378
111	101	755	746	96	954	594	749	852	216	322	475	747	224	999	871	414	478	657	800
285	605	150	937	62	791	79	85	539	828	713	558	354	934	441	610	256	556	246	868
551	656	23	805	284	917	470	775	662	664	398	230	772	14	663	462	390	981	369	99
394	382	474	693	3	413	434	448	265	704	856	581	484	15	603	397	202	319	238	809
807	172	461	262	542	449	646	412	27	527	841	130	112	743	203	38	28	604	758	120
838	425	259	779	60	994	798	228	439	740	251	850	201	770	957	647	367	997	298	206
962	629	268	388	897	843	643	633	55	569	2	996	793	80	336	760	815	92	481	104
312	110	171	951	458	590	450	925	624	355	405	208	468	225	339	1000	560	456	912	304
103	822	445	174	818	651	159	840	655	648	451	94	834	790	137	9	33	739	240	968
915	26	400	768	641	926	859	757	90	974	358	695	7	989	40	379	674	22	168	362
531	697	347	48	432	948	185	632	526	867	606	803	550	279	198	896	787	933	342	164
368	184	759	741	801	993	684	620	78	402	331	71	889	592	737	890	936	455	306	862
661	283	679	864	467	215	535	46	961	326	77	975	699	146	136	703	67	34	783	876
593	170	167	833	628	725	627	359	504	990	585	959	231	160	720	320	141	365	649	715
482	147	178	173	156	45	597	502	489	946	940	814	602	245	43	510	32	767	914	127
299	810	738	286	727	582	574	52	128	811	654	781	947	387	435	175	278	69	385	87
826	115	338	635	665	769	863	64	35	261	323	963	384	808	496	366	831	63	584	144
483	941	84	177	615	920	93	634	98	255	967	667	82	1	724	204	851	905	276	44
313	557	169	816	290	490	270	124	348	702	622	143	497	417	717	607	113	726	157	765
155	763	321	118	242	292	296	433	335	13	782	419	74	528	982	639	683	500	247	519
676	587	904	792	678	710	282	766	396	210	821	970	341	61	209	588	337	653	109	521
399	30	332	561	942	294	568	275	893	873	273	892	846	410	252	446	363	66	81	845
562	817	59	571	546	802	916	730	479	600	680	883	186	235	771	824	220	421	117	784
36	41	820	139	161	269	866	380	977	666	935	214	389	300	65	287	343	406	197	701
258	10	773	516	983	599	524	213	909	305	70	148	25	333	194	316	517	669	263	325
360	466	346	344	311	72	690	901	529	226	244	142	513	971	349	409	464	723	972	218
0	742	408	289	212	364	334	554	182	422	31	505	555	829	804	392	898	924	583	114
329	696	430	958	911	966	578	506	19	17	56	565	21	266	140	712	745	271	854	295
138	837	233	267	761	126	614	796	24	91	260	492	229	58	393	616	685	249	563	880
744	100	428	340	424	485	121	223	660	192	894	152	158	658	301	442	465	116	190	609
992	900	861	162	700	29	549	107	721	469	274	719	681	965	250	778	756	799	297	789
288	243	906	49	882	553	330	985	750	415	939	491	135	938	611	75	645	511	794	494
960	520	88	437	132	945	919	309	878	956	291	976	572	538	819	454	910	543	860	105
686	541	179	887	573	515	509	310	457	752	106	638	677	163	698	391	472	438	953	383
122	401	403	979	452	97	37	980	523	848	537	636	57	423	181	200	8	353	995	429
716	827	254	694	559	692	16	499	907	488	566	921	673	733	324	76	176	836	922	899
776	512	637	932	857	885	514	564	188	598	586	361	317	460	39	987	166	183	689	731
552	865	895	293	764	913	732	377	734	754	525	642	774	930	129	253	375	612	272	374
595	477	476	964	536	463	222	619	308	370	580	908	675	180	631	440	927	123	777	447
576	493	618	211	728	823	73	237	736	955	608	314	644	42	671	327	54	431	12	969
303	507	986	705	870	418	682	753	381	196	372	302	847	352	350	691	376	672	621	498
923	881	11	495	884	50	345	471	426	931	232	508	453	5	102	411	404	459	601	575
395	722	988	149	522	788	68	544	706	486	625	869	872	952	991	480	718	307	711	371
855	670	780	659	943	264	189	227	795	825	151	248	219	902	944	577	842	984	193	668

363	362	719	714	378	151	404	386	458	33	807	484	809	977	167	129	374	858	520	691
230	830	339	973	154	170	791	988	899	570	844	518	513	371	466	107	141	82	133	144
383	130	675	85	930	978	340	13	701	597	464	548	277	991	18	156	979	15	437	682
761	646	561	412	102	390	398	661	865	250	800	868	912	996	37	115	446	401	173	882
336	352	184	118	876	549	763	274	651	654	385	450	369	244	72	329	995	624	736	746
962	234	47	307	264	990	998	500	70	994	94	489	132	911	656	961	688	892	27	778
186	919	474	543	684	742	366	787	306	813	41	707	395	36	150	20	544	516	866	695
535	453	405	147	861	760	849	825	583	648	299	582	951	831	356	443	473	610	104	287
923	108	295	25	166	196	291	379	273	879	510	532	811	172	350	818	335	169	213	921
896	735	900	612	460	937	376	931	785	12	718	225	249	381	635	832	733	871	52	545
364	683	63	981	806	235	183	247	49	689	886	351	562	770	268	158	944	237	414	537
904	160	686	755	575	142	829	218	672	590	289	431	211	960	79	955	580	216	669	710
83	530	406	885	256	983	615	949	87	629	442	880	54	483	11	820	125	796	341	155
663	0	633	241	7	17	773	53	556	699	555	5	916	708	678	345	965	602	343	297
934	756	810	180	60	808	540	499	413	636	578	720	393	285	221	509	877	959	767	324
312	293	639	987	445	2	680	246	529	465	586	772	997	332	301	819	598	572	506	754
407	399	426	322	726	890	224	525	309	685	22	98	571	948	888	956	588	895	420	294
84	136	476	4	538	833	827	219	266	722	717	441	577	502	681	524	638	486	565	354
534	64	897	617	77	933	677	242	814	205	353	51	259	298	131	671	430	308	837	817
842	229	816	6	344	938	579	481	939	967	24	630	58	74	260	189	197	403	16	862
587	46	853	855	10	384	355	873	906	3	1	854	589	66	124	622	769	889	847	38
758	989	985	954	137	852	749	546	89	375	515	96	493	618	679	843	81	789	750	135
206	857	459	713	204	367	429	907	149	397	851	28	349	552	296	29	492	418	34	271
200	348	117	164	999	1000	370	859	972	711	928	165	45	357	62	275	835	305	494	704
139	400	391	69	270	652	44	427	188	223	823	551	739	421	634	97	8	338	163	103
872	783	195	438	215	891	55	491	673	372	697	181	177	984	59	776	560	599	120	436
559	440	824	503	258	288	609	647	664	193	601	240	330	905	265	496	692	457	507	595
21	214	596	594	128	192	883	411	382	716	514	946	519	303	14	487	626	217	323	564
903	658	964	48	471	346	207	982	439	109	573	950	792	279	485	521	751	302	604	290
114	30	834	902	40	402	123	539	449	281	784	740	748	940	729	745	526	423	779	567
388	953	874	209	909	497	781	786	768	451	910	208	232	470	468	774	143	35	187	856
878	424	705	627	161	394	311	929	659	947	455	550	226	452	448	157	676	467	508	304
76	553	623	91	753	757	153	220	727	969	111	19	780	741	765	607	826	670	321	314
236	517	359	113	581	700	148	360	93	318	347	210	227	71	968	662	881	631	504	533
276	943	56	373	893	592	788	732	358	752	632	39	650	408	283	992	73	99	252	703
687	971	619	976	333	712	731	766	603	317	198	199	523	31	867	901	171	845	542	531
600	568	251	952	614	690	243	434	822	261	569	368	86	90	797	482	802	182	479	392
721	26	666	233	799	95	585	643	380	918	511	490	728	432	313	841	709	660	498	387
176	527	884	557	463	194	389	121	327	178	435	168	342	850	231	365	798	106	61	92
838	649	839	253	396	112	461	68	43	723	864	409	566	812	860	105	815	212	32	696
922	174	591	238	606	88	920	970	821	203	110	914	936	924	698	255	175	50	536	836
558	935	140	730	505	908	927	269	278	958	932	67	122	315	267	794	495	334	286	57
608	263	134	759	245	547	300	942	628	641	702	377	674	42	554	145	657	764	248	724
254	78	201	417	725	775	222	328	777	100	65	805	974	980	645	870	101	993	146	793
422	361	655	228	272	605	202	179	80	803	915	425	477	828	512	191	475	331	444	846
637	23	282	957	945	190	782	159	456	284	419	522	771	319	975	621	616	280	875	576
986	738	804	433	665	668	917	644	926	744	593	162	642	541	316	478	734	152	737	941
869	75	185	790	762	469	428	9	528	326	795	887	653	801	563	262	611	310	416	480
747	119	584	488	126	257	667	966	620	848	894	239	325	574	410	715	501	693	863	337
640	898	840	613	116	447	706	127	625	320	925	292	472	454	963	138	913	415	462	743

5	4	497	94	78	865	275	604	778	945	487	949	287	262	685	673	97	746	642	792
693	268	349	691	212	318	453	245	505	602	828	99	880	140	421	612	424	572	611	255
302	331	135	494	576	325	545	204	567	442	270	752	68	842	668	991	888	948	79	908
732	278	532	200	183	907	295	55	395	124	58	598	881	740	553	584	427	393	874	535
213	844	565	284	760	679	218	759	926	613	137	371	822	256	882	30	269	547	294	314
674	258	595	13	700	103	672	811	873	381	941	623	780	868	107	407	928	742	515	762
590	621	217	549	250	854	12	244	955	400	794	466	338	872	846	227	130	904	568	467
821	843	718	80	377	891	947	982	783	585	59	455	805	50	531	562	511	363	483	169
446	706	301	277	24	694	271	923	998	374	297	772	205	801	176	159	303	884	587	507
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313	95	228	116	618	677	184	210	35	411	496	444	403	47	725	289	902	475	243	729
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285	636	477	647	815	56	737	199	779	649	448	577	101	464	802	20	48	952	883	296
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701	493	29	800	191	713	144	550	942	970	816	409	233	913	852	431	657	37	10	156
221	785	18	31	964	52	546	643	392	449	498	372	869	491	506	735	175	983	329	916
147	575	433	182	28	263	766	456	580	619	726	610	518	633	641	855	470	753	126	736
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965	830	61	290	876	528	622	438	484	656	526	695	809	782	889	808	469	980	954	75
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976	131	410	254	45	559	241	989	563	919	44	41	733	541	583	368	311	22	214	897
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836	230	343	440	994	734	105	16	600	748	810	993	471	617	739	999	626	895	863	827
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581	396	818	242	722	49	936	878	160	835	391	644	198	25	291	319	596	93	27	501
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933	815	139	28	191	508	173	902	185	411	756	40	424	467	748	296	716	545	152	366
939	971	154	910	190	562	3	680	687	45	717	907	20	116	995	178	205	446	816	571
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585	872	740	427	840	436	992	774	125	826	216	797	557	794	742	590	421	471	893	60
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827	34	770	364	644	99	119	295	27	358	632	387	346	447	269	145	891	920	669	259
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947	946	562	967	80	794	959	586	968	227	292	256	88	449	208	907	852	664	299	202
969	92	266	103	133	253	264	423	445	337	736	368	194	31	257	813	43	479	136	780
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198	782	749	113	417	516	631	171	310	897	525	891	819	833	956	737	580	252	705	439
280	384	665	591	654	936	939	666	527	672	491	100	517	647	195	859	793	375	201	863
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620	199	238	3	941	115	683	221	261	485	492	510	906	269	397	163	628	579	334	387
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349	169	267	401	187	494	324	559	803	915	0	765	399	660	318	981	687	882	407	778
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94	218	352	856	499	436	212	929	328	134	158	376	70	83	456	501	788	360	167	108
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379	243	408	723	812	301	383	979	978	293	690	305	288	905	51	593	258	570	364	722
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739	149	327	950	78	769	119	974	824	954	652	548	684	181	363	97	386	385	994	554
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734	356	636	511	403	16	942	278	300	873	532	689	842	634	602	716	927	8	358	143
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927	699	981	239	985	636	606	602	158	236	149	382	623	818	838	181	29	955	86	934
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541	540	258	485	372	915	751	119	760	849	537	57	543	442	192	440	884	201	938	705
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133	558	804	931	713	990	710	652	702	571	531	13	801	650	620	994	971	60	817	436
977	828	199	885	272	477	690	508	964	777	246	223	103	108	292	515	506	671	878	59
685	142	106	755	979	328	224	855	153	749	949	773	881	336	995	63	19	134	952	899
361	764	355	302	349	291	18	375	730	89	449	438	924	718	954	102	305	7	825	251
306	320	48	893	396	354	114	886	100	247	547	683	879	494	95	77	728	925	787	238
922	525	446	319	782	397	492	335	352	15	785	284	933	911	831	455	451	484	595	692
363	895	889	638	282	725	675	357	676	998	963	827	578	434	809	356	987	695	132	443
746	841	983	463	411	164	553	330	226	829	241	188	467	227	242	143	876	514	606	731
285	918	843	271	582	345	486	643	509	860	555	642	976	664	287	627	610	104	862	67
740	875	956	69	912	489	248	417	845	17	996	374	433	970	935	636	262	585	580	337
45	598	766	504	622	796	32	203	97	591	637	392	252	101	600	376	748	56	810	207
589	835	269	666	586	988	609	303	628	618	75	20	288	548	869	213	857	228	635	68
882	478	989	297	611	480	644	426	960	312	468	986	928	64	384	481	400	90	378	9
112	797	482	388	961	163	487	80	853	789	498	33	569	991	182	404	202	327	23	105
298	704	94	214	722	939	721	333	122	937	92	947	672	890	475	160	512	229	518	409
975	565	83	266	689	183	734	669	815	929	96	812	900	78	898	82	235	402	870	679
904	559	430	340	395	418	750	204	116	47	950	321	162	385	260	523	838	462	767	854
253	564	588	420	107	459	304	872	688	496	379	641	39	277	665	111	948	141	127	6
62	684	448	85	583	148	34	761	479	71	120	992	197	453	712	629	193	942	756	407
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726	439	136	240	566	280	694	699	427	871	405	867	775	631	534	469	216	800	719	174
316	957	237	187	4	859	413	181	239	167	816	874	892	798	1	88	150	222	763	441

373	372	185	317	294	801	947	857	631	721	977	566	707	426	105	287	757	114	585	487
887	649	889	638	646	441	552	333	643	536	555	139	922	763	588	871	154	115	264	902
710	834	685	905	969	803	764	90	36	689	953	62	108	793	149	69	296	586	450	249
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517	201	670	700	57	666	920	299	423	20	704	541	963	482	967	635	155	604	309	53
496	166	473	673	815	122	532	101	652	856	192	248	966	305	740	906	912	984	909	135
27	358	162	440	285	629	681	347	92	753	829	903	614	879	735	811	279	324	111	331
29	511	957	556	118	609	12	397	406	736	914	598	194	768	612	676	190	428	297	357
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817	730	183	621	717	136	797	719	438	286	342	780	577	435	269	429	724	22	362	352
919	418	939	527	304	633	422	722	254	822	895	538	915	339	697	245	535	930	186	937
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789	746	981	864	505	3	745	437	701	307	129	596	932	93	170	49	545	997	138	77
691	777	752	284	820	499	732	225	410	675	924	859	395	913	39	934	302	365	660	993
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255	727	991	329	526	348	849	739	949	334	901	349	394	404	262	964	868	528	600	592
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516	434	606	300	918	405	747	942	873	804	298	424	910	559	808	974	467	30	250	951
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948	852	205	419	411	67	257	278	217	214	825	662	854	921	540	622	561	731	774	431
38	630	60	377	408	867	112	222	6	134	132	207	458	620	750	656	227	82	56	384
674	180	332	800	344	439	251	601	480	626	703	636	933	359	624	648	900	52	462	374
767	195	669	161	313	908	593	814	892	292	116	314	76	295	618	160	71	743	85	983
842	198	167	341	33	175	813	558	150	88	63	469	972	445	744	147	72	318	749	231
171	737	211	433	18	998	651	514	50	281	617	904	962	543	389	444	821	153	692	203
276	489	94	142	238	567	168	530	470	765	14	273	678	925	843	688	899	370	632	502
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409	838	125	897	95	456	960	306	446	823	683	665	212	215	361	390	368	323	611	459
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243	378	481	870	218	525	420	987	494	478	275	827	103	436	663	637	310	786	40	830
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599	667	75	498	880	837	15	267	7	841	42	58	490	4	866	779	239	805	659	802
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324	323	415	410	389	711	944	478	562	556	30	27	792	606	830	70	406	959	865	515
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852	927	321	184	120	403	154	778	777	684	245	744	375	390	712	394	828	238	146	649
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969	369	95	584	886	715	951	247	253	25	819	891	257	990	318	334	939	514	632	99
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162	306	737	443	83	425	331	530	360	899	825	815	1	119	122	761	839	383	371	630
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471	414	384	992	269	127	235	454	493	750	31	185	934	687	9	311	258	675	732	108
207	291	625	144	118	467	355	380	297	246	667	919	308	210	786	28	718	634	4	743
616	905	608	458	765	583	492	849	733	45	72	622	94	278	546	827	346	941	686	883
947	888	442	762	89	958	783	205	706	981	46	503	241	766	911	219	517	166	922	320
573	336	780	296	352	274	101	335	361	428	997	873	821	283	485	623	585	488	638	697
745	270	294	551	787	908	500	882	59	861	560	807	259	412	487	962	49	168	996	635
595	138	201	220	451	244	137	367	338	131	54	366	223	599	441	915	963	461	298	994
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961	995	178	484	79	663	387	754	670	167	96	867	350	610	764	753	469	424	24	975
920	799	851	878	884	834	212	669	17	344	524	620	326	837	262	48	116	531	798	299
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139	52	111	69	103	189	248	845	589	660	791	874	444	5	936	250	639	56	62	135
43	209	404	482	621	519	749	460	877	87	725	53	339	935	548	688	804	826	960	419
78	261	156	948	159	553	784	527	721	748	617	97	40	176	161	674	392	16	272	217
586	374	722	315	75	106	181	290	195	21	395	588	552	987	572	3	605	129	728	685
422	150	609	473	627	964	671	102	575	377	93	965	600	770	885	844	388	801	0	307
986	287	991	252	814	810	755	440	657	977	7	742	554	539	532	26	818	364	735	218
566	376	288	115	438	897	832	967	342	396	82	373	604	193	881	142	956	850	400	689
196	904	35	636	664	98	512	868	204	823	700	795	333	58	172	582	561	932	618	598
468	66	391	759	77	590	690	946	647	717	234	41	580	504	509	434	974	452	429	673
84	662	624	455	214	525	464	165	811	18	68	730	279	656	426	637	362	870	57	808
317	526	368	702	862	813	215	577	646	970	337	173	496	972	328	236	88	100	486	999
91	875	416	729	802	550	705	227	226	105	651	273	633	302	949	843	1000	276	803	876
90	629	945	924	81	472	427	838	658	370	782	871	869	594	985	597	480	925	520	587
901	913	459	955	547	109	740	952	199	916	430	44	12	386	855	578	8	10	113	698
683	206	666	313	704	203	591	555	232	741	614	809	345	631	393	703	641	816	305	533
11	643	329	231	411	938	153	896	463	330	833	695	887	549	665	978	237	160	716	149
285	680	736	200	405	824	36	931	309	528	38	439	304	817	988	559	65	652	593	846
691	188	63	498	734	124	942	264	359	341	55	164	158	914	659	929	353	224	385	14