COMMONWEALTH OF KENTUCKY

BEFORE THE PUBLIC SERVICE COMMISSION

In the Matter of:

INVESTIGATION OF KENTUCKY UTILITIES	**)**	
COMPANY'S AND LOUISVILLE GAS AND	**)**	**CASE NO. 2015-00194**
ELECTRIC COMPANY'S RESPECTIVE NEED	**)**	
FOR AND COST OF MULTIPHASE	**)**	
LANDFILLS AT THE TRIMBLE COUNTY	**)**	
AND GHENT GENERATING STATIONS	**)**	

REBUTTAL TESTIMONY OF
JOHN N. VOYLES, JR.
VICE PRESIDENT, TRANSMISSION AND GENERATION SERVICES
KENTUCKY UTILITIES COMPANY AND
LOUISVILLE GAS AND ELECTRIC COMPANY

Filed: September 10, 2015

Q. Please state your name, position and business address.

A. My name is John N. Voyles, Jr. I am the Vice President of Transmission and Generation Services for Kentucky Utilities Company ("KU") and Louisville Gas and Electric Company ("LG&E") and I am an employee of LG&E and KU Services Company, which provides services to LG&E and KU (collectively "the Companies"). My business address is 220 West Main Street, Louisville, Kentucky, 40202.

Q. Please describe the purpose of your rebuttal testimony.

A. My rebuttal testimony responds to the pre-filed direct testimony of John W. Walters, Jr. and J. Steven Gardner. Specifically, I will (1) explain that the Companies' analyses consistently demonstrated that the Ghent and Trimble County Landfills were the least-cost feasible solutions for the Companies' coal combustion residuals ("CCR") storage needs; (2) reiterate the need for the CCR treatment and transport ("CCRT") facilities at Ghent and Trimble County; and (3) describe the deficiencies in Sterling Ventures' pre-filed testimony and discovery responses regarding transportation, materials handling and lack of adequate disposal capacity and temporary storage that cause significant concern regarding the feasibility of Sterling Ventures' offer.

<u>Clarification of Communications between the Companies and Sterling Ventures</u>

Q. Did Mr. Walters adequately describe the prior communications between the Companies and Sterling Ventures?

A. Generally yes, but a few points merit clarification. First, Mr. Walters claims that in 2010 "***KU approached Sterling*** about the possibility of using Sterling's mine in connection with KU's plans to increase the capacity of Ghent's gypsum stack."[1] This is not my understanding, as it was Sterling Ventures that first wrote KU regarding taking gypsum from Ghent and selling limestone to the Companies. All of the documents referred to in my testimony that are not already part of the record are attached as Collective Exhibit 1. Mr. Walters is correct in stating that KU explored this offer, including having its environmental group visit the mine, but an agreement was not reached because Sterling Ventures' proposed price to remove, transport, and place the gypsum was too high.[2]

Q. Did you review Mr. Walters' and Mr. Gardner's testimony regarding Sterling Ventures' belief that storing CCR in its underground mine will constitute beneficial use?

A. Yes, I did. I share the same concerns as Mr. Gary Revlett and Mr. Richard Kinch regarding whether placing CCR in Sterling Ventures' underground limestone mine would be considered beneficial use under the CCR Final Rule, or would be in fact disposal that is subject to the CCR Final Rule and its associated costs. Mr. Walters and Mr. Gardner claim throughout their testimonies that Sterling Ventures' offers to transport and store CCR constitute beneficial use, but in reviewing the written offers Sterling Ventures has provided to the Companies over the years, Sterling Ventures' own correspondence contains inconsistencies regarding whether Sterling Ventures believes its gypsum and CCR offers are disposal, or could qualify as beneficial reuse prior to the release of the CCR Final Rule. For example, in July 2010 when Sterling Ventures first submitted a written offer to the Companies to haul and store gypsum

[1] Pre-filed Direct Testimony of John W. Walters, Jr. of August 6, 2015 ("Walters Direct") at page 2, lines 7-8 (emphasis added).
[2] Walters Direct at pages 2-3.

from Ghent, Sterling Ventures described the offer as "***disposal***."[3] In September 2011, in submitting a revised cost offer, Sterling Ventures stated that it had met with the Kentucky Division of Solid Waste, and as a result of that meeting, planned "to submit an application to permit [Sterling Ventures'] Jessamine County mine as a special waste landfill to receive all CCPs" (which is another acronym for CCR).[4] This shows that as early as 2011, Sterling Ventures believed storing all types of CCR (gypsum, fly ash, and bottom ash), as it has proposed to do for Trimble County, would constitute a ***special waste landfill***, which is not beneficial reuse under the state regulations in effect at that time. Similarly, in January 2012, when Sterling Ventures updated its offer, it again described its offer as "***disposal***."[5] Likewise, Sterling Ventures again referred to its offer as "***disposal***" when it contacted the Companies in September 2014 inquiring about storing Trimble County's CCR.[6] Collectively, these documents, in Sterling Ventures' own words, evidence Sterling Ventures' inconsistent and uncertain understanding of the state's Special Waste regulations, and now, the CCR Final Rule.

Q. Do these offers reveal an additional inconsistency regarding Sterling Ventures' requested relief in this case?

A. Yes, they do. Mr. Walters states that Sterling Ventures' tendered complaint has challenged the Companies' ability to "fully recover the cost of the first phase" of the Ghent Landfill.[7] But in reviewing the various offers Sterling Ventures submitted to the Companies, Sterling Ventures always stated that its offer could defer ***later*** phases

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3 The offers discussed in this portion of the testimony are included in Collective Exhibit 1.
4 *Id.*
5 *Id.*
6 *Id.*
7 Walters Direct at page 1, lines 19-20.

of the Ghent Landfill; Sterling Ventures never claimed it would eliminate the need for Phase I:

- "Taking all of Ghent's excess Gypsum would, at a minimum, eliminate the need for Phase III of the new landfill, and substantially delay the need for Phase II."[8]
- "…it may be possible to completely eliminate the need for Phases II and III of your landfill."[9]
- "…you can delay Phase II of the Ghent Landfill project by eleven years, and completely eliminate Phase III…However, these savings assume that all gypsum is beneficially reused at Sterling's underground mine starting with the opening of Phase I in 2013."[10]

In fact, Mr. Walters' direct testimony states that "Sterling's proposal for Ghent did not stop the construction of the Ghent landfill…"[11] The Companies agreed with Sterling Ventures that their offer could have merit in deferring the next phase of the Ghent Landfill presuming it would be a least cost option, but Sterling Ventures did not claim that exercising their offer would have eliminated the need for Phase I. It is unreasonable for Sterling Ventures to request the Commission to disallow a portion of the costs for Phase I, when they concede Phase I was necessary. As explained in Mr. Sinclair's direct testimony, Sterling Ventures' allegation that it could have disposed of gypsum at a lesser cost than in the Ghent Landfill is simply wrong.

[8] Collective Exhibit 1.
[9] *Id.*
[10] *Id.*
[11] Walters Direct at page 10, lines 19-20.

The Necessity of the CCRTs

Q. Do the economics of Sterling Ventures' claims in its direct testimony hinge on the necessity of certain capital improvements?

A. Yes. At the outset, I must reiterate that the Companies' analyses have continuously demonstrated that the Ghent and Trimble County CCRT facilities and Landfills remain the least-cost feasible option for CCR disposal. The cost comparisons that Sterling Ventures has submitted in this case hinge entirely on eliminating capital improvements that are necessary to the Companies' responsible management of CCR. With respect to the Ghent Landfill, Sterling Ventures' calculations eliminate the costs of the CCRT related to the disposal of gypsum. With respect to the Trimble County Landfill, Sterling Ventures' calculations did not include the transport costs of the CCRT. Notwithstanding the significant feasibility issues with the Sterling Ventures claims, Sterling Ventures' entire complaint warrants dismissal because their offers cannot be least-cost. The Commission thoroughly investigated the need for KU Project 30 for Ghent and KU Project 32 and LG&E Project 24 for Trimble County in the course of the 2009 ECR Plan proceedings and correctly approved these projects.

Q. Before addressing the particulars of Sterling Ventures' claims regarding the CCRTs at Ghent and Trimble County, can you please explain what a CCRT is?

A. Certainly. As I described in my direct testimony, the CCRT facility is required to treat, dewater and prepare the CCR for transport to a facility for disposal regardless of whether the disposal site is an onsite landfill, trucked or barged offsite, or loaded for beneficial use or reuse. As I explained in the 2009 ECR Plan proceedings, CCR transport for disposal in a landfill can be accomplished in one of two ways: by truck hauling or by automated conveyance systems.[12] The Companies designed the CCRT facilities that included conveyer systems in order to reduce particulate emissions and fugitive dusting concerns. Had the Companies attempted to truck, rather than convey, significant quantities of CCR on haul roads located near property boundaries to the landfill, it would have had to include any dust emissions within the constraints of the Title V air permits and it likely would have been impossible to avoid visible particulate emissions reaching neighboring properties. In short, the Companies were compelled to construct CCRT facilities that allowed for the movement of CCR by conveyer because it was the best method to control the fugitive dust associated with the movement of CCR at these locations for meeting the air permit requirements.

The Companies' decision to construct the CCRT systems has been reaffirmed by the EPA just this year; the preamble to the CCR Rule published in the Federal Register on April 17, 2015 stated that "the single most frequent issue presented during the public hearings was the allegation by individual citizens of damage caused by fugitive dusts from neighboring CCR facilities." The preamble further noted that "absent dust control measures, ***such as the conditioning of CCR***, both CCR landfills and CCR piles have the potential to generate significant amount of fugitive dust."[13] The CCRT is precisely the type of conditioning to which the EPA refers. The preamble demonstrates that regardless of whether the CCR is being disposed of in a landfill, or placed in a pile to be trucked offsite, conditioning the CCR in a CCRT is a best practice for fugitive dust control.

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[12] *In the Matter of: Application of Kentucky Utilities Company for Certificates of Public Convenience and Necessity and Approval of Its 2009 Compliance Plan for Recovery by Environmental Surcharge* (Case No. 2009-00197), John N. Voyles Direct Testimony at 13.
[13] (emphasis added).

Q. With respect to the Ghent Landfill, does Sterling Ventures claim that a portion of the CCRT was unnecessary under its offers?

A. Yes. Although Sterling Ventures admits that the CCRT would have been necessary even if the Companies had agreed to one of Sterling Ventures' offers regarding gypsum at Ghent, it claims that the Companies should have constructed a CCRT that did not allow for the treatment and transport of gypsum.[14] To be clear, the CCRT at Ghent has been fully constructed and is in operation, including the components pertaining to gypsum.

Q. Even if the Companies had accepted Sterling Ventures' offers regarding disposing of Ghent's gypsum, would it have been prudent for the Companies to build a CCRT facility that did not allow for the transport and treatment of gypsum?

A. Absolutely not. As I have explained, three types of CCR are created when coal is burned to generate electric power: gypsum, fly ash, and bottom ash. From a percentage basis, more gypsum is created during the generation process than the two other types. It would not be prudent to build a CCRT that cannot transport and treat ***all*** CCR, including the type created in the largest volume. As early as the 2009 ECR Plan cases, which were before Sterling Ventures first contacted the Companies regarding gypsum, I explained that the CCRT was necessary to manage the transport of CCR in order to address fugitive dusting concerns associated with the materials. As discussed above, the preamble to the CCR Rule recommends conditioning all types of CCR as a dust control measure.

[14] Walters Direct at 10.

The Companies are more than surprised that Sterling Ventures, based on their position regarding the CCRT, believe they could haul and transport gypsum and bottom ash that had not been dewatered and transported by conveyors. In addition to the dusting issues that would arise from dry CCR material movement, some CCR is initially moved from the generating unit using large quantities of water. The Companies described the individual streams of CCR produced at its stations at the informal conference with Sterling Ventures and the Commission Staff on July 29, 2015 and in the Companies' response to Question 9 of Sterling Ventures' 1st data request. Also, in response to a data request by Commission Staff, Sterling Ventures stated the Companies would remain responsible for the CCR while it is being loaded and barged to Warsaw; it is the Companies' position that the best practice is to use a transport system to load the barges to minimize fugitive dust[15], similar to the current gypsum and fly ash beneficial reuse barge loading operations at Trimble County.

Not dewatering CCR would significantly increase the weight and volume of materials to be transported, regardless if hauled by truck, barge, or a combination of both. Sterling Ventures is aware that when materials are not dewatered, the cost of transporting those materials increases substantially, as well as adding handling and transporting complexities. When Sterling Ventures submitted a limestone bid to the Companies in 2013, it claimed that it hoped to lower the Companies' cost by selling limestone that contained less water than the types that were being barged.[16] The very same principle applies to CCR, as well.

[15] Sterling Ventures' Response to Item No. 2 of the Commission Staff's Supplemental Data Requests.
[16] Collective Exhibit 1.

Q. Would it have made sense to construct the gypsum portion of the Ghent CCRT at a later date if the Sterling Ventures offer ended for some reason or proved impracticable?

A. No, it would not. If the Companies constructed the gypsum components of the CCRT at a later date than the other components, it would have increased the total cost of the facility by extending the Companies' construction cycles, and adding costs for escalation and incremental equipment for electrical power. The CCRT is not a ready-made facility that can be purchased and installed on short notice. Regardless, it is not consistent with the Companies' Coal Combustion Byproduct Management strategies and prudent utility planning to exclude gypsum treatment and transport from the CCRT given the roughly forty years that the Companies expect to generate gypsum at Ghent and the need to condition the gypsum as a dust control measure. The Companies' CCR projects provide a backstop against any beneficial use and reuse market changes through the phased construction approach the Companies utilize.

Q. Was the existing gypsum stack a sufficient long-term storage solution at Ghent?

A. No, it was not. One of the principal reasons the Companies needed to build the Landfill and CCRT at Ghent was because the gypsum stack reached a capacity that required the Companies to begin constructing additional storage. This is not surprising, as the gypsum stack was initially designed to serve only one unit at Ghent, and began serving all four units, which produced increased volumes of gypsum due to the installation of scrubber technologies in response to the EPA's CAIR regulations. This increase in the volume of gypsum sent to gypsum stack at Ghent not only rapidly consumed the capacity of the stack facility, it also caused the Companies to begin assessing the stability of the stack due to an increase in gypsum fines that were accumulating. The gypsum fines do not readily settle and dewater in the gypsum stack process and were creating operating concerns. Now that the Landfill and CCRT are in commercial operation, the Companies are placing minimal quantities of gypsum in the gypsum stack in the ordinary course of operations. A portion of the gypsum, adequate to meet the contractual requirements, is still pumped to the SynMat facility holding tanks adjacent to the gypsum stack. In addition to the capacity issue, it is likely that the Companies will have to close the gypsum stack under the CCR Final Rule.

Q. Does Sterling Ventures believe a CCRT is required a Trimble County?

A. Mr. Walters' testimony does not take a position on whether a CCRT is required at Trimble County because he claims that Sterling Ventures has not "had the time nor opportunity in this proceeding to review in any substantive manner the Companies' claims as to the need" for the CCRT.[17] Mr. Walters makes this assertion notwithstanding the opinion he has expressed about the CCRT for the Ghent Landfill or the fact that Companies' 2009 ECR Plan cases for the Trimble County Landfill expressly included the CCRT facility as a component of Phase I. That being said, there are no costs associated with the transport portion of the Trimble County CCRT in Sterling Ventures' calculation of the PVRR. If the transport costs are included, even under Sterling Ventures' calculations, the Trimble County Landfill project remains least cost.

Q. Have the Companies provided sufficient information to allow Sterling Ventures to reach a conclusion regarding whether a CCRT at Trimble County is needed?

[17] Walters Direct at page 26, lines 5-7.

A. Yes, it has. As I have testified, the Companies thoroughly explained the need for the CCRTs at Ghent and Trimble County in the 2009 ECR Plan cases. Sterling Ventures reviewed the records in those cases, as well as subsequent cases involving these projects in great detail, as they have used the Companies' information from those proceedings as the basis of many of their allegations and have cited extensively to those cases in their complaint. As such, they have had the same amount of time to review the need for the CCRT as the other portions of the record. Also, Sterling Ventures had the opportunity in this case to ask data requests about the CCRT facility prior to filing their testimony, and in fact asked 14 questions, including subparts, about the CCRTs.[18] In addition, the Companies provided detailed information regarding the CCRTs and associated CCR materials handling issues at Sterling Ventures' request at the July 29, 2015 informal conference in this case.

Q. Do the Companies need a CCRT at Trimble County?

A. Yes, it remains necessary to responsibly treat and transport the CCR. As explained, the CCRT facility is required to treat and condition the fly ash, dewater the bottom ash and gypsum, raise the moisture content of dry fly ash, and transport the CCR to the landfill in a condition suitable for placement. The CCRT will allow the Companies to employ the best methods to reduce fugitive emissions from these materials during transport and handling. It is important to recall that the Commission granted CPCNs for the Ghent and Trimble County Landfills, which included the CCRT facilities. Nothing has changed since those cases that in any way lessen the need for the facilities. Moreover, Sterling Ventures, which has not taken a position on the Trimble County CCRT, has not provided any evidence that the CCRT is not

[18] See Sterling Ventures' First Data Requests to the Companies.

necessary at Ghent or Trimble County. In fact, they have avoided discussing this issue in their responses to date with regards to how they would handle and transport CCR that has not been moved by conveyer.[19] Acceptance of these unrebutted points renders Sterling Ventures' claims non-economic, even accepting as true all of their calculations for the sake of evaluating their arguments.

Transportation and Storage Calculations

Q. Are you concerned with the feasibility of the transportation and material handling scenarios Mr. Gardner has proposed in his direct testimony?

A. Yes, because there are a number of feasibility concerns. Mr. Gardner has proposed loading barges at the Trimble County generating station, and transporting the loaded barges up the Ohio River through the Markland Locks to a site in Warsaw, Kentucky.[20] From there, Sterling Ventures plans to truck the CCR from the Warsaw unloading facility to Sterling Ventures' limestone mine that is ten miles away in Verona, which is in Gallatin County.[21] I set forth below some of the feasibility concerns regarding Sterling Ventures' offer. I do not do this to discredit Sterling Ventures or its witnesses; instead, I intend to convey the piecemeal nature of the offer that causes the Companies to believe that in addition to not being least-cost, there are serious feasibility concerns with Sterling Ventures' approach. Cumulatively, these feasibility concerns demonstrate that the operational, financial, and regulatory risks associated with this offer are simply too great.

[19] See, e.g., Sterling Ventures' Response to Item No. 8 of the Commission Staff's Supplemental Requests for Information, in which Sterling Ventures simply states that it does not anticipate dust issues in connection with material movement.
[20] Pre-filed Direct Testimony of J. Steven Gardner of August 6, 2015 ("Gardner Direct") at page 12, lines 1-2.
[21] *Id.* at lines 3-4.

Q. Is there an overarching issue with Mr. Gardner's barging, trucking, and storage space calculations?

A. Yes, there is an issue that materially understates Mr. Gardner's calculations. The annual cubic yard projections the Companies have utilized are ***compacted*** yards in a landfill. When CCR is placed in a landfill, the Companies are able to tightly compact the CCR by operating heavy equipment on top of it to flatten and compact it, which reduces the cubic yards of volume in the available landfill space that are consumed. As Sterling Ventures is barging and trucking the CCR, it will not be possible to transport the CCR as tightly compacted as in the Companies' landfill. The CCR is treated prior to transport and is processed through the CCRT facility. Since the treated streams of the CCR have most of the process water removed, those streams will comprise transportable volumes that are significantly ***less*** cubic yards than they would in their original condition prior to treatment in the CCRT, but require ***more*** cubic yards of volume for shipping of the loose CCR than when disposed in a landfill because they will not be compacted as they are in their final placement within the landfill. This means that the barging and trucking volumes, which form the basis of Sterling Ventures' transportation schedules, are understated by a material difference.

Q. Does this affect the amount of CCR that Sterling Ventures must store underground?

A. Yes, it does. As with the transportation estimates, the ultimate space consumed by the cubic yards of CCR disposed of in the limestone mine are also understated. As explained in the testimony of Mr. John Feddock, due to the physical limitations of the applicable equipment, the compacted volume in the underground mine landfill is expected to be materially greater than the compacted volume in the Companies' landfills. Pushing materials laterally into place in mine voids will not be compacted to the same degree as the on-site landfills, particularly when attempting to compact horizontally near a mine ceiling.

Q. Are there other concerns about Sterling Ventures having enough space to store the CCR?

A. Yes, there are. I have reviewed Mr. Feddock's testimony, which shows that the amount of usable storage space is a small fraction of the 8 million cubic yards that Sterling Ventures has claimed. After considering Mr. Feddock's testimony, I am very concerned that absent a fundamental redesign of Sterling Ventures' mining patterns there will not be sufficient space in the limestone mine to store the CCR that will be produced over the next thirty-seven or so years. I reiterate from my direct testimony that it is very important to our customers that the operation of the coal-fired units at Trimble County and Ghent not be adversely affected by the Companies' failure to have a sufficient and reliable CCR disposal plan. The Companies must consider their obligation to serve their customers in assessing the degree of operational risk posed by potential disposal alternatives that could affect the economic dispatch of the Companies' generating fleet.

Warsaw Barge Site

Q. Are there issues associated with the Warsaw barge site described in Mr. Gardner's direct testimony?

A. Yes. To start with, significant in-river and on-land capital improvements would be required before the site could begin to accept CCR in the volumes produced by Trimble County's coal-fired generating units. Mr. Gardner concedes as much by describing the site as "vacant property."[22] From what Sterling Ventures has told the Companies, the vacant property is owned by an unaffiliated third party. Mr. Gardner states that the Warsaw site, under Sterling Ventures' offer, "will include the barge unloading equipment; a temporary unloading/storage pad; turnaround staging space for the trucks and loader equipment; and a small operations structure."[23] Sterling Ventures recognizes substantial construction and equipment will be required at the Warsaw site, but did not attempt to estimate them; instead relying on the Companies' conceptual cost estimates for a different barge site that was contained in the Alternatives Analysis and stating in a discovery request that the Companies will be responsible for these costs.[24] Moreover, the temporary storage pad would likely have to satisfy the CCR Final Rule requirements, which will likewise increase costs. These are meaningful examples of the piecemeal nature of Sterling Ventures' offer.

Q. Is it clear from Mr. Gardner's testimony that Sterling Ventures appreciates the type and scope of equipment that will be required at the Warsaw barge site?

A. No, it is not. Mr. Gardner's testimony does not provide any specifics other than the sentence quoted above - no specific equipment is identified; no schematics are provided. This is troubling to the Companies, as the "barge unloading equipment" to which Mr. Gardner refers will be substantial, and will include, for example, a large automated barge loader because mobile equipment is not practicable given the expected CCR volumes. Sterling Ventures admittedly does not have experience in handling CCR, which has very different handling properties than the limestone it is accustomed to mining regarding how the materials flow, attract and retain water, and

[22] *Id.* at page 13, lines 9-10.
[23] *Id.* at lines 11-13.
[24] Sterling Ventures' Response to Item 41(e) of the Companies' First Data Requests.

their susceptibility to releasing fugitive dust. Moreover, even getting the CCR to the Warsaw site will require significant equipment, as well. The Companies expect that a minimum of eight 1,200 ton open hopper barges would be required, in addition to a large push boat that would haul the barges from the loading and unloading areas. Equipment of this scope, through ownership or service contracts, comes at a considerable cost, the inclusion of which will further render Sterling Ventures' offer non-economic.

Q. Is the existing layout of the Warsaw barge site conducive to rapidly loading and unloading barges and trucks?

A. No, it is not. One of the principal limitations with the Warsaw barge site is that the existing access ramp has a very sharp switchback, or hairpin, curve that is constructed with a limestone dense grade aggregate gravel. It is not known if the ramp is sufficiently designed to handle the weight and volume of the large equipment suggested by Mr. Gardner. The present design of the ramp, which includes the sharp curve, will make it very difficult to execute the rapid loading of trucks that would be required under the trucking schedule Sterling Ventures has proposed. Additionally, management of water runoff from the unloading operation must be appropriately considered, including discharge permits, to avoid the environmental concerns from surface water set forth in the CCR Final Rule.

Another limitation with respect to the Warsaw barge site is that it may not be large enough to construct the necessary equipment and structures required to rapidly load trucks. It would be necessary to at least partially demolish the warehouse adjacent to the ramp or acquire other parcels of additional adjacent property. Sterling Ventures has no legal rights to the barge site, and stated in a discovery response that the Companies would have to lease the site from the unaffiliated third party. While it is currently the practice of the Companies to transfer contractual responsibilities of CCR materials shipped offsite at the point of initial loading of the materials, it is unknown whether the unaffiliated third party that owns the property would acquiesce to improvements of this scope (or even enter into a lease agreement), which may necessitate acquiring the property and/or nearby property.[25] The Companies are not aware if such costs have been included in Sterling Ventures' calculations.

Q. Will the Warsaw barge site Army Corp of Engineers permit be adequate for establishing a CCR unloading site?

A. No. Based on the current permit provided in response to Item 15(a) of the Companies Supplemental Data Requests, the current permit issued to Riverside Industrial Properties, LLC is for loading and unloading equipment and other non-hazardous non-liquid commodities. The permit specifically states "Commodities that would not be trans-loaded at this facility include such items as sand and gravel, cement and coal." Clearly, a permit modification for unloading CCR materials would need to be obtained adding time to the schedule. Also, a permit from the Army Corps of Engineers will also be required to install needed river cells for the mooring of full and empty barges, which is another cost likely not included in Sterling Ventures' comparisons.

Q. Will Sterling Ventures have to obtain air permits for the Warsaw barge site?

A. Yes, for the site to be utilized as an unloading site for CCR materials, Sterling Ventures will have to obtain air permits. Mitigation equipment, such as mechanical

[25] Sterling Ventures' Response to Item 41(b) of the Companies' First Data Requests.

dust collectors, will also be required. It is not known how quickly, if at all, these air permits could be obtained.

Q. Could permits with respect to water be required, as well?

A. It is possible that the Army Corps of Engineers could require section 401 and 404 permits under the Clean Water Act if streams or wetlands are impacted. Moreover, Sterling Ventures' testimony makes no mention of its plans with respect to storm water. It will be very important that Sterling Ventures prevent storm water from contacting the CCR so that CCR is not introduced into the surface water or groundwater at either the Warsaw site or the above ground facilities at the limestone mine. The unloading area thus must be designed for containing water runoff in some way. The preamble to the CCR Rule published in the Federal Register on April 17, 2015 stated that CCR that is "subject to external factors such as rain and wind…can adversely affect human health and the environment. For example, uncontrolled run-on and run-off can result in ponding of water in and around the unit resulting in increased leachate which has the potential to affect groundwater." To address this, a lined impoundment and a pumping station(s) would likely be required, along with a water treatment system(s). Water discharge points would need to be established, which may require permitting.

<u>Trucking from the Warsaw Barge Site to the Limestone Mine in Verona</u>

Q. Even if the Warsaw barge site could be utilized to unload barges of CCR, are there additional feasibility concerns in trucking the CCR from Warsaw to Sterling Ventures' limestone mine in Verona?

A. Yes, there are. It is important to understand that even after barging the CCR to Warsaw, the CCR must then be trucked over ten miles to Sterling Ventures' limestone mine in Verona. Based on Sterling Ventures' testimony, which does not account for the additional cubic yardage resulting from the uncompacted CCR, up to ***168 round trips per day*** will be required to dispose of the CCR. The route between Warsaw and the mine in Verona is less than ideal for trucking of this magnitude. First, reaching the Warsaw barge site currently requires traveling an intersection that is across the street from the Gallatin County school complex that experiences significant public traffic most of the year. Athletic and other extracurricular events at the schools will also increase traffic. The trucks would traverse state highways that require passing by small businesses, a church and local residential homes, as well as school bus traffic twice daily during the school year.

Q. How will this route impact the trucking of CCR?

A. It will impact the trucking in several ways. First, the fact that the trucks will have to travel in the community and throughout the school year means there will likely be times during the day that the trucks' ordinary travel times will be delayed due to traffic. Second, it has been our experience in prior projects that members of the community will be concerned about the amount of traffic and the safety of the schoolchildren given the amount of large trucks that will be used for over 8 hours daily under the schedule set forth by Mr. Gardner. For example, when the Companies obtained approval from the Kentucky State Board on Electric Generation and Transmission Siting for construction of Trimble County Unit 2, the Board included measures to lessen the impact of construction traffic, including the timing of work hours to avoid school and commuter traffic and avoiding the use of those roads most likely to be affected by increased traffic. This concern is especially pronounced in this case given the fact that the intersection with the Warsaw barge site is so near the

Gallatin County schools. Third, similar to our prior experiences, residents of Warsaw and those that reside along the travel route may be concerned about dusting and emissions from the trucks that will be loaded with CCR. It is very unlikely there would not be some form of public opposition to a plan that places large trucks on the road making trip after trip loaded with CCR essentially all day, every day in Warsaw. In fact, a new access road could be required to address these concerns, which would come at additional cost.

Q. Have you driven this route and reached an opinion on the feasibility of trucking CCR from Warsaw to Verona?

A. Yes, I have. I personally drove the route to gain a firsthand understanding of what would be entailed. Given the length of the route, the properties located nearby the roadways, and the number of trucks Sterling Ventures would put on the road, I do not believe this is feasible because of the many complications that are likely to ensue. In addition to engineering feasibility, as a member of the Companies' leadership team I must also consider the impact to the residents of the communities we have the privilege to serve. It is my opinion that the onsite landfills will reduce the likelihood of emissions onto adjoining properties and is a safer and more reliable method of disposing CCR.

<u>Disposing of CCR at the Limestone Mine</u>

Q. Even after barging the CCR to Warsaw, and then trucking it ten miles to Verona, is the CCR disposal complete under Sterling Ventures' plan presented in its direct testimony?

A. No, it is not; now the CCR must be placed underground in Sterling Ventures' limestone mine. Mr. Gardner's testimony does not make clear how Sterling Ventures plans to place the limestone underground. Instead he sets forth three conceptual options: (1) dump the CCR through a shaft; (2) haul the CCR underground by trucking or ramping; or (3) haul the material underground on a new 10% slope. I will respond to each of these options in turn.

Q. Please discuss the feasibility of dumping the CCR through a shaft.

A. When Sterling Ventures previously made offers to the Companies regarding disposing of the gypsum generated at Ghent, it proposed dumping the CCR through a shaft. After reviewing Mr. Gardner's testimony regarding this option, I am left with a number of questions that likely arise from Sterling Ventures' lack of experience in handling CCR. Mr. Gardner's response to Item 12 of the Companies' Supplemental Data Requests provides additional information about the shaft dimensions, but how this method could be accomplished without dusting problems or a determination if dust controls are needed in the design at the surface or below ground remains a concern. In response to the Commission's Staff's inquiry on this issue, Mr. Gardner stated that Sterling Ventures "does not anticipate dust issues in connection with material movement."[26] As someone who has years of experience in handling CCR, unless Sterling Ventures develops detailed plans to avoid fugitive dust, issues will arise.

CCR is comprised of non-homogenous particulates and are highly susceptible to significant dusting. It is also not uncommon for CCR materials under some conditions to stick to walls. Failure to appropriately size the shaft could cause either of these two problems. If the shaft is not appropriately designed, there will be even greater difficulties in preventing significant dusting when the CCR is dumped through

[26] Sterling Ventures' Response to Item No. 8 of the Commission Staff's Supplemental Data Requests.

a shaft that is up to 500 feet deep. Mr. Gardner indicates there may be a hopper at the bottom of the shaft for managing the materials prior to placement. Our experience with CCR would indicate this would establish a significant problem for clogging the shaft from the bottom up, as the materials will have the opportunity to bridge over from interrupting the flow or from natural compaction as a result of the long drop to the hopper.

In addition to recognizing these feasibility concerns, Mr. Feddock's testimony discusses further issues he has identified related to moving CCR around for placement in the mine itself.

Q. Please discuss the feasibility of hauling or trucking the CCR underground.

A. Before I address the feasibility of this option, I first must note my surprise that Sterling Ventures believes this is possible because it previously described trucking the CCR underground as "cost prohibitive."[27] Regardless, there are a number of feasibility concerns with this approach. The first concern is that in order to haul the CCR from the surface to underground, trucks will have to traverse a 23% slope. This is a steep, and potentially unsafe, angle for trucks loaded with CCR to drive.

Second, because of the layout of the limestone mine and presuming the permit can be modified, trucks will have to drive through the first two levels of the mine in order to reach level three of the mine. As discussed in Mr. Feddock's testimony, because Sterling Ventures mines limestone throughout the perimeter of the mine, and the necessary crushing equipment is only on level one, not only will there be significant truck traffic entering and exiting the mine as a result of CCR disposal,

[27] Collective Exhibit 1.

there will be also be traffic associated with the ordinary working conditions of the mine itself. This may pose feasibility, and safety concerns.

Mr. Feddock's testimony also discusses further concerns with this approach.

Q. Please discuss the feasibility of hauling or trucking the material underground on a new 10% slope.

A. The fact that Sterling Ventures mentions this alternative suggests that Sterling Ventures is aware that the existing 23% grade is likely not an acceptable long term option to truck CCR. Mr. Gardner's testimony regarding the new 10% slope does not provide any information on the location or cost of the slope, which makes it very difficult to evaluate. However, all of the concerns regarding underground traffic on the 23% slope are an issue with this method, as well.

Mr. Feddock's testimony also discusses further concerns with this approach.

Storage Interruptions

Q. Do you agree with Mr. Walters that the one month shutdown the Sterling Ventures mine experienced due to an accident would not have impacted the disposal of gypsum from Ghent?

A. My concern with Mr. Walters' comments regarding the one month shutdown of the limestone mine is that he does not concede this is of rightful concern to the Companies. The idea that the Companies would not have access to their CCR disposal site for an entire month is a significant operational risk.

Q. Do the alternatives Mr. Walters mentions, which include utilizing the new gypsum storage pond at Trimble County, provide reasonable solutions for temporary disposal solutions?

A. No, they do not. The first alternative Mr. Walters suggests is to use the new gypsum storage pond at Trimble County to store CCR if disposal is interrupted.[28] The Trimble County gypsum storage pond is only permitted for non-ash contaminated CCR, which means that bottom ash and fly ash – two of the three types of CCR – cannot be stored in the gypsum storage pond, even temporarily. The other alternative Mr. Walters suggests, which is to truck the CCR from Trimble County to Ghent, is likewise not suitable. First, the Ghent Landfill is not currently permitted for Trimble County's CCR. A permit modification would require time to obtain and, if granted, would shorten the available capacity in the Ghent Landfill for the amount of time of the interruption. In addition, this alternative requires the Companies to truck the same volumes CCR over public roadways that are 3 times the distance as between Warsaw and the Sterling Ventures' mine. Responsible utility management requires the Companies to have at least three days – although more would be better – of temporary storage. In light of Sterling Ventures' prior one-month shutdown, one month of temporary storage would be prudent. The Companies, through the CCRT and other existing infrastructure, do not have the requisite amount of storage. To avoid interruptions of Trimble County's electric production, which could ensue with a one month shutdown of the Sterling Venture's offer, additional storage, which will come at a cost, must be constructed. Importantly, the onsite landfill provides the Companies with the best flexibility to respond to changes in any viable offsite alternative, whether temporary or market driven.

[28] Walters Direct at 24.

Q. What is your recommendation to the Commission?

A. I respectfully request the Commission deny Sterling Ventures' request to cap the Companies' cost recovery related to the Ghent Landfill because it was, and remains, the least cost and most feasible long-term CCR disposal solution.

I further respectfully request the Commission deny Sterling Ventures' request to revoke the Companies' CPCN for the Trimble County Landfill. As with the Ghent Landfill, it is the least cost and most feasible long-term option to dispose of CCR.

Finally, I request the authority granted by the Commission with the CPCN in 2009 for the Companies to begin construction of the Trimble County Landfill, including the CCRT, be reaffirmed.

Q. Does this conclude your testimony?

A. Yes, it does.

VERIFICATION

COMMONWEALTH OF KENTUCKY)
) SS:
COUNTY OF JEFFERSON)

The undersigned, **John N. Voyles, Jr.**, being duly sworn, deposes and says that he is Vice President, Transmission and Generation Services for Kentucky Utilities Company and Louisville Gas and Electric Company and an employee of LG&E and KU Services Company, and that he has personal knowledge of the matters set forth in the foregoing testimony, and that the answers contained therein are true and correct to the best of his information, knowledge and belief.

John N. Voyles, Jr.

John N. Voyles, Jr.

Subscribed and sworn to before me, a Notary Public in and before said County and State, this 10th day of September 2015.

Judy Schooler (SEAL)

Notary Public

My Commission Expires:

JUDY SCHOOLER
Notary Public, State at Large, KY
My commission expires July 11, 2018
Notary ID # 512743

APPENDIX A

John N. Voyles, Jr.

Vice President, Transmission and Generation Services
Louisville Gas and Electric Company and Kentucky Utilities Company
220 West Main Street
Louisville, Kentucky 40202
(502) 627-4762

Education

Rose-Hulman Institute of Technology, B.S. in Mechanical Engineering - 1976

Previous Positions

E.ON U.S. LLC

June 2008 - Present -Vice President, Transmission and Generation Services
2003 - 2008 -Vice President, Regulated Generation

LG&E Energy Corp.

February - May 2003 -- Director, Generation Services

Louisville Gas and Electric Company

1998 - 2003 -- General Manager, Cane Run, Ohio Falls and Combustion Turbines
1996 -1998 -- General Manager, Jefferson County Operations
1991 - 1995 -- Director, Environmental Excellence
1989 - 1991 -- Division Manager, Power Production, Mill Creek
1984 - 1989 -- Assistant Plant Manager, Mill Creek
1982 - 1984 -- Technical and Administrative Manager, Mill Creek
1976 - 1982 -- Mechanical Engineer

Professional Development

Emory Business School -- Management Development Program
Center for Creative Leadership (La Jolla, CA)
University of Louisville -The Effective Executive
Harvard Business School - Finance for the Non-Financial Manager
MIT - Leading Innovation & Growth: Managing the International Energy Co.

Board/Committee Memberships

Fund for the Arts - Board Member
Ohio Valley Electric Co. (OVEC) - Board member and Executive Committee member
Electric Energy, Inc. - Board member
Edison Electric Institute (EEI) - Committee member Energy Supply Executive Advisory Committee and the Environment Executive Advisory Committee
Electric Power Research Institute (EPRI) - Chairman, Research Advisory Committee

Attachment
Confidential

The entire attachment is Confidential and provided separately under seal.

COMMONWEALTH OF KENTUCKY

BEFORE THE PUBLIC SERVICE COMMISSION

In the Matter of:

INVESTIGATION OF KENTUCKY UTILITIES	**)**	
COMPANY'S AND LOUISVILLE GAS AND	**)**	**CASE NO. 2015-00194**
ELECTRIC COMPANY'S RESPECTIVE NEED	**)**	
FOR AND COST OF MULTI-PHASE	**)**	
LANDFILLS AT THE TRIMBLE COUNTY	**)**	
AND GHENT GENERATING STATIONS	**)**	

REBUTTAL TESTIMONY OF
JOHN E. FEDDOCK
SENIOR PRINCIPAL
CARDNO, INC.

Filed: September 10, 2015

Q. Please state your name, position, and business address.

A. My Name is John E. Feddock. I am a Senior Principal and Vice President of Cardno, Inc. (*Cardno*) in the Engineering and Environmental Services Division, and practice in the Mining Group.

Q. Mr. Feddock, what are your responsibilities as a Senior Principal with Cardno, Inc.?

A. I serve as the principal investigator in mineral economic and mining geotechnical projects in coal and stone and in a variety of other minerals. My underground mine projects include mine planning and entry layout, ventilation design, subsidence prediction and control, productivity analysis and prediction, equipment applications, roof support analysis, and pillar sizing. At surface mines, I provide surface mine planning, blasting damage control, groundwater and hydrologic impacts, environmental site assessments, productivity analysis and prediction, and highwall stability analysis. I coordinate mineral economics projects including operating cost forecasting and analysis, mine feasibility studies and company valuations. I have provided expert witness testimony in both State and Federal courts. In addition, I serve as manager of Cardno's Lexington, KY, office. My resume is attached as Appendix A.

Q. Have you been retained by Kentucky Utilities Company and Louisville Gas and Electric Company (collectively "the Companies") as an expert witness in this matter?

A. Yes.

Q. Have you previously testified before this Commission?

A. No, I have not.

Q. What is the purpose of your testimony and how is it organized?

A. I have been asked to provide rebuttal testimony to the statements and assertions made by Sterling Ventures, LLC (*Sterling*) in its claim to the Commission in the referenced matter, and to the testimony of Steven J. Gardner, a mining expert retained by Sterling. I will discuss those mining and material handling facts that refute many of the statements and assertions made by Sterling and Gardner in the claims of beneficial use of coal combustion residuals (*CCR*) underground at Sterling's underground mine (**Mine Safety and Health Administration (*MSHA*)** ID. No. 1518068), in the claims of adequate volume available for underground disposal of CCR, and in the claims of no environmental impacts of underground CCR disposal. I will also testify regarding operational factors that have not been addressed by Sterling but have technical and economic impacts which indicate Sterling's plans are not a reasonable alternative to the surface disposal plans developed by the Companies.

Q. What are your qualifications to testify on these matters and subjects?

A. Since 1988, I have provided mining engineering, mineral economics and geotechnical consulting services to the mining, energy and financial industries. Since joining Cardno, I have continued these services, and, with an expanded staff, have directed and completed numerous evaluations, both technical and financial, of mines, processing facilities and mining companies. To date, I have performed, coordinated, or directed, numerous evaluations of surface and underground mining operations in both coal, stone, and hard rock mineral deposits. Such evaluations have included representing mine operators, property owners, insurance companies, banks and other financial institutions. Evaluations include start-up verification, capacity determination, reserve assessment, mine planning, cost estimation, sales contract suitability, and valuations of mineral, plants, property, equipment, and corporations.

Q. What is your professional work experience with respect to underground limestone mining operations?

A. I have been involved in stone operations my entire consulting career, from designing safety benches and defining scaling procedures at a 300-foot highwall at a Kentucky quarry so the quarry could resume production, to determining the Fair Market Value of the mineral, property, plant, and equipment of a seven million ton-per-year quarry for the **U.S. Army Corps of Engineers** regarding the municipal water authority of Chicago, Illinois. I provide technical support and expert witness services to stone producers and other companies regarding production and blasting issues at underground quarries producing in excess of 1.5 million tons per year. I have designed and reviewed designs of shaft and slope access from the surface to underground strata containing high calcium content limestone for several operators in Kentucky including Nugent Sand and Gravel, Carmeuse Stone, and Hilltop Basic Resources, Inc.

Q. Have you formulated opinions on the subjects you mentioned above?

A. Yes, I have.

Q. Please describe the documents in Appendix B.

A. Appendix B consists of documents I have reviewed or prepared in forming my opinions. Appendix B consists of: documents of record in this case that I reviewed, a storage capacity calculation Excel file, Feddock Exhibits 1 through 4, and references reviewed.

Q. Are you sponsoring any exhibits?

A. Yes I have prepared four exhibits in Appendix B to support my opinions.

Exhibit 1 is the Sterling Venture Mine Map of Level 1 showing restricted entries.

Exhibit 2 is the Sterling Venture Mine Map of Level 2 showing restricted entries.

Exhibit 3 is the Sterling Venture Mine Map of Level 3 showing restricted entries.

Exhibit 4 is a surface photograph of the quarry site superimposed with the mine outlines of Levels 1, 2 and 3.

Q. Have you visited Sterling's facility and underground mine in Gallatin County, Kentucky in forming your opinions?

A. No, I did not have an opportunity to visit the underground mine, but I did not feel it was necessary given the access to mine maps for the past several years of operations, the documents developed and submitted by Sterling is support of their claims, and based upon my knowledge of and experience with underground stone operations.

BENEFICIAL USE OF CCR

Q. Sterling claims that storage or disposal of all CCR generated by the Trimble County Generating Station within its limestone mine will provide functional ventilation benefits. Please describe the need for underground mine ventilation and how it is accomplished underground.

A. The primary purpose of ventilation in underground stone mines is the circulation of fresh air, the removal of diesel particulate matter and engine exhaust, and the removal of blasting dusts and gases. To circulate air in a deep underground mine, and Sterling's mine would be considered a deep mine at more than 350 feet below the surface, vertical circular shafts are excavated from the surface to the limestone bed and a large diameter fan or fans are erected over one of the shafts exhausting air from the mine. Fresh air enters through one shaft and exhausted out the other, creating circulation underground.

Underground stone mines use a room and pillar system, where rectangular tunnels (entries) are excavated through blasting at right angles to one another leaving a rectangular pillar to support the overlying strata. Fresh air circulates from the fresh air intake shaft around the pillars until it reaches the exhaust shaft carrying the diesel exhaust, dust, and blasting gases out of the mine. Most underground stone mines, including Sterling's mine, use open ventilation, where portable fans circulate the air to different areas of the mine. Another rarely used method is to erect walls (stoppings) between the pillars that direct the circulating air to a specific entry where it can flow to the production areas. Stoppings are typically not used by underground stone mines due to the cost of erection and stability in large openings. For example, Sterling's openings are approximately 40 feet wide and 25 to 30 feet high. Sterling has repeatedly stated in its submittal documents[1] that is does not use stoppings. When asked to "identify and describe by type all existing ventilation stoppings…" Gardner responds "the ventilation stoppings are shown on the mine maps"[2]. This

[1] See Sterling's Maps from 2011 to the present, and Sterling's Response to LGE-KU DR No. 8, July 16, 2015.
[2] Sterling's response to Supplemental Data Request of LGE-KU, Question No. 6.

represents one of the many inconsistencies in Sterling's ventilation descriptions. The Sterling mine maps depict an open ventilation system as shown by the directional air flow arrows in different portions of the mine.

Q. How does Sterling bring fresh air into its mine and remove gases from its mine?

A. Sterling's mine ventilation plan is complex and varies between the three levels developed in the mine. Sterling constructed one vertical air shaft and two inclined shafts (slopes) to bring fresh air into Level 1 of the mine, and constructed two vertical shafts from Level 1 to the surface with large diameter fans to exhaust the dust and gas laden air to the atmosphere. Air is circulated down to Level 2 from Level 1 through eleven (11) small shafts with fans between the two levels. Air is circulated down to Level 3 from Level 2 through two slopes, one being the truck roadway which circulates air into Level 3, and the second slope is connected to ventilation tubing which removes dust and gas laden air with fans to Level 2. If the description seems confusing it is because the system is complex and relies upon circulation from Level 1 to Level 2 to Level 3 before it is pushed back to Level 1 where it can be exhausted to the surface atmosphere. The reliance of each lower level upon the one above creates an interdependence that is unusual in multilevel mines.

Q. What are your opinions regarding Sterling's claims that storage or disposal of all CCR generated by the Trimble County Generating Station within its limestone mine will provide functional ventilation benefits to the limestone mining operation and what are the grounds for your opinions?

A. I find that placement of CCR in Sterling's underground mine provides no functional ventilation benefits to the limestone mining operation. As shown on Sterling's mine maps, air circulates across broad areas so as to ventilate the entire perimeter for future production. Sterling excavates its entries around the entire perimeter of the mined areas on all three levels and uses the central portions of the mine to circulate air to each quadrant of its perimeter. The central entries also provide roadways for stone haulage and for infrastructure (crushing stations, conveyor entries, ramps to lower levels, maintenance areas, and storage of supplies). The only remaining space on each level for CCR placement is the unused entries between the production perimeter and the central entries used for haulage, infrastructure, and ventilation. Therefore, filling of the remaining space with CCR does not replace existing ventilation controls or stoppings. Based upon my review of the mine maps, the placement of CCR in the available areas for CCR disposal under the current mine plan would further complicate an already complex ventilation system. Finally, I opine that the claim that placement of CCR will reduce electrical consumption by fans is doubtful and un-documented. The placement of CCR underground in such large quantities in all available space is of no beneficial use, and therefore is a simple plan for large scale disposal of CCR.

Q. Would there be a net decrease in energy needs for the mine under Sterling's CCR disposal plan?

A. The claim that the placement of CCR will reduce electrical consumption by fans is dubious and unsubstantiated for several reasons. First, Sterling notes that "analyses have not been performed to quantify the reduction in ventilation needs." Second, the following factors undermine any such claim of energy benefits. Placing CCR to force air streams into only one or two entries will likely increase ventilation pressure as airways are restricted, and would require more energy to circulate air. The placement of CCR underground will require more air, as newly dedicated diesel equipment to place the CCR will increase the amount of diesel exhaust and diesel particulate matter in the air requiring more circulation. The placement of CCR underground will generate fugitive CCR dust during hauling, dumping, dozing and compacting CCR, and require an increase in air circulation to reduce the dust and fumes exposure to personnel. Placement of CCR within all central areas of each level of the mine would hamper production by largely restricting air and truck movement to the perimeter entries, by increasing truck haulage distances and the volume of air required for ventilation. Lastly, these issues are exacerbated as the production faces advance away from the main intakes and the exhaust shaft locations. This causes longer distances for air to travel and requires increased volumes of ventilation air. In addition to the increase in ventilation energy, the overall consumption of energy will significantly increase on a net basis due to equipment added for the transport and the placement of CCR underground.

Q. In order to direct intake and return ventilation by filling entries with CCR as proposed by Sterling, would it be necessary to fill all mine voids in abandoned areas?

A. The filling of all mine voids in the available areas would not be necessary to restrict circulating air to certain entries. Only the space between pillars in a line would have to be filled to assure directed movement of air in an entry. Filling the spaces between the pillars in a line would replace stoppings, but as noted previously, Sterling has repeatedly stated it does not use stoppings. The open void behind the line of pillars would not have to be filled as those areas would be effectively isolated.

Q. Do you have an opinion as to whether CCR disposal in all available voids is a comparable substitute for construction of ventilation stoppings in the underground mine?

A. If Sterling were to construct stoppings to control ventilation, there would be a single line of stoppings around the perimeter and there would be no need to fill all of the abandoned void space. Filling all available voids behind the line of pillars would be an excessive use of CCR.

Q. How would CCR disposal in the mine affect air quality in the mine?

A. Given the current ventilation plan, the placing of CCR underground would adversely affect air quality in the mine and increase the level of pollutants discharged from the mine.

Q. What are the sources of these increased pollutants that would be in the ventilation air?

A. The addition of trucks, track dozers, and compacting equipment to handle the CCR underground will definitely increase the levels of diesel particulate matter and engine exhaust in the air stream. Placing CCR underground through dumping, placing, and compacting will produce fugitive dust, which if not controlled by a separate return or air entry to exhaust, would circulate into the active working areas creating a potential health risk in the confined spaces underground. Sterling's opinion that "CCR is a fine particulate similar in nature to other materials handled in and around the

…operation"[3] reflects two major misunderstandings regarding CCR. First, dust generated in Sterling's operations would be mostly at point sources such as drilling, and crushing the stone, where water sprays can control the fugitive dust. CCR carried in trucks and dumped on the ground and then pushed with track dozers are open sources without water sprays to control. Second, CCR material is predominantly fine material (the particle size of fly ash is almost always less than 45 microns in diameter). This high percentage of minute particles makes fugitive dust plentiful each time it is moved and therefore difficult to control.

Q. Would all these additional pollutants ultimately be emitted to the atmosphere?

A. The increased level of pollutants in the underground mine space would pass from Level 3 to Level 2, from Level 2 to Level 1, and from Level 1 through two exhaust shafts which vent the mine air directly into the atmosphere.

Q. In your opinion, would a stone mine operator agree to dispose of such large quantities of CCR in their underground mine, if they did not receive a large tipping fee in return?

A. No. Considering the increased costs and complications involved in placing CCR underground, a stone operator would only agree to do so if there was a profit potential.

Q. Do you have an opinion as to whether placement of CCR in the Sterling mine would be a future resource upon the cessation of stone mining operations as

[3] Sterling's response to Commission Staff's Second Data Request, Question No. 8.

stated on page 3, line 13-18 of J. Steven Gardner's August 6, 2015 pre-filed direct testimony?

A. There are several issues that make this claim unreasonable. The CCR contemplated for delivery from Trimble will be a random comingling of fly ash, gypsum scrubber waste, and bottom ash. Separating the fly ash or the gypsum would be difficult. Second, the cost of conducting a recovery operation underground would be more expensive than recovering such products from surface disposal areas, of which most if not all operating power plants will have such disposal areas available, should waste CCR become a viable reclamation product. Lastly, there is already an excess supply of fly ash and gypsum such that a market for secondary recovery is doubtful.

Q. Do you have an opinion as to whether placement of CCR in Sterling's mine will provide additional long-term roof support within the mined out areas as stated by J. Steven Gardner on page 4, lines 8 and 9 of his testimony?

A. The assertion that CCR will provide additional support to the roof is considered not physically possible as confirmed by Sterling when it states that "it is fully anticipated that the [CCR] material cannot be filled to the full height of the void"[4]. Further, Sterling admits the gap at the roof could be several feet, a fact, that as discussed later, also undercuts their claim of a 90 percent fill factor. Those familiar with CCR know that it cannot be placed in the mine void and against the roof with sufficient compaction so as to provide positive resistance against roof rock movement. Although Sterling asserts that it is developing a procedure to do just that, it is clear that the placement and compaction involved with CCR disposal have not been

[4] Sterling's response to Supplemental Data Request of LGE-KU, Question No. 3b.

planned or considered by Sterling in an organized approach using engineering methods. In summary, without sufficient mechanical compaction, the CCR will settle, and therefore provide no vertical support to the roof. In addition, there is no evidence that additional roof support is necessary in Sterling's mine.

Q. Would CCR disposal at Sterling's mine allow Sterling to recover more limestone as implied on page 5, lines 6-8 of J. Steven Gardner's August 6, 2015 pre-filed direct testimony?

A. The assertion that CCR disposal placed underground will allow Sterling to recover more limestone relies upon the ability of the CCR to provide roof support in the mined entries. As discussed previously, the CCR cannot provide roof support, and therefore the assumption that more stone can be recovered is baseless.

<u>ENVIRONMENTAL IMPACTS</u>

Q. Did you review J. Steven Gardner's August 6, 2015 pre-filed direct testimony regarding the environmental impacts of the Sterling plan for disposal of CCR?

A. Yes, I did.

Q. Do you agree with Mr. Gardner's opinions that there would be no groundwater impacts associated with placement of the CCR in the mine over the life of the operation due to the presence of a bentonite layer strata above the mine?

A. In underground quarries that I have visited which operate beneath a consistent bentonite layer, there has been little evidence of groundwater seepage into the underground voids. However, Sterling has not demonstrated that the bentonite layer is of uniform occurrence across the extent of its mineral control to support a 37-year mine life that is proposed for CCR disposal. Prudent engineering requires verification that assumption of a continuous bentonite layer of adequate composition be verified for the proposed 37 year need for CCR disposal.

Q. Do you have an opinion on whether disposal of CCR in the mine as proposed by Sterling would have additional impacts on air emissions from the mine?

A. Fugitive fly ash and gypsum dusts and higher levels of diesel exhaust and particulate matter would be exhausted from the underground mine based upon current practices. If CCR were to be placed within the Sterling Ventures underground quarry under the current ventilation system, fugitive fly ash and gypsum dusts will be circulated into the normal fresh air current in the confined space underground. Depending upon the disposal location and the lack of existing ventilation controls underground, these dusts would be exhausted from the underground mine through the fan shafts. In addition, the placement of CCR underground will involve additional diesel equipment operating underground which will also be exhausted through the fan shafts.

STORAGE VOLUME

Q. Do you have an opinion as to whether Sterling's mine currently has net available storage volume for CCR disposal that exceeds 8 million cubic yards as stated on page 10 of J. Steven Gardner's August 6, 2015 pre-filed direct testimony?

A. The allegation that there is 8 million cubic yards is a gross exaggeration of the available volume for CCR disposal due to operational, ventilation, and infrastructure requirements.

Q. What is the basis for that opinion?

A. The underground mining operations are not conducted in an orderly plan but in a rather arbitrary perimeter fashion. Limestone is planned to be mined around the entire perimeter of the existing excavations on each level. This 'perimeter' mining requires open access be maintained around the entire perimeter on each level. Open and unrestricted entries must be maintained to provide access to unmined stone reserves and ventilation during drilling, blasting and loading activities during production. The current ventilation plan uses an exhausting system where fresh air is drawn from the surface to Level 1 through the two slopes and a separate intake shaft. Eleven (11) small diameter boreholes, some with fans, are used to circulate that air from Level 1 to Level 2. Air is circulated from Level 2 through one slope entry to Level 3, and return air laden with dust and other pollutants is exhausted from Level 3 back to Level 2 through a second slope. Two additional slopes between Levels 2 and 3 appears to be under construction. The large horsepower fans exhaust the return air from Level 1 to the surface. Operations on multiple levels require an abnormally high number of entries that must be left open to provide adequate volume on each level. In addition, there are certain entries that must be left available for haulage of stone, and infrastructure which includes crushing stations, conveyor haulage, explosives storage, maintenance of equipment, and other underground support functions. These requirements for open entries are not evaluated by Sterling in any detail for current or future mining areas.

Q. How do you determine how much volume is available at the underground mine?

A. Available volume is defined as those entries that are not committed by Sterling to the production operations, ventilation, or infrastructure functions. Using the Sterling mine maps provided during disclosure, the entries required for production operations, for ventilation, and for infrastructure were outlined. For operations, at least two open entries around the perimeter of the underground mine must remain open for equipment access, ventilation, and safe ingress and egress of mine personnel. Entries committed for ventilation include entries where the small borehole fan and intake shafts between Level 1 and Level 2 exist. There are 11 separate locations where these small diameter shafts exist and require the commitment of a large number of entries. In addition, certain entries are maintained as roadways for truck haulage underground, as well as areas required for storage of explosives and diesel fuel. The area left after excluding the operational, ventilation and infrastructure commitments would be available for CCR disposal.

Q. How much available volume is there at the Sterling Ventures underground mine?

A. I estimate that as of June of 2015 there was approximately 1.65 million cubic yards of uncommitted available mine space on all three mine levels for CCR disposal. The quantities on each level were calculated based upon the areas on each level available for storage after excluding those areas required for operations, ventilation, and infrastructure. This volume would be available if the CCR placed underground could be compacted to the same density that is possible in the proposed landfill. The remaining available space for CCR storage is shown in yellow highlight in Exhibits 1, 2, and 3.

	Headers Mined Volume (cu yds.)	Floor Bench Volume (cu yds.)	Total Available Storage Capacity (cu yds.)
Level 1	909,000	436,700	1,345,700
Level 2	78,800	62,100	140,900
Level 3	102,400	63,600	166,000
Total	***1,090,200***	***562,400***	***1,652,600***

Q. Do you agree that 90% of the available mine space can currently be used for CCR storage and 90% of voids could be used in the future as stated in Sterling's response to Item No. 21 of the Companies' First Set of Data Requests and as referenced at page 11 of J. Steven Gardner's August 6, 2015 pre-filed direct testimony?

A. No, the assumption by Sterling Ventures of 90 percent is arbitrary for numerous reasons. There is no allowance for entries required for ventilation, haulage and infrastructure, and there is no demonstrable plan to access the high quality limestone surrounding the perimeter of the excavations on each level. Based upon my calculations, there is no way Sterling can routinely provide 90 percent of excavated space for CCR disposal.

Q. Are there other factors that limit how much CCR can be placed into the available disposal space?

A. It is not possible to utilize all of the available space for CCR disposal because the CCR cannot be compacted into the underground mine space, the physical properties of CCR require special handling for compaction, and the limitations of material handling equipment operating in a confined space. These factors limit Sterling's ability to fill the voids that are available for disposal of CCR underground to less than 80 percent of that available volume for CCR Storage.

Q. What is the impact of the compaction?

A. The cubic yards of material discussed in all of the technical reports for the Trimble and Ghent Stations are reported as compacted yards, which requires mechanical compaction. The CCR material delivered to Sterling's mine will be loose or uncompacted yards. The volume of uncompacted yards is estimated to approximately 20 percent greater than the volumes of compacted yards. Therefore, the trucking volumes to be handled by Sterling are much greater than are currently estimated, and the volumes underground cannot be fully utilized unless the CCR is compacted.

Q. What is the impact of the physical properties of CCR on placement underground?

A. Fly ash has a very low angle of repose which is the angle of the sides of a conical pile. While gypsum and bottom ash have an angle of repose of 45 degrees, fly ash has a much lower angle of repose, between 5 and 10 degrees. Consequently, it is very difficult to stack fly ash unless it is conditioned and compacted. The result requires more area to place CCR up to the height of the mine entry.

Q. What is the impact of the limitations of equipment used underground to place CCR?

A. Due to the height and size of the equipment required to place and compact the CCR underground, it is difficult to place compacted CCR within 10 or 12 feet of the roof. Therefore, in a mine entry 30 feet high, only 18-20 feet of compacted CCR could be placed. Any CCR placed on top of the previously compacted material would not be compacted to the same degree and therefore, the volume near the roof cannot be filled completely. In addition, Sterling confirmed that "it is fully anticipated that the [CCR] material cannot be filled to the full height of the void. There could be a gap of several feet depending on the mining height at a particular location in the mine"[5]. If Sterling knows that it cannot fill the void to within several feet of the roof, the gap alone could represent 10 percent or more loss of volume.

Q. Do you have an opinion as to whether Sterling's mine would provide sufficient storage volume for the CCR generated at Trimble Station?

A. Sterling Ventures does not have available storage volume anywhere close to the 8 million cubic yards reported by Sterling. A reasonable calculation at the current time is only 1.65 million cubic yards of available space for CCR disposal. Compaction of CCR limits the full utilization of these available cubic yards. Further, the future production by Sterling Ventures is estimated to be 1.25 million tons per year which is equivalent to approximately 600,000 cubic yards (cu yds.) of total additional volume each year.

Due to a random mine production plan on Levels 2 and 3 for the last several years, it is unrealistic to assume that Sterling can make available 90 percent of the annual volume for CCR disposal. The area needs for production, ventilation, and infrastructure could be at least 25 percent or more of annual volume of 600,000 cu yds. Therefore, available annual volumes could vary between zero and 480,000 cu yds. per year.

In addition, it has been demonstrated that the placement of compacted cubic yards underground is not addressed by Sterling and the physical limitations of placement limit the actual CCR placement volume to below that needed for

[5] Sterling's response to Supplemental Data Request of LGE-KU, Question No. 3b.

operations. Sterling alleges that it cannot finalize mine drawings showing the placement of CCR pending further conversations with LGE/KU on the timing and exact volumes of CCR to be placed in the mine[6]. This statement is inconsistent with the Complaint and the tables provided by Sterling in Item No. 21 of the Companies' First Set of Data Requests and as referenced at page 11 of J. Steven Gardner's August 6, 2015 pre-filed direct testimony. My exhibits demonstrate how maximum available disposal areas can be delineated for existing and future mining areas. I conclude that Sterling's assumption of 90 percent is exaggerated and unreliable. Sterling's plan for CCR disposal is not developed in a way that provides a guaranteed estimate of space available annually, or for the next 37 years.

PRODUCTION

Q. Do you know whether Sterling has adequate, high quality limestone reserves for the next 37 years at its assumed production rate?

A. Sterling appears to have sufficient property ownership at the current time to contain a 37-year supply of high calcium content limestone for calcined lime production. However, Sterling has not documented in a reserve or market report that it has measured reserves for 37 years.

Q. Do you find Sterling's refusal to provide reserve or market reports as being commercially reasonable?

A. Not providing reports is unreasonable when the ability to provide excavated volume for CCR disposal is contingent upon Sterling's contention that a market will exist to sell a product on a consistent basis for 37 years. It is similar to a contract to supply

[6] Sterling's Response to Supplemental Data Request of LGE-KU, Question No. 5.

coal where the supplier has to demonstrate that it has sufficient reserves to produce coal for the life of the contract. Moreover, the assumption of a 1 percent increase in sales annually for 37 years is also unsupported and speculative as Sterling has not demonstrated or documented that it will even have a market to sell the 1.2 million annual tons it forecasts.

Q. Do you have an opinion as to whether Sterling can successfully implement the material handling plan to dispose of CCR in its mine as proposed in their data request responses and in Mr. Gardner's pre-filed direct testimony at pp. 15-17?

A. There are sufficient physical and practical impediments to the three methods discussed by Gardner as to raise serious concerns that the plans are hypothetical at best.

Q. Do you have any technical concerns with the proposal to dump CCR to Level 1 of the mine through a shaft as proposed by Sterling in its Method 1 proposal?

A. Method 1 is described as dumping CCR through a shaft from the surface to the mine void on Level 1 and then trucking the CCR material from the bottom of the shaft to the available space underground. Sterling has not identified a possible shaft location under the current mined extent of Level 1. In *Exhibit 4* the mine workings are superimposed on a satellite photograph (Google Earth) of the surface facilities. When viewed that way, the available areas for a shaft would have to be in places already devoted to underground production, ventilation, and infrastructure, or to surface processing facilities. In addition, the shaft would be 350 feet to 500 feet deep to reach Level 1, the cost of which would be several million dollars, not including the material handling equipment. Dumping the CCR down a shaft requires definitive engineering to account for impact at the bottom, storage within the shaft, compaction when the material falls upon itself, and clogging of the shaft. At this juncture, Sterling theorizes the diameter of the shaft required[7], further indicating that Sterling's plans are not developed to where any reliable costs can be estimated. Every time you handle CCR, the material creates fugitive dust and in a shaft 350 to 500 feet deep, the dusting could be blinding. Underground trucking of the CCR to the available disposal areas is also a problem addressed as part of Method 2.

Q. Do you have any technical concerns with the proposal to dump CCR on the surface and haul the material using articulated trucks as proposed by Sterling in its Method 2 proposal?

A. Method 2 is described as transferring the material on the surface from over-the-road trucks to articulated trucks that would haul the CCR material underground through the existing slope and underground roadways. Referring again to *Exhibit 4*, there is only a single roadway from the surface into the box cut and thence down the existing 23 percent slope. Although this might appear to be a simple task to a layman, there would have to be an ability to unload, store, and reload even temporary amounts of CCR on the surface. This is further complicated by the probable shipping of four types of CCR-- fly ash alone, bottom ash alone, gypsum alone, or a combination of any of the above. In addition, environmental runoff controls would be required.

The material hauled underground would be loose uncompacted yards so the current number of trucks calculated by Mr. Gardner on page 13 of his Testimony would be increased by as much as 20 percent to handle loose cubic yards of CCR. This additional truck traffic could interfere with existing limestone haulage and require

[7] Sterling's response to Supplemental Data Request of LGE-KU, Question No. 12.

additional infrastructure (maintenance and fuel storage space) to accommodate the increased truck fleet. The potential conflict of loaded limestone trucks hauling opposite CCR trucks into areas where both production and CCR disposal is ongoing is not planned or considered. Lastly, the majority of production would probably occur on Level 3, the lowest level in the Sterling Ventures mine, where the thickest bed of high calcium quality limestone exists. In the future, additional trucks will be required to address the longer haul down steep slopes to the lowest level. There are also valid safety concerns in hauling the material underground down a 23 percent slope as confirmed by past accidents and a fatality.

Q. Do you have an opinion as to the viability of Method 3 as described on page 15 of J. Steven Gardner's pre-filed testimony under which CCR material would be hauled underground on a new 10% slope with the over-the-road trucks?

A. Method 3 is described as hauling the material underground using over the-road trucks on a new 10 percent slope. As the majority of production may occur on Level 3, CCR disposal would involve construction of an approximately 7,500-foot long slope which is one and one half miles to access Level 3. The length and cost of such a slope entry that would be large enough to accommodate only certain on-road trucks, would require extensive financing for this hypothetical Method 3, which Sterling neither presents nor discusses. This Method 3 is a multi-million dollar proposal that without documentation cannot be considered a viable alternative.

Q. Do you have any other concerns or opinions with respect to the technical feasibility of Sterling's proposal for disposal of CCR underground?

A. Sterling's proposals to dispose CCR underground have multiple technical limitations (available volume, ventilation, haulage, mine plan, and CCR handling methods), which ignore the complications involved in handling CCR. The proposals also lack a systematic mine plan that is both adaptable to limestone production and waste disposal, and fail to demonstrate that Sterling has sufficient high calcium limestone reserves and the ability to produce and market that limestone 37 years into the future.

Q. What is your overall expert opinion regarding the viability of Sterling's proposal to dispose of up to 33.4 million cu yds. of CCR in the mine over the next 37 years?

A. Sterling has not presented a viable plan that substantiates its ability to dispose of up to 33.4 million cu yds. of CCR in the underground mine over the next 37 years. The technical limitations are ignored by Sterling and consequently, only hypothetical methods for disposal are postulated under unsubstantiated assumptions related to available storage volume, ventilation improvements, reserve, and market forecasts. Therefore, Sterling's alternative for underground disposal of CCR is an unreliable and speculative alternative to the Companies.

Q. Does this conclude your testimony?

A. Yes.

VERIFICATION

COMMONWEALTH OF KENTUCKY)
) **SS:**
COUNTY OF Jefferson)

The undersigned, **John E. Feddock**, being duly sworn, deposes and says he is Senior Principal of Cardno, Inc., and that he has personal knowledge of the matters set forth in the foregoing rebuttal testimony, and the answers contained therein are true and correct to the best of his information, knowledge and belief.

John E. Feddock
JOHN E. FEDDOCK

Subscribed and sworn to before me, a Notary Public in and before said County and State, this 9th day of September, 2015.

(SEAL)

Judy Schooler
Notary Public

My Commission Expires:
JUDY SCHOOLER
Notary Public, State at Large, KY
My commission expires July 11, 2018
Notary ID # 512743

John E Feddock

Current Position

Senior Principal, Practice Leader - Engineering

Profession

Mining Engineer

Years' Experience

40+

Joined Cardno

1996

Education

MS - Mining Engineering (Mineral Economics, Rock Mechanics), Columbia University, Henry Krumb School of Mines, New York, New York

Professional Registrations

PE - IL, KY, OH, PE, UT, VA, WV

Land Surveyor - WV

SME - Founding Registered Member, Competent Person for Mineral Reporting

MSHA Certified Trainer

MSHA 8 Hour Annual Refresher

Affiliations

SME
KY P E's in Mining
NSPE

www.cardno.com

Summary of Experience

Mr. Feddock serves as the principal investigator in mineral economic and mining geotechnical projects to meet standards as developed by the U.S. Securities and Exchange Commission (SEC), the Canadian National Instrument (NI) 43-101, and the Australian Joint Ore Reserves Committee (JORC) code. Previously, he served as Vice President/Manager of Engineering for two major coal companies. In addition, he serves as an expert witness and manages all administrative aspects of the Lexington, KY, office.

Significant Projects

> Served as consultant for projects at surface and underground mines for both the coal and stone industries *(underground mine projects included mine planning and entry layout, longwall applications, subsidence prediction and control, productivity analysis and prediction, continuous miner and longwall equipment applications, roof support analysis, and coal pillar sizing)*
> Served as principal design engineer of the Minova USA, Inc. (Minova), 120 psi and 50 psi ventilation seals
> Provided designs for surface mine planning, mountaintop removal, blasting damage control, groundwater and hydrologic impacts, environmental site assessments, productivity analysis and prediction, and highwall stability analysis
> Coordinated mineral economics projects that included discounted cash flow and rate of return analysis; equipment and facility investment requirements; the valuation of property, plant, equipment, and reserves; mine operating cost forecasting and analysis; mine feasibility studies and company valuations
> Provided expert witness testimony, attorney technical support, insurance claim analysis for cases that involved: longwall mining, blasting, subsidence, groundwater impacts, lost coal claims, personal injury, production capability, sales contracting, and other mining engineering issues in both State and Federal courts

Specific Projects

> **Overseas Assignments**: Australia, Chile, China, Colombia, United Kingdom
> **Valuation of Reserves, Mines and/or Facilities:** Colorado, Indiana, Illinois, Kentucky, Utah, Virginia, and West Virginia in the U.S.A., and Chile and China
> **Design of Plug-Type Mine Seals** in compliance with 30CFR§75.335 (Federal regulation for mine seals)
> **Evaluation of Business Interruption Claim** at open pit copper mines
> **Regional Search for Coal Seams** containing specific trace elements
> **Longwall Equipment Entrapment**, damage, assessment and performance
> **Reclamation Liability** (Asset Retirement Obligation) **Assessment**

Professional History

2001 – Present

Senior Principal
Practice Leader – Engineering,
Cardno, Inc., Lexington, Kentucky

Senior Vice President
Cardno MM&A, formerly Marshall Miller & Associates, Inc., Lexington, Kentucky

1998 - 2001
1996 – 1998

Senior Vice President
Vice President - Mining and Minerals
Marshall Miller & Associates, Bluefield, Virginia

Senior Mining Engineer

Consultant specializing in mineral due-diligence, management of mineral companies including bankruptcy, financial analysis, valuation, mine design, expert witness testimony, attorney technical support, equipment application and insurance claim analysis. Responsible for direction, coordination, scheduling, and review of engineering projects investigated by staff engineers and consultants in the mineral and construction industries. Principal Engineer responsible for due-diligence reviews of both underground and surface mines and mining related facilities, business valuations, financial analysis of mining operations, and Balance Sheet valuation of reserves, mining property, plants and equipment. Primary Consultant providing expert witness testimony, attorney technical support, and insurance claim analysis, specific cases involve: longwall mining, blasting, subsidence, groundwater impacts, lost coal claims, personal injury, production capability, coal contracting, and other mining engineering issues. Experience spans coal mining, quarry operations, tunnel and shaft construction, property management, geo-technical and rock mechanics studies and environmental assessments.

1989 – 1996

Vice President – Mining
L.A. Gates Company, Beckley, West Virginia

Provided mining engineering and technical support to various mining and civil clients. Supervised and managed projects in mine planning, longwall applications, subsidence control, blasting damage, operations analysis, and equipment operation. Involved in over 80 cases where background, experience, and knowledge had been used to evaluate mining impacts on property, equipment, and safety. Prepared background reports, assisted in depositions, been deposed, and testified as an expert. Prepared affidavits and declarations on behalf of clients and provided expert technical support.

1988-1989

President
Feddock Engineering Company, Lexington, Kentucky

Provided mining engineering and expert technical support to mining events on reserve acquisition and operations analysis. The firm was dedicated to implementing Quality in mining engineering, production, and management.

1986-1989

Vice President - Engineering, Geology and Properties
Island Creek Corporation, Lexington, Kentucky

Supervised property and coal reserve evaluations, disposals, and acquisitions. Settled several trespass issues including two that were in arbitration. Approved contract operators selected for deep and surface mining, and participated as primary corporate officer in three major divestitures of coal reserves and plant facilities. Supervised negotiations with major coal property holding companies in Virginia, West Virginia, and Kentucky.

Directed the economic justification, planning, contracting, and completion of over $50 million per year of construction and equipment expenditures. Construction projects included several shafts, buildings, silos, material handling, and preparation plant facilities.

Supervised the development of a longwall subsidence monitoring program including vibration monitoring, settlement prediction and damage assessment and reparation administration. Directed a longwall performance evaluation of six company mines and coordinated a long term comprehensive program of longwall system replacement and equipment rebuild.

Coordinated a comprehensive coal quality forecasting program incorporating statistical process control of mine production with company laboratory operation.

1982-1986

Chief Engineer
Rochester & Pittsburgh Coal Company, Indiana, Pennsylvania

Directed all engineering services, including geology and private property damage assessment, at all divisions and corporate headquarters for this major coal company which produced in excess of 9 million TPY. Managed the engineering department with 110 persons and an annual budget in excess of $5 million.

Developed surface mine engineering and environmental departments within the company to give timely response to re-permitting and environmental compliance under Pennsylvania's Primacy of the Surface Mine Control and Reclamation Act of 1977 (SMCRA). As a member of the Environmental Committee of the Keystone Coal Association and the AMC Subsidence Workgroup, participated in public forums and testimony regarding the impact of various Federal and State legislation upon the mining industry.

1979 – 1982

Fuel Supply Manager
Keystone Conemaugh Project, Indiana, Pennsylvania

Administered coal supply agreements with a value of U.S. $240 million between utility owners and captive coal suppliers. As a member of a four-person administrative team, acted as liaison between a consortium of ten utilities and the operation of two 1800 MW coal-fired generating stations which burn an aggregate eight million TPY. Reviewed and approved annual capital and expense budgets and mining plans of captive suppliers' underground mines. Coordinated consultant inspections, evaluations, and reports.

Instituted and coordinated the development of a linear, stochastic program computer model to select the most economical coal supplies for a generating station over a 35-year period. The model incorporated alternative sources of supply (short, intermediate, and long term), coal price forecasts, market constraints, station operating parameters and material handling constraints. A detailed report on the coal supply strategy was accepted and, based on the technical and economic evaluations: several long term agreements were renegotiated.

1976 – 1979

Senior Mining Engineer
GPU Service Corporation, Reading, Pennsylvania

Supervised utility-funded coal exploration programs and technical evaluations of coal mines, dedicated reserves, and coal supply and utilization problems for three wholly owned electric utilities, which burned 16 million TPY. Provided technical expertise and developed numerous interactive language computer programs to evaluate coal preparation schemes, coal mining problems, coal sampling and environmental regulations. A coal cleaning versus flue gas desulfurization (FGD) strategy was developed.

Chaired an inter-utility Task Force to select and develop coal supplies for an innovative technology cleaning plant as an alternative to scrubbing. Evaluated the reliability of supply and coal preparation characteristics of several coal producers to generate a purchasing philosophy for a multi-unit, jointly owned 1850 MW generating station complex which burned five million TPY.

1973 – 1976

Maintenance Superintendent and Project Engineer
Morton Salt Company, Painesville, Ohio

Supervised a 60-person Maintenance Department for a 1.15 million TPY rock salt mining and milling operation. Instituted preventive maintenance programs and a satellite maintenance area. As Project Engineer, responsible for design, acquisition, installation and economic justification of modifications and additions to the plant and mine facility.

1972-1973

Mine Engineer
Bethlehem Mines Corporation, Ebensburg, Pennsylvania

Performed the duties of a Mine Engineer at the Revloc, No. 32 Mine and at the Division Office where responsibilities concentrated on the economic and financial analysis of mining projects. Prepared a simulation model of mine ventilation and removed a ventilation shaft from service.

1971 – 1972

Research Assistant
Krumb School of Mines, Columbia University, New York, New York

Participated in Rock Mechanic Studies at an iron ore mine in eastern Pennsylvania.

1969 – 1970

Tunnel Engineer
Poirier McLane Raymond DiMenna Joint Venture, New York, New York

Monitored daily progress and designed specialized equipment for the construction of a 28 foot diameter Intercepting Sewer tunnel in rock using drill and blast, in mixed face using ground freezing, and in submerged unconsolidated material utilizing a compressed air caisson.

Publications

“Assessment of Technology for Non-Destructive Testing of In-situ Underground Mine Seals,” Technical Report, Contract No: 200-2012-52497, National Institute of Occupational Safety and Health (*NIOSH*) and the Centers for Disease Control and Prevention (*CDC*) , September 2014, co-authored with Cary Harwood.

“Mineral Resource and Reserve Reporting for Public Companies”, Current Trends in Mining Finance Seminar, The Society for Mining Metallurgy and Exploration (SME) and the New York Section of SME, April 29-30, 2013, City University of New York Graduate Center, New York, NY.

“International Reserve Evaluation Standards”, Kentucky Professional Engineers in Mining Seminar, August 17, 2012, Marriott Griffin Gate Resort, Lexington KY, US.

“Mineral Reserve and Resource Reporting for Public Companies”, Natural Resources Conference, Kentucky Society for Certified Public Accountants, August 13, 2012, Embassy Suites Hotel, Lexington KY, US.

“Coal Mine Acquisition: Understanding the Basics – Mine Planning and Construction, Mine Operations, Reserve Quality & Quantity, and Geology”, MET COKE 2010 14th Annual World Summit, November 1-3, 2010, Omni William Penn Hotel, Pittsburgh PA, US, co-authored with Peter Lawson.

“Mine Safety Progress”, Bluefield Coal Symposium, A Comprehensive Analysis of Safety Progress including Regulations, Safety Practices, and Operator Reporting Greater Bluefield Chamber of Commerce, Bluefield WV, September 2010.

“Design and Installation of Plug-Type Mine Seals”, Wellmore Coal Company, Mine Safety Training Class, MSHA Refresher Training, Wellmore, Virginia, April 2009.

“Coal Mine Sealing Strategies”, Bluefield Coal Symposium, Coal Mine Safety: The Road to Zero Harm Greater Bluefield Chamber of Commerce, Bluefield West Virginia, August 2008, co-authored with Edmundo Laporte, P.E.

“120 psi MINOVA Main Line TekSeal® - In a Stable Entry”, Prepared for Minova USA, Inc., MSHA Approved Mine Seal Design, Pittsburgh, PA, Approval Number 12M-02.0 October 2008, and 120-75.336.1.07.15.1 October 2007.

“Analysis and Application of Coal-Seam Seismic Waves for Detecting Abandoned Mines”, Geophysics Vol.72 No.3, September/October 2007, Page M7-M15, co-authored with D.J. Yancey, M.G. Imhof, and C.F. Gresham.

“Coal Mine Safety in China and Degasification of Longwall Panels using In-Seam Directional Drilling Technology”, Proceedings of the 26th International Conference on Ground Control in Mining, Sponsored by West Virginia University, Morgantown West Virginia, August 2007, co-authored with Jinrong Ma, Ph.D., and Hu YuHong.

“The Rapidly Changing Economics of the Coal Mining Industry”, CAS/SME 2007 Annual Spring Meeting, April 14, 2007, Marriott Griffin Gate Resort, Lexington, Kentucky, co-authored with Peter Lawson.

“New Mine Safety Regulations”, North Carolina Coal Institute, Southern Pines, NC, October, 2006.

“Retreat Mining Practices, Can Additional Training Improve Safety, An Update”, Bluefield Coal Symposium on Mine Safety, Mining Legislation and Training, Bluefield, West Virginia, September 2006.

“Retreat Mining Practices”, Kentucky Professional Engineers in Mining Seminar, Lexington, Kentucky, co-authored with Jinrong Ma, Ph.D., August 2006.

“Safety: A Review and Evaluation of Current Retreat Mining Practices in Kentucky,” 25th International Conference on Ground Control in Mining, Morgantown, West Virginia, co-authored with Jinrong Ma, Ph.D., August 2006.

“Retreat Mining Practices in Kentucky,” Environmental and Public Protection Cabinet, Kentucky Department for Natural Resources, Frankfort, Kentucky, February, 2006.

“The Unique Nature of Mineral Property Appraisal”, American Society of Appraisers, Kentucky Chapter Meeting, Louisville, Kentucky, June, 2004.

“Economic Benefits of Coal-based Synthetic Fuel – 1997-2007”, Private presentation for Headwaters, Inc., Lexington, Kentucky, May, 2004.

“Economic Benefits of Coal-based Synthetic Fuel • 1998-2007 Produced under Section 29 of the Internal Revenue Code, As promulgated through the Oil Windfall Profits Tax

Act of 1980", co-authored with Justin S. Douthat, P.E., December 2003.

"Valuation of Minerals in Condemnation Proceedings Hypothetical Application of Valuation Methods", Conference of Government Mining Attorneys (COGMA), Knoxville, Tennessee, September 2003.

"Determination of Rock Strength Properties Using Geophysical and Ultrasonic Logging in Exploration Drill Holes", International Conference on Ground Control in Mining, Morgantown, West Virginia, August 2003.

"Haul Roads" – Chapter 10, SME Mining Reference Handbook, Lowrie, Raymond L., P.E., Editor, Society for Mining, Metallurgy, and Exploration, Inc., Littleton, Colorado, 2002.

"Permitting of New Mining Operations, Problems & Possibilities", Electric Power Research Institute – Coal Markets Workshop, Hilton Washington Dulles Airport, Herndon, Virginia, June 2002.

"Engineering Aspects of Synfuel Projects", co-authored with Justin S. Douthat, P.E. at the Central Appalachian Section of the Society of Mining Engineers of the American Institute of Mining, Metallurgy and Exploration (CAS/SME/AIME) Spring Meeting, Marriott Griffin Gate Resort, Lexington, Kentucky, April 2001.

"Subsidence and Groundwater Impacts", Central Appalachian Section of the Society of Mining Engineers of the American Institute of Mining, Metallurgy and Exploration (CAS/SME/AIME) Spring Meeting, Martha Washington Inn, Abingdon, Virginia, June 2000.

"Permitting and the Haden Decision", Energy and Mineral Law Foundation Workshop, Ft. Myers Beach, Florida, February 2000.

"Subsidence and Ground Water", June 10, 1999, Abingdon, Virginia, presented at the Central Appalachian Section of the Society of Mining Engineers Conference, co-author Ronald Mullennex C.P.G.

"Due Diligence: Reserve Assessment and Engineering Considerations", March 1, 1999, St. Pete Beach Florida, presented at the Financial Times Energy/Coal Outlook Conference, co-authors Marshall S. Miller and K. Scott Keim.

"Engineering Aspects of Mountaintop Surface Mining", The 1998 Bluefield Coal Rally sponsored by the Greater Bluefield Chamber of Commerce, Panel Discussion of Mountaintop Mining, Fincastle Country Club, Bluefield, Virginia, October 1998.

"Mine Planning and Production Costs for MTR and Non-MTR Mining", Economic Committee of the Governor's Task Force on Mountaintop Removal and Related Mining Methods, Marshall University Graduate Center, Charleston, West Virginia, October 1998.

"Practical Applications of Geology and Insurance in Recovering Longwalls," Longwall USA International Conference, D.L. Lawrence Convention Center, Pittsburgh, Pennsylvania, June 1998

"Longwalls in Peril – The Roles of Geology and Insurance", CAS/SME-WVCMI Joint Meeting, The Greenbrier, White Sulfur Springs, West Virginia, October 1997.

“Coal Mining: Development, Operations and Management”, Special Institute on Mining and Environmental Law for Trust Officers and Land Managers, Eastern Mineral Law Foundation, Charleston, West Virginia, September 1991.

“Horizontal Ground Movements and Mining Damage”, Mine Subsidence Prediction and Control Symposium, Association of Engineering Geologists, 33rd Annual Meeting, Pittsburgh, Pennsylvania, October 1990.

“Engineering Quality into Surface Mine Planning”, Surface Mining And Reclamation Conference, Charleston, West Virginia, April 1990.

“PRODUCTIVITY . . . Who is Responsible for Improving It?”, Pittsburgh Section SME Pittsburgh, Pennsylvania, March 1990.

“Charting a Course Through a Maze of Opportunities”, Career Planning Workshop, Society for Mining, Metallurgy and Exploration (SME), 119th Annual Meeting of AIME, Salt Lake City, Utah, February 1990.

“Productivity Improvement through Quality Management”, West Virginia Coal Mining Institute of America, White Sulfur Springs, West Virginia, November 1989.

“PRODUCTIVITY . . . Who is Responsible for Improving It?”, Central Appalachian Section of AIME and NICOA Joint Meeting, Lexington, Kentucky, April 1989.

“Ethics and the State of the Industry”, University of Kentucky Norwood Student Chapter of AIME, Lexington, Kentucky, 1987.

“Coal and the Environment”, Indiana University of Pennsylvania Business Day IX, Indiana, Pennsylvania, 1986.

“Compliance with SMCRA in Pennsylvania”, Society of Mining Engineers of AIME - Off the Record Meeting, Pittsburgh, Pennsylvania, 1984.

“Economics of the Energy Industry”, Armstrong Indiana County Economic Education Foundation, Indiana, Pennsylvania, 1983.

“Ground Freezing as Used in the Excavation of a Mixed Face”, co-authored with M.T. Wane, SME Fall Meeting, St. Louis, Missouri, 1970.

APPENDIX B

Disclosure Documents Reviewed

Formal Complaint, Sterling Ventures, LLC v Kentucky Utilities Company, before the Public Service Commission, Case No. 2015 – 00194

Exhibit A – 2014 Rate Increase Application, Capital Review – Trimble County CCR, Attachment to Filing Requirements, 807 KAR 5:001, Section 167(7)(c)I. Project Engineering 2015 Business Plan dated September 17, 2014. -

Exhibit B – PVRR Alternatives Analysis for Ghent Landfill. Coal Combustion Byproduct Plan for Ghent Station for E. ON/U.S. Subsidiaries Kentucky Utilities and Louisville Gas and Electric, June 2009.

Exhibit C – PVRR Alternatives Analysis for Trimble County Landfill. Coal Combustion Byproduct Plan for Trimble County Station for E. ON/U.S. Subsidiaries Kentucky Utilities and Louisville Gas and Electric, June 2009.

Exhibit D – Summary of Projected Capital and Maintenance and Operating Costs for Ghent Landfill through 2018 – Revenue Requirements Summary 2009 Amended Plan KU.

Exhibit E – Summary of Projected Capital and Maintenance and Operating Costs for Trimble Landfill through 2018 – Revenue Requirements Summary 2009 Amended Plan KU.

Exhibit F – 2009 KU Application, Ghent Landfill (Phase 1) Capital Expenditures, Attachment to Response to KIUC Question No. 1-4(a).

Exhibit G – Sterling's PVRR Calculation of Ghent Landfill Gypsum Disposal Cost (Revenue Requirement Summary).

Exhibit H – Sterling's Ghent Station Alternative for CCP/Gypsum Disposal.

Exhibit I – 2014 Rate Increase Application, Capital Review-Ghent CCR, Attachment to Response to AG-1 Question No. 106. Project Engineering 2012-2016 MTP dated October 13, 2011.

Exhibit J – MACTEC Engineering and Consulting, Inc., Section 404 Alternatives Analysis, Coal Combustion Residuals Storage Project, LG&E Trimble County Generating Station, issued December 2010 and revised March 2012.

Exhibit K – 2014 Rate Increase Application, Capital Review – Trimble County CCR, Attachment to Response to AG-1 Question No. 106. Project Engineering 2012-2016 MTP dated October 13, 2011.

Exhibit L – Letter from James D. Giattina, Director, Water Protection Division, U.S. Environmental Protection Agency, to Colonel Luke T. Leonard, District Engineer, Louisville District Corps, April 25, 2012.

Exhibit M – Alternatives Analysis Report for LG&E and KU Services Company, Trimble County Generating Station Landfill Project, Trimble County, Kentucky, January 2014, GAI Consultants, Inc.

Exhibit N – 2014 Rate Increase Application, Capital Review – Trimble County CCR, Attachment to Response to AG-1 Question No. 106. Project Engineering 2012-2016 MTP dated September 12, 2013.

Exhibit O – Letter from James D. Giattina, Director, Water Protection Division, U.S. Environmental Protection Agency, to Colonel Luke T. Leonard, District Engineer, Louisville District Corps, July 11, 2014.

Exhibit P – Supplement to Alternatives Analysis Report for LG&E and KU Services Company, Trimble County Generating Station Landfill Project, Trimble County, Kentucky, January 2014, Lee Wilson and Associates, Inc., GAI Consultants, Inc., and Civil and Environmental Consultants, Inc.

Exhibit Q – Trimble County Station TC2 Overview and Update for IMEA Annual Meeting, October 22, 2011.

Exhibit R – Email from John Walters, General Counsel/CFO, Sterling Ventures, LLC to Scott Straight, Dire4ctor of Project Engineering, LG&E and KU dated September 24, 2014 regarding CCP's Trimble County Landfill.

Exhibit S – Sterling's PVRR Analysis of CCR to Sterling Materials. Revenue Requirements Summary of Trimble CCR to Sterling Materials, [637,000 TCCR].

Exhibit T – 2014 Rate Increase Application, Project Engineering 2015 Business Plan.

Exhibit U– Sterling's PVRR Analysis of Trimble CCR to Sterling Materials. Revenue Requirements Summary. 12/31/2014-12/31/2070, [637,000 TCCR].

Exhibit V – Sterling's PVRR Analysis of Trimble CCR to Sterling Materials. Revenue Requirements Summary. 12/31/2014-12/31/2070, [416,700 TCCR].

Exhibit W - Sterling's PVRR Analysis of Trimble CCR to Sterling Materials. Revenue Requirements Summary. 12/31/2014-12/31/2070 [153,100 TCCR].

First Data Request of Sterling Ventures, LLC to Kentucky Utilities Company, Case No. 2015-00194 Investigation –dated 07/02/2015.

Data Requests of Kentucky Utilities Company and Louisville Gas and Electric Company Propounded to Sterling Ventures LLC, KY Public Service Commission Case No. 2015-00194, 07/02/2015.

Response to Data Request of Kentucky Utilities Company and Louisville Gas and Electric Company, Public Service Commission Case No. 2015-00194, 7/16/15

Response to Data Request of Staff of Public Service Commission, Public Service Commission Case No. 2015-00194, 7/16/15

Sterling Ventures' Responses to Commission Staff's Second Request for Information, Public Service Commission Case No. 2015-00194, 9/03/15

Sterling Ventures' Responses to Supplemental Data Request of Kentucky Utilities Company and Louisville Gas and Electric Company, Public Service Commission Case No. 2015-00194, 9/03/15

Responses of Kentucky Utilities Company and Louisville Gas and Electric Company to the Supplemental Data Request of Sterling Ventures LLCC, Public Service Commission Case No. 2015-00194, 9/03/2015

Responses of Kentucky Utilities Company and Louisville Gas and Electric Company to the Commission Staff's Second Request for Information, Public Service Commission Case No. 2015-00194, 9/03/2015.

Sterling Ventures Response to LG&E Questions, 2012.

Pre-Filed Direct Testimony J. Steven Gardner on behalf of Sterling Ventures, LLC, Public Service Commission Case No. 2015-00194, 8/06/2015.

Pre-Filed Direct Testimony John W. Walters, Jr. on behalf of Sterling Ventures, LLC, Public Service Commission Case No. 2015-00194, 8/06/2015.

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Map Sterling Materials, MSHA ID # 15-18068, Level 1 – Tyrone Seam, 2013 Sep Mining Extents and Escapeway, 9/25/13.
Map Sterling Mateials, MSHA ID # 15-18068, Level 2 – Nelson Seam, 2013 Sep Mining Extents and Escapeway , 9/25/13.
Map Sterling Materials, MSHA ID # 15-18068, Level 3 – Nelson Seam, 2013 Sep Mining Extents and Escapeway, 9/25/13.
Map Sterling Materials, MSHA ID # 15-18068, Level 1 – Tyrone Seam, 2012 Sep Mining Extents and Escapeway, 9/27/12.
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Map, Sterling Materials, Permit Boundary and Mine Works, 7/10/2015.

Storage Capacity Calculation
Estimated Average Storage Capacity (See attached Excel file)

Feddock Exhibits (See Attached)
Exhibit 1, Sterling Venture Mine Map of Level 1, Cardno, Inc. September 2015
Exhibit 2, Sterling Venture Mine Map of Level 2 showing restricted entries.

Exhibit 3, Sterling Venture Mine Map of Level 3 showing restricted entries.

Exhibit 4, Aerial photograph of the quarry site superimposed with the mine outlines of Levels 1, 2 and 3.

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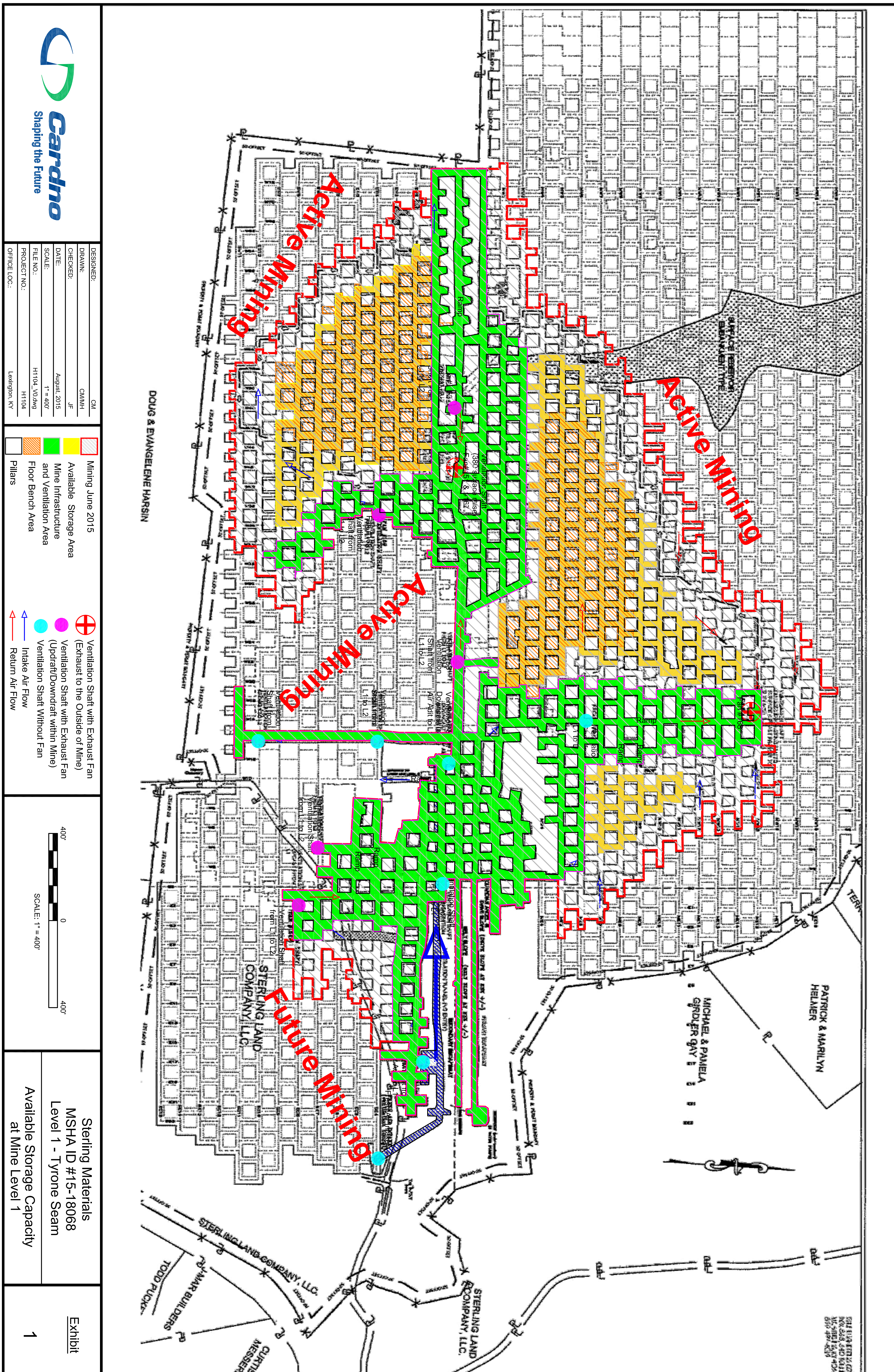
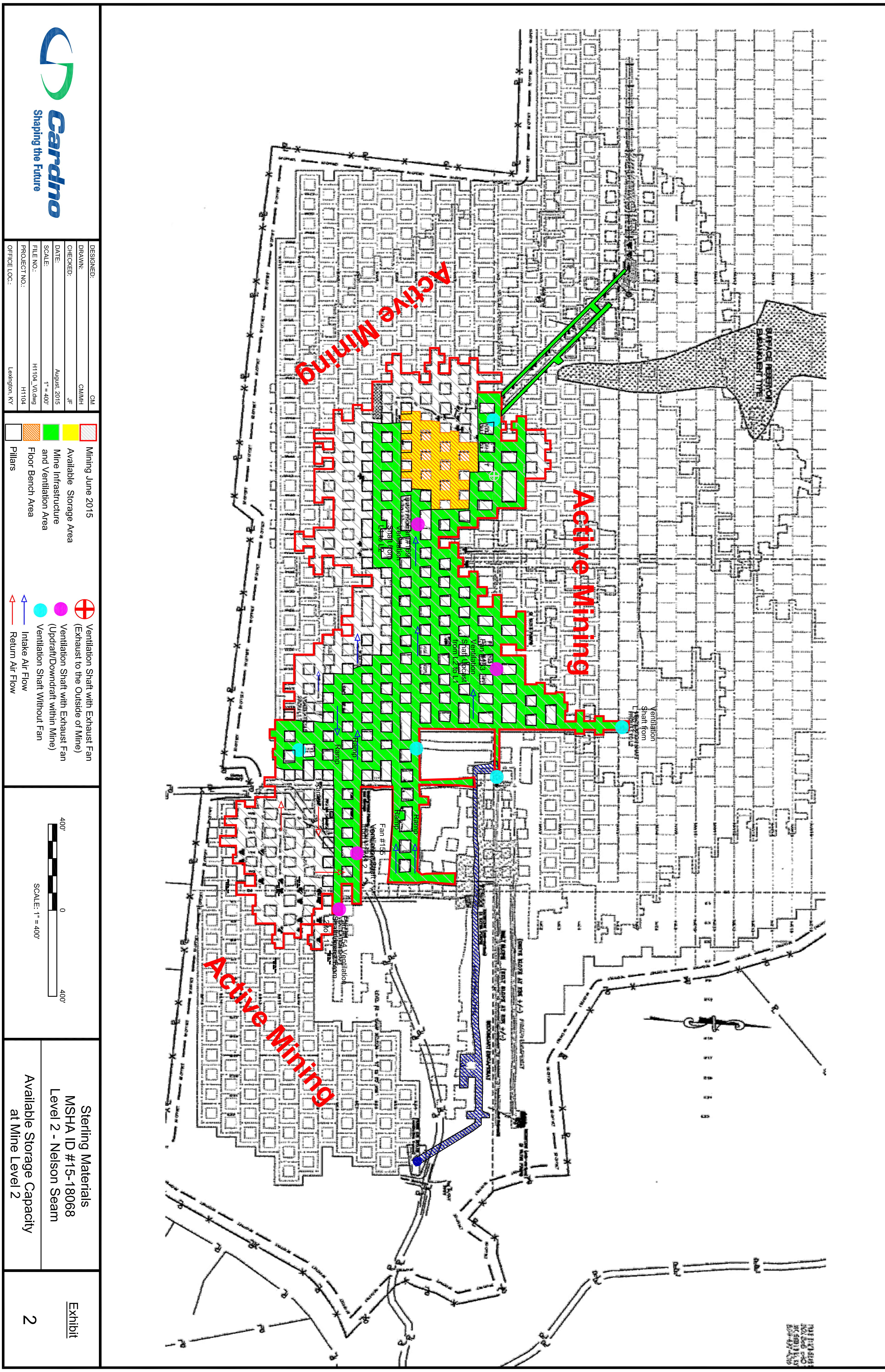
Attachment in Excel

The attachment(s) provided in separate file(s) in Excel format.


Cardno
Shaping the Future
DESIGNED: CM
DRAWN: CM/MH
CHECKED: JF
DATE: August, 2015
SCALE: 1" = 400'
FILE NO.: H1104_V0.dwg
PROJECT NO.: H1104
OFFICE LOC.: Lexington, KY
Mining June 2015
Available Storage Area
Mine Infrastructure and Ventilation Area
Floor Bench Area
Pillars
Ventilation Shaft with Exhaust Fan (Exhaust to the Outside of Mine)
Ventilation Shaft with Exhaust Fan (Updraft/Downdraft within Mine)
Ventilation Shaft Without Fan
Intake Air Flow
Return Air Flow
SCALE: 1" = 400'
Sterling Materials
MSHA ID #15-18068
Level 1 - Tyrone Seam
Available Storage Capacity at Mine Level 1
Exhibit
1
Active Mining
Active Mining
Active Mining
Future Mining
DOUG & EVANGELENE HARSIN
STERLING LAND COMPANY, LLC
MICHAEL & PAMELA GIRDLER GAY
PATRICK & MARILYN HELMER
Ramp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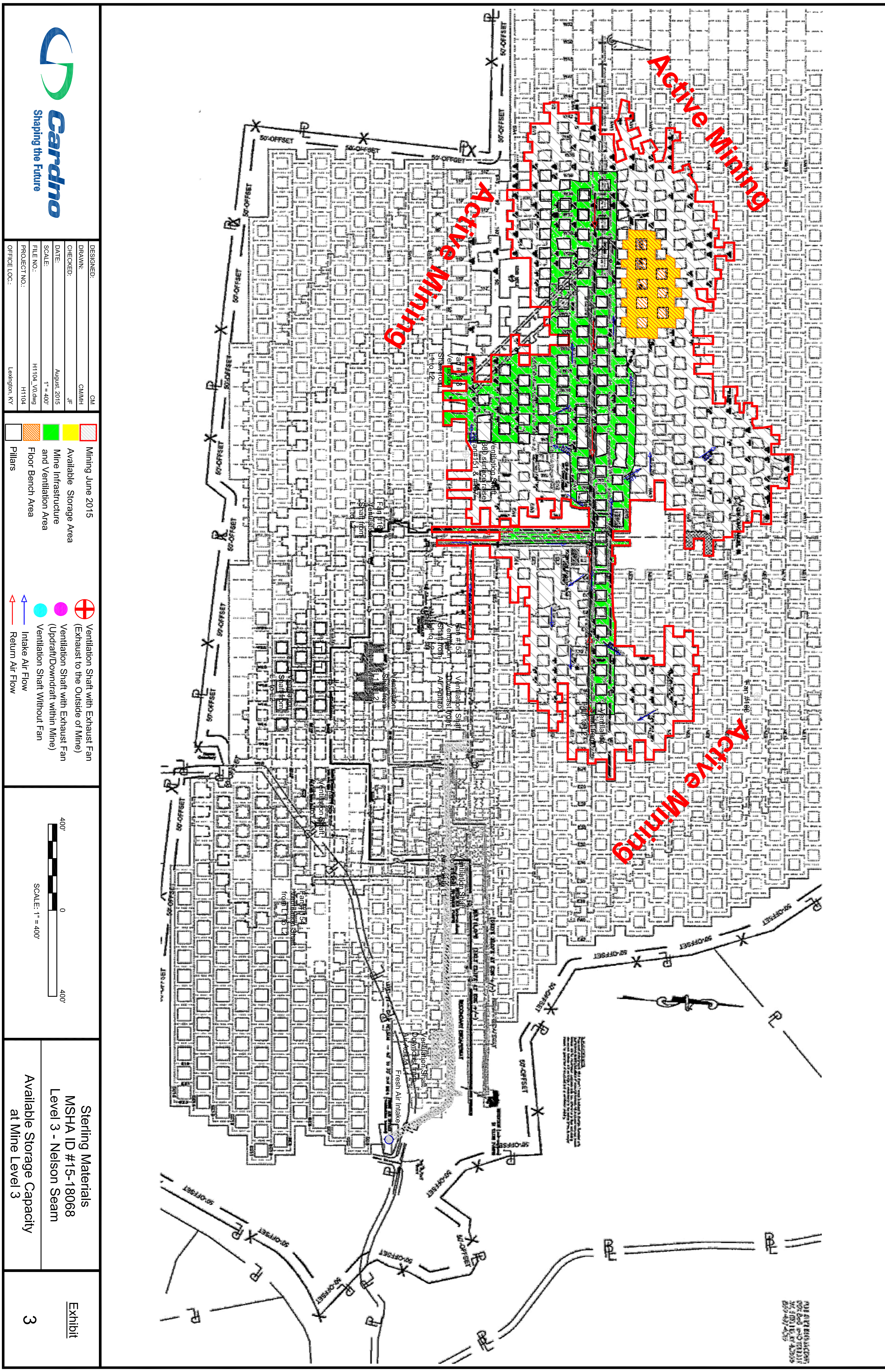
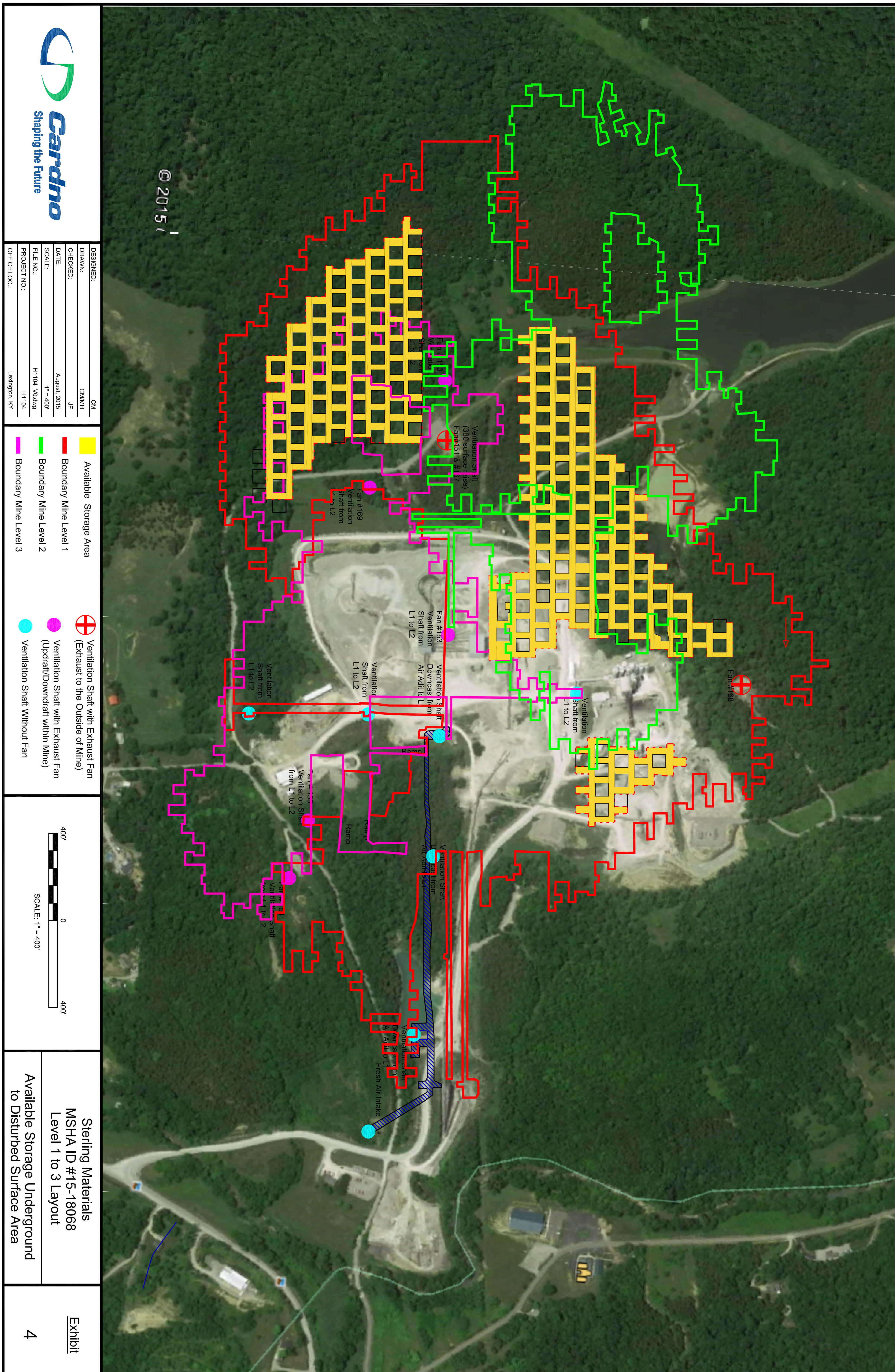
FILE NO.: H1104_V0.dwg
PROJECT NO.: H1104
OFFICE LOC.: Lexington, KY
Mining June 2015
Available Storage Area
Mine Infrastructure and Ventilation Area
Floor Bench Area
Pillars
Ventilation Shaft with Exhaust Fan (Exhaust to the Outside of Mine)
Ventilation Shaft with Exhaust Fan (Updraft/Downdraft within Mine)
Ventilation Shaft Without Fan
Intake Air Flow
Return Air Flow
400'
0
400'
SCALE: 1" = 400'
Sterling Materials
MSHA ID #15-18068
Level 2 - Nelson Seam
Available Storage Capacity at Mine Level 2
Exhibit
2
Active Mining
Active Mining
Active Mining
Ventilation Shaft from L1 to L2
Ramp
Ramp
Ramp
Ramp
Fan #155


Cardno
Shaping the Future
DESIGNED: CM
DRAWN: CMMH
CHECKED: JF
DATE: August, 2015
SCALE: 1" = 400'
FILE NO.: H1104_V0.dwg
PROJECT NO.: H1104
OFFICE LOC.: Lexington, KY
Mining June 2015
Available Storage Area
Mine Infrastructure and Ventilation Area
Floor Bench Area
Pillars
Ventilation Shaft with Exhaust Fan (Exhaust to the Outside of Mine)
Ventilation Shaft with Exhaust Fan (Updraft/Downdraft within Mine)
Ventilation Shaft Without Fan
Intake Air Flow
Return Air Flow
400' 0 400'
SCALE: 1" = 400'
Sterling Materials
MSHA ID #15-18068
Level 3 - Nelson Seam
Available Storage Capacity at Mine Level 3
Exhibit
3
Active Mining
Active Mining
Active Mining
Fresh Air Intake
50'-OFFSET

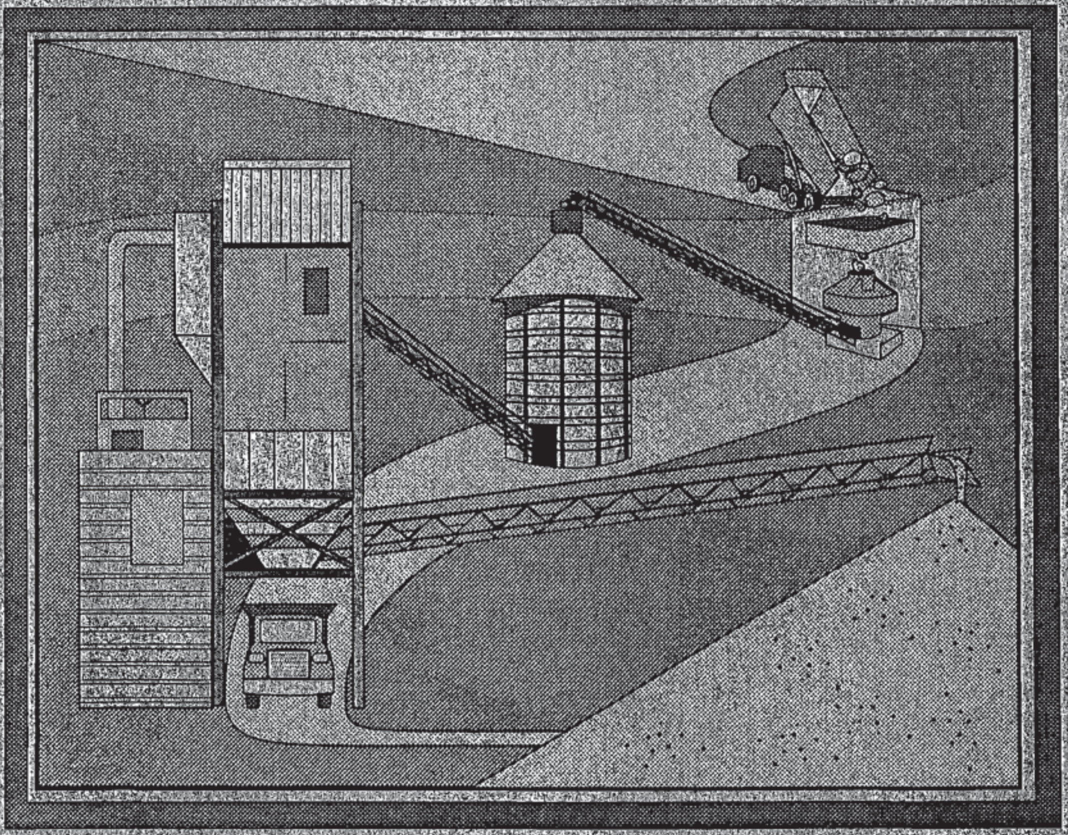

Cardno
Shaping the Future
DESIGNED: CM
DRAWN: CM/MH
CHECKED: JF
DATE: August, 2015
SCALE: 1" = 400'
FILE NO.: H1104_V0.dwg
PROJECT NO.: H1104
OFFICE LOC.: Lexington, KY
Available Storage Area
Boundary Mine Level 1
Boundary Mine Level 2
Boundary Mine Level 3
Ventilation Shaft with Exhaust Fan (Exhaust to the Outside of Mine)
Ventilation Shaft with Exhaust Fan (Updraft/Downdraft within Mine)
Ventilation Shaft Without Fan
SCALE: 1" = 400'
400'
0
400'
Sterling Materials
MSHA ID #15-18068
Level 1 to 3 Layout
Available Storage Underground to Disturbed Surface Area
Exhibit
4
© 2015
Ventilation Shaft (380 surface raise) Fan #151 & #157
Fan #169 Ventilation Shaft from L1 to L2
Fan #153 Ventilation Shaft from L1 to L2
Ventilation Shaft from L1 to L2
Fan #168
Ramp
Fresh Air intake

Kentucky Geological Survey
Donald C. Haney, State Geologist and Director
UNIVERSITY OF KENTUCKY, LEXINGTON

ISSN 0075-5583

High-Carbonate, Low-Silica, High-Calcium STONE in the High Bridge Group (Upper Ordovician) Mason County, North-Central Kentucky

Warren H. Anderson
and
Lance S. Barron



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KENTUCKY GEOLOGICAL SURVEY
Donald C. Haney, State Geologist and Director
UNIVERSITY OF KENTUCKY, LEXINGTON

HIGH-CARBONATE, LOW-SILICA, HIGH-CALCIUM STONE IN THE HIGH BRIDGE GROUP (UPPER ORDOVICIAN), MASON COUNTY, NORTH-CENTRAL KENTUCKY

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INFORMATION CIRCULAR 53

Series XI, 1995

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HIGH-CARBONATE, LOW-SILICA, HIGH-CALCIUM STONE IN THE HIGH BRIDGE GROUP (UPPER ORDOVICIAN), MASON COUNTY, NORTH-CENTRAL KENTUCKY

Warren H. Anderson
and
Lance S. Barron

ABSTRACT

The High Bridge Group (Middle Ordovician) of northeastern Kentucky is a major source of limestone and dolomite for construction, agricultural, and industrial stone. These industries require carbonate rocks of high chemical purity. Chemical analyses of foot-by-foot samples from a Mason County core show that three zones of high-calcium and several thick zones of high-carbonate and low-silica stone are present in the High Bridge at a mineable depth. Mason County is located in northeastern Kentucky, on the Ohio River, and offers river access to transportation to the metropolitan Covington–Cincinnati market and the northern portion of the Eastern Kentucky Coal Field for mine-related markets.

INTRODUCTION

The Kentucky Geological Survey is conducting a regional study of the High Bridge Group (Upper Ordovician) to determine its chemical characteristics and to outline the occurrence of deposits suitable for industrial uses requiring carbonate rocks of high chemical purity. This is the third publication in a series of reports on the chemical characteristics of High Bridge carbonate rocks; analyses of foot-by-foot samples from Boone and Fayette County cores were previously published (Dever, 1974, 1981).

This report presents the chemical analyses of foot-by-foot samples of the High Bridge section from a core taken in Mason County. The core contains three zones of high-calcium and several thick zones of high-carbonate and low-silica stone.

The High Bridge Group (Middle Ordovician) is a thick (430 to 570 feet), widespread body of limestone and dolomite that is at a mineable depth beneath a large area of central and north-central Kentucky. It is being mined for construction and agricultural stone, for the production of lime for flux, and for flue-gas desulfurization (FGD). Lime is also used for rock dust, to neutralize acid mine drainage from coal mines, and in chemical industries. The High Bridge Group is being mined at two sites along the Ohio River in north-central Kentucky by the Dravo Lime Company: the Cabin Creek Mine at Springdale near Maysville in Mason County and the Black River Mine at Carntown in Pendleton County.

The Mason County core was given to the Kentucky Geological Survey by Cominco American, Inc. It is on file and available for inspection at the Survey's Well Sample and Core Repository. The interval from 474 to 1,093 feet was split and sampled for analysis. Laboratory analyses were performed under the supervision of Lance S. Barron, Kentucky Center for Energy Research Laboratory (KCERL) (now known as the University of Kentucky Center for Applied Energy Research), and Henry E. Francis, Kentucky Geological Survey (KGS), University of Kentucky. Catherine Crace (KCERL) and Mark Thompson (KGS) performed the actual laboratory analyses.

GEOGRAPHIC AND GEOLOGIC SETTING

The Cominco American core was drilled at a site in northwestern Mason County near the community of Minerva, approximately 2.5 miles east of the Mason–Bracken county line (Fig. 1). The core hole is on the east

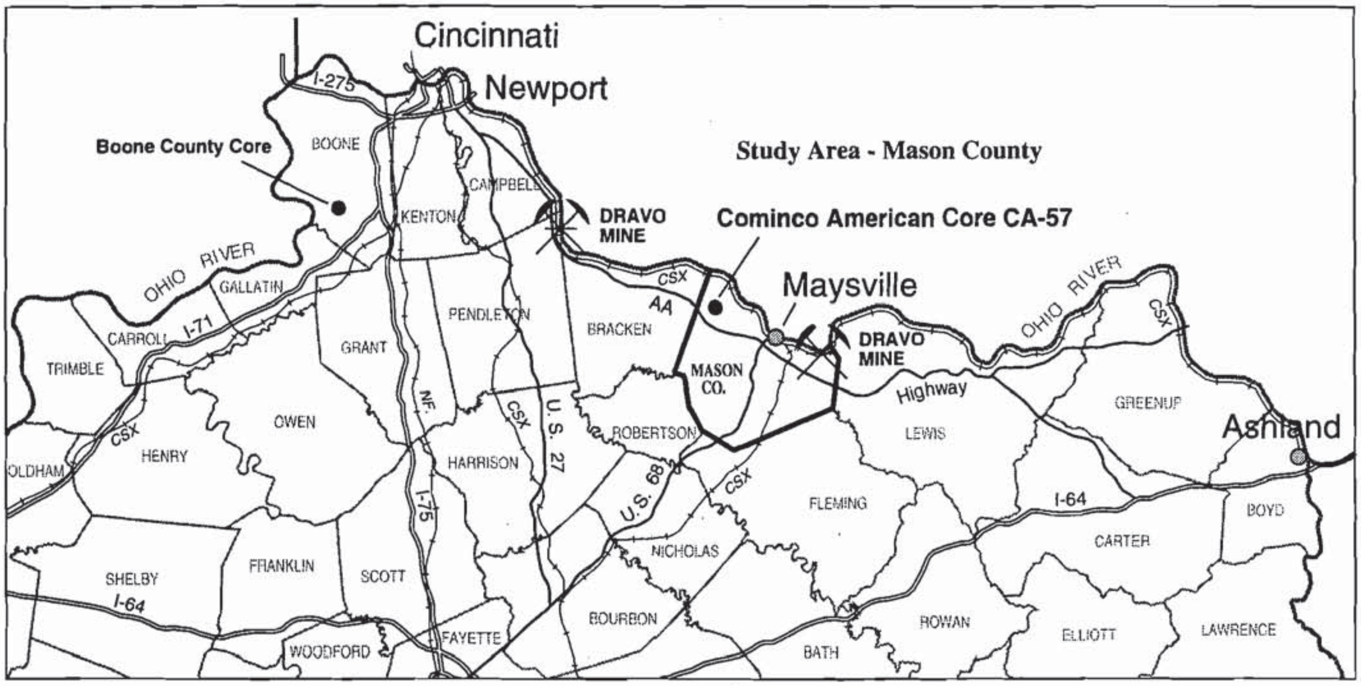

Figure 1. Generalized map of northern Kentucky showing locations of existing mine operations and Boone and Mason County cores, and major highways and railroads.

side of Kentucky Highway 435, 1.5 miles east of Minerva along an unnamed tributary of Lee Creek. The immediate area is covered by the Germantown topographic and geologic (Outerbridge, 1971) quadrangle maps, both at a scale of 1:24,000.

The core hole is located 2 miles from the Ohio River, and river access is readily available via state highways. Kentucky Highways 435 and 546 ("AA" Highway) furnish access to the network of Federal and State highways in Mason County. The county is served by the CSX System Railroad, which runs from Covington to Ashland through Maysville. The TransKentucky Transportation Inc. Railroad, a subsidiary of CSX Transportation, runs from Maysville to Paris, where it connects with additional CSX systems.

The core hole is in the Outer Blue Grass Region, near the southern extent of Pleistocene glaciation. Topography is flat to moderately rolling hills along the Ohio River. The elevation of the collar of the drill hole is 718 feet above sea level, which is about 225 feet above the Ohio River.

The site is on the eastern flank of the Cincinnati Arch (Fig. 2). Some faults occur to the east along the Lewis–Mason county line (Schilling and Peck, 1967), but no known faults exist in the vicinity of the core hole. Surface rocks in the immediate area are principally limestone and shale of the Upper Ordovician Kope Formation, Fairview Formation, and the Grant Lake Limestone (Outerbridge, 1971). Pleistocene glacial outwash occurs as sand and gravel deposits along the Ohio River.

HIGH BRIDGE GROUP
General

The High Bridge Group consists of three formations, which are, in descending order, the Tyrone Limestone, Oregon Formation, and Camp Nelson Limestone (Fig. 3). Total thickness of the High Bridge in the Mason County core is 510.5 feet, of which the Tyrone is 146.6 feet, the is Oregon is 7.4 feet, and the Camp Nelson is 357.5 feet. The Tyrone consists of micrograined limestone, and the Oregon consists of very finely crystalline dolomite. The Camp Nelson is a micrograined limestone, partly mottled with finely crystalline dolomite. The depositional environments of the Tyrone, Oregon, and upper Camp Nelson have been interpreted by Cressman and Noger (1976), Horrell (1981), Kuhnhenn and others (1981), Lazarsky (1983), and Gorman (1984).

Several thin bentonites serve as useful markers for local and regional correlation in the High Bridge. The two most prominent bentonites occur in the upper Tyrone, and their regional association has been discussed in Huff and Kolata (1990). They are the Millbrig or "Mud Cave," present locally at or near the top of the formation, and the Deicke or "Pencil Cave," present across the region, 15 to 30 feet below the top of the Tyrone (Wolcott and others, 1972). In the Mason County

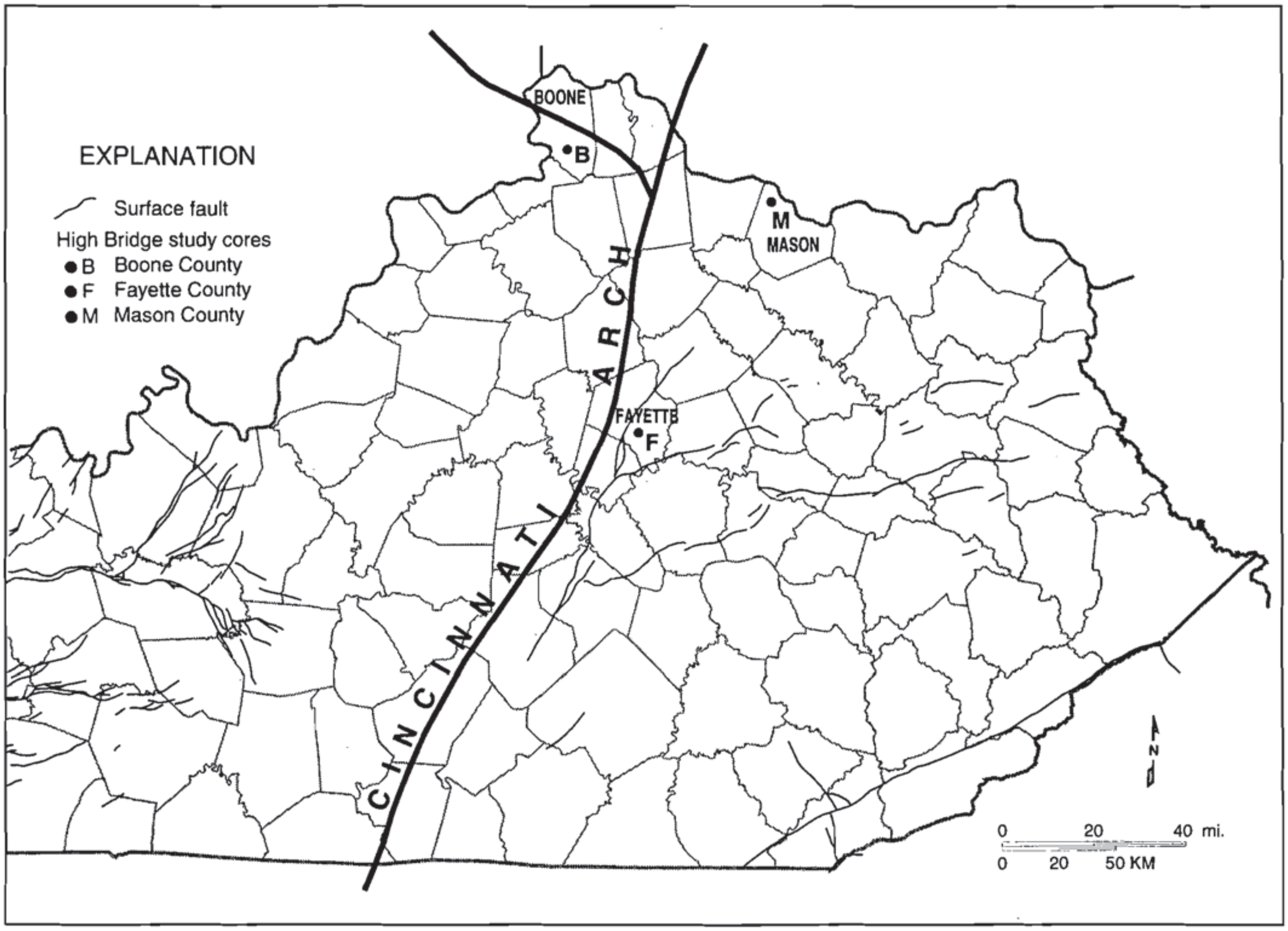

Figure 2. Structural features in central and eastern Kentucky, and their relation to the Boone, Fayette, and Mason County cores.

core, two additional thin bentonites are present, one about 51 feet above the base of the Tyrone and another about 132 feet below the top of the Camp Nelson.

The Tyrone is overlain by the Lexington Limestone, a coarse, crystalline, fossiliferous limestone. The Camp Nelson is underlain in turn by the Wells Creek Dolomite and, where present, the St. Peter Sandstone. In this core, the Wells Creek rests unconformably upon the Knox Group. The contact between the micrograined limestone of the Tyrone and the bioclastic limestone of the basal Lexington is distinct, but the contact between the Camp Nelson and Wells Creek is gradational. The lower Camp Nelson in the Mason County core is mainly limestone (in part slightly dolomitic) and shale; the Wells Creek is an interbedded dolomite and shale and the basal portion is a sandy dolomite. In this study, the contact between the Camp Nelson and Wells Creek has been placed below the lowest occurrence of micrograined limestone, a characteristic High Bridge lithology.

Potential Industrial Uses

The Federal Clean Air Act Amendments of 1990 (Public Law 101-549), also known as the Acid Rain Bill, will create a large demand for limestones and lime for reducing sulfur dioxide emissions from coal-burning power plants. Sulfur sorption techniques (Fluidized Bed Combustion [FBC] or Flue Gas Desulfurization [FGD]) generally require the use of limestone or lime, which react with the combustion coal gases. This reaction by-product is then a disposable commodity. In an FBC method, coal is burned on a bed of limestone or dolomite that is suspended or "fluidized" by an upward flow of air (Dever, 1990). As the coal burns, sulfur (SO_2) is released and reacts with the calcined limestone or dolomite and forms the by-product calcium sulfate ($CaSO_4$, gypsum). When the FGD method is used in existing plants, a hydrous lime mixture is sprayed into the flue gases to form a similar chemical reaction between sulfur and limestone (Cobb and Eble, 1992).

With an increased reliance on the use of coal to meet the energy requirements of the United States, greater quantities of stone will be needed for sulfur sorption capabilities such as fluidized bed combustion and flue-gas desulfurization. Limestone and lime are used for rock dust, spoil-bank reclamation, and acid-mine-drainage neutralization in coal mining. The High Bridge is also a source of construction and agricultural stone for the area's mixture of agricultural and expanding urban markets near Cincinnati.

Chemically pure limestone and dolomite have industrial uses such as raw material for the production of lime, portland cement, agricultural lime products, and chemical products; and flux for steel and other metallurgical industries and fillers. Specifications for many of these industrial uses require that the stone be essentially free of non-carbonate constituents such as silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), sulfur (S), and phosphorus (P). For certain industrial uses, magnesium carbonate ($MgCO_3$) is a deleterious constituent (Dever, 1981).

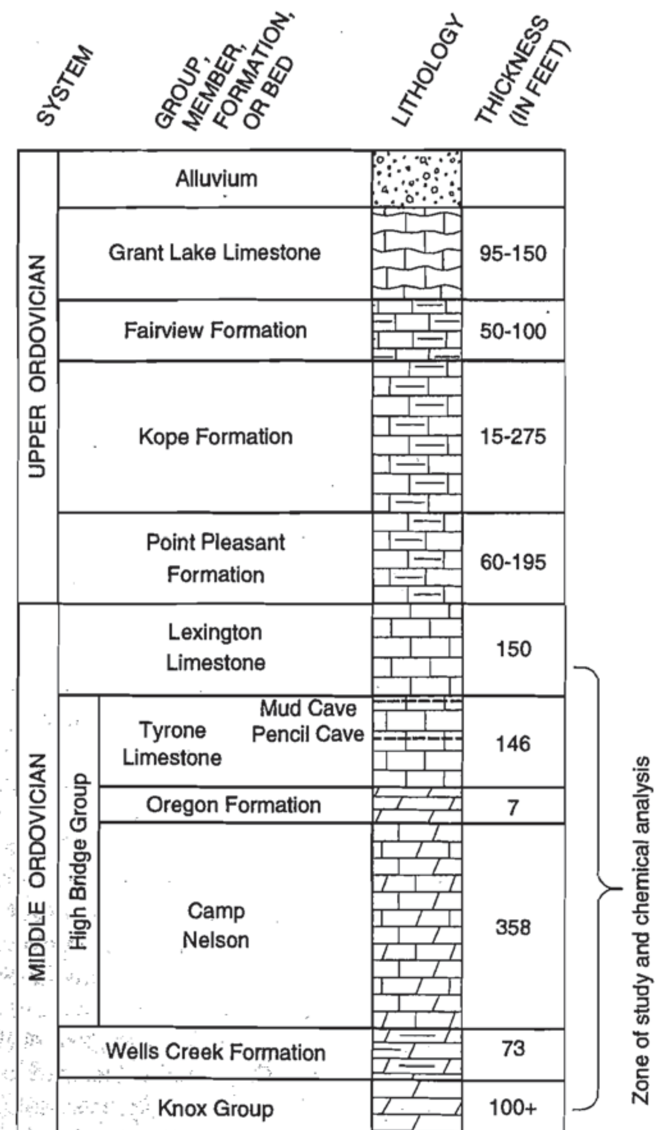

Figure 3. Generalized stratigraphic section for Mason County.

The term "high-calcium limestone" designates carbonate rocks composed of 95 percent or more calcium carbonate ($CaCO_3$). Carbonate rocks of high chemical purity are described by Dever (1974, 1981, 1990) and Dever and others (1991, 1992). These reports also provide a summary of several potential uses for high-carbonate and low-silica stone. The term "high-carbonate stone" designates carbonate rocks composed of 95 percent or more total carbonates—calcium carbonate plus magnesium carbonate ($CaCO_3$ + $MgCO_3$). The term "low-silica stone" designates carbonate rocks with a total (free and combined) silicon dioxide (SiO_2) content of 4 percent or less (Dever, 1981).

DISCUSSION OF ANALYTICAL DATA

In the Mason County core, a 10-foot-thick zone of high-calcium limestone occurs in the Tyrone, between the Mud Cave and Pencil Cave bentonites (Fig. 4). A thicker zone of high-calcium limestone can be obtained when averaged over an 18-foot interval (Table 1). This 18-foot-thick zone is not present in the Boone County core (Dever, 1974) and may be restricted to northeastern Kentucky. This zone could be worthy of exploration for high-calcium stone since it has a depth of approximately 500 feet, although the magnesium and silica contents (Table 1 and Appendix A) may restrict its use as a source of lime (John Ames, oral communication). Additional zones of high-calcium limestone in the core are only 1 to 2 feet thick and occur in the Camp Nelson. Several zones of high-carbonate stone, 12 to 61 feet thick, are present in the Mason County core (Fig. 4, Table 1, Appendix A); the zones are in the Camp Nelson and show a close correlation with the stratigraphic position of the high-carbonate zones of the Camp Nelson in the Boone County core, 50 miles to the northwest (Fig. 2).

The High Bridge is being mined at two sites on the Ohio River in north-central Kentucky for the production of lime. The Dravo Lime Company's Cabin Creek Mine in Mason County is producing a low-magnesium lime (MgO) for stack-gas scrubbing (Mining Engineering, 1977). The Cabin Creek Mine also produces limestone for FBC. Dravo's Black River Mine at Carntown in Pendleton County produces a high-calcium quicklime for FGD, steel-furnace flux, and chemical industries, and a hydrated lime for chemical industries and

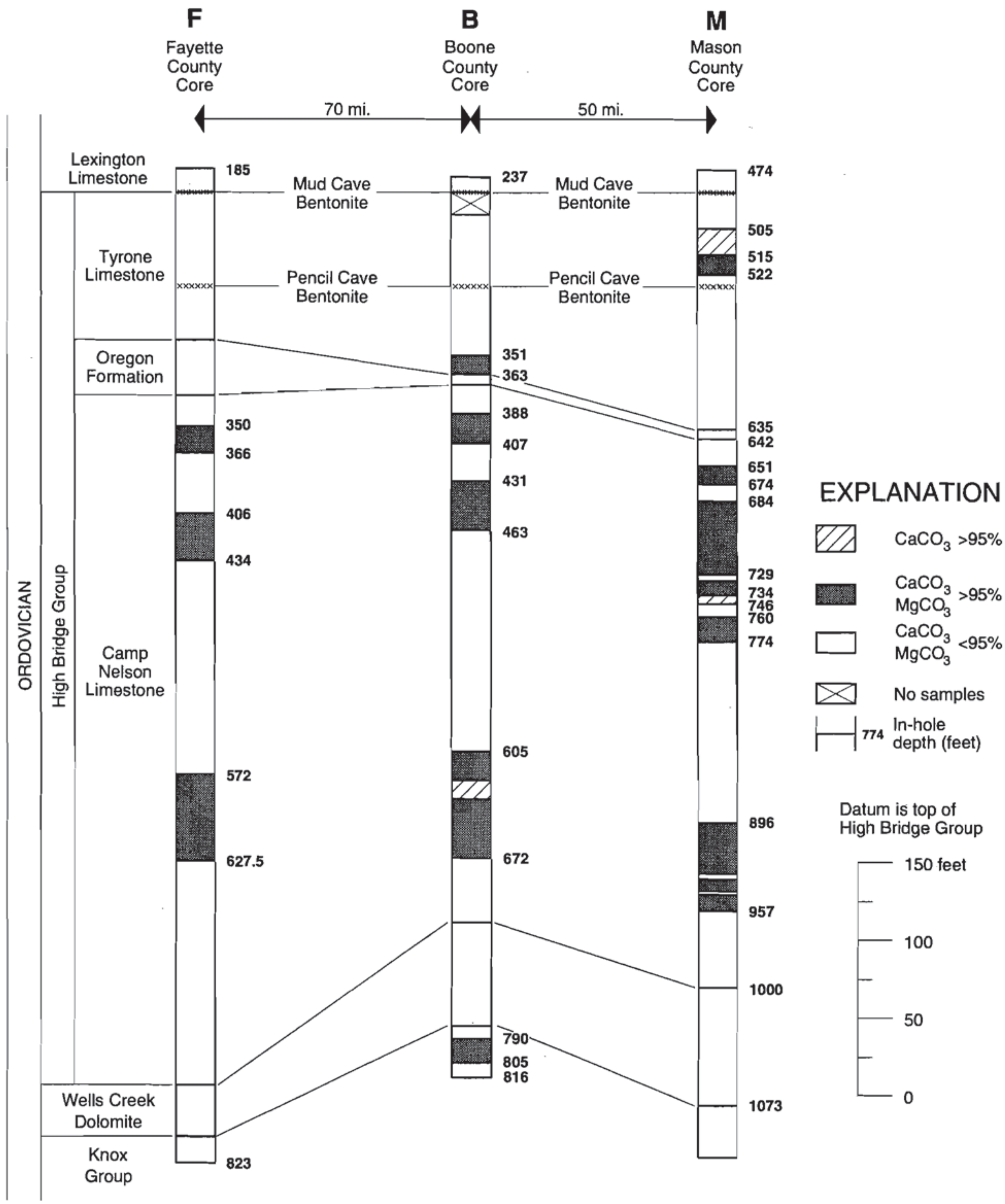

Figure 4. Zones of high-carbonate and high-calcium stone, and stratigraphy of analyzed sections in cores from Fayette, Boone, and Mason Counties. Section from Fayette County to Boone County is along the Cincinnati Arch, and section from Boone County to Mason County is across the arch and into the Appalachian Basin. Modified from Dever (1981).

water treatment (John Ames, oral communication). Limestone from the Pendleton County mine also is marketed for the production of rock dust for coal mines (Dever, 1981).

Most of the limestone in the Camp Nelson appears suitable for construction stone. A zone of argillaceous limestone and shale in the uppermost Camp Nelson of central Kentucky is not present in the Mason County or Boone County cores, correlative with the approximate interval from 670 to 690 feet in the Cominco American core (Appendix A). Rock in this zone in central Kentucky does not meet specifications for construction stone.

Limestone and dolomite samples from Kentucky have been tested in an atmospheric fluidized bed combustion pilot plant at the Kentucky Center for Energy Research Laboratory (now University of Kentucky Center for Applied Energy Research) (Barron and others, 1991). One of the samples studied by Barron and others (1991) was from the Oregon Formation. Barron and others (1991) found that dolomites or calcareous dolomites such as those in the Oregon have a greater sulfur sorption capacity and calcium utilization potential than the limestones in this study. The Oregon dolomite in the study by Barron and others (1991) was obtained from stockpiles at the Vulcan Materials Central Mine, Fayette County. Dolomitic limestone from Dravo's Cabin Creek Mine is also being used in FBC (Dever, 1990).

Structure contours on the top of the Tyrone in north-central Kentucky (top of High Bridge) have been compiled by Potter (1993) in a map covering a large area of north-central Kentucky (Fig. 5). Depth to the top of the High Bridge is generally less than 800 feet along the Ohio River in northern Kentucky. Wolcott and others (1972) used a trend-surface statistical analysis to predict thickness trends in the High Bridge of central and north-central Kentucky. This information could benefit exploration for additional mine sites.

CONCLUSIONS

Thick deposits of chemically pure carbonate rock are present in the High Bridge Group in north-central Kentucky. Regional stratigraphic correlation between deposits across northern Kentucky suggests that the deposits are widespread and represent large reserves of stone for industrial use. The High Bridge of north-central Kentucky along the Ohio River has potential for the production of limestone and lime for various industrial and agricultural uses. These carbonate rocks are being used for the production of lime for flue-gas desulfurization and as sorbent stone in a fluidized-bed combustion system.

ACKNOWLEDGMENTS

Appreciation is extended to Garland R. Dever, Jr., who contributed much of the work and analytical data on limestones in Kentucky. Without his advance work, knowledge, and stimulating discussions, this publication would not have been possible.

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Table 1. Average chemical analysis of high-calcium and high-carbonate zones.

Footage	*Thickness*	*Total Carbonate*	*$CaCO_3$*	*$MgCO_3$*	*SiO_2*	*Al_2O_3*	*Fe_2O_3*	*K_2O*	*Na_2O*	*Total*
High-calcium zone										
504-522	18 ft.	97.28	95.49	1.79	1.60	0.64	0.22	0.24	0.05	100.03
High-carbonate zone										
651-674	23 ft.	96.27	91.04	5.23	1.67	0.36	0.18	0.21	0.05	98.76
684-729	46 ft.	96.41	88.47	7.94	2.23	0.25	0.17	0.13	0.07	99.26
734-746	12 ft.	97.27	91.53	5.74	1.39	0.20	0.13	0.10	0.06	99.16
760-774	14 ft.	95.68	90.44	5.24	3.17	0.54	0.34	0.41	0.19	100.33
896-957	61 ft.	96.59	84.66	11.93	1.65	0.14	0.17	0.16	0.08	98.79

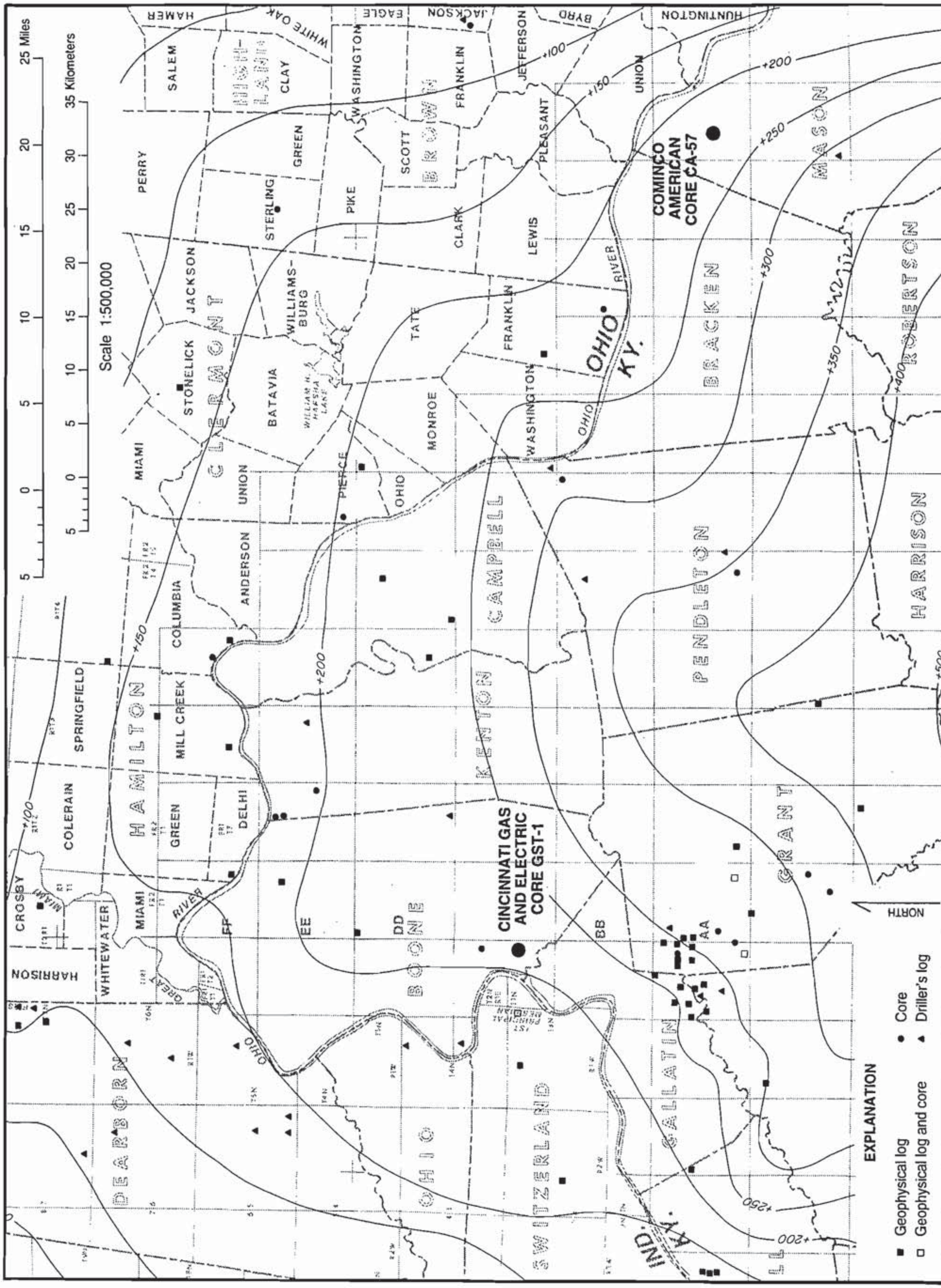

Figure 5. Structure-contour map on top of the High Bridge/Black River Groups. Modified from Potter (1993).

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APPENDIX A:
Major-Element Analyses and Lithologic Descriptions of Cominco American Inc. Core CA-57, Mason County, Kentucky

County: Mason
Operator: Cominco American Inc.
Carter Coordinate Location: sec. 14-AA-68 (Germantown Quadrangle)

Chemical Analysis							
% $CaCO_3$	% $MgCO_3$	% SiO_2	% Al_2O_3	% Fe_2O_3	% K_2O	% Na_2O	% Total
78.30	1.81	15.98	1.53	0.50	0.42	0.39	98.93
85.58	1.14	10.29	0.81	0.48	0.16	0.11	98.57
77.07	2.70	14.97	2.34	0.87	0.73	0.43	99.11
67.17	1.83	26.99	1.15	0.64	0.42	0.29	98.49
82.89	1.09	11.70	1.85	0.92	0.32	0.17	98.94
89.65	0.77	7.09	1.15	0.26	0.22	0.10	99.24
81.95	1.15	13.70	0.17	0.32	0.57	0.22	98.08
93.90	0.96	3.80	1.19	0.18	0.36	0.07	100.46
92.61	1.00	4.46	1.15	0.20	0.32	0.08	99.82
92.17	0.60	4.35	0.87	0.26	0.22	0.06	98.53
90.48	0.77	6.17	1.53	0.26	0.46	0.11	99.78
90.06	0.65	6.01	1.26	0.39	0.33	0.07	98.77
87.96	0.56	7.93	1.26	0.32	0.43	0.17	98.63
83.81	0.91	11.39	3.14	0.32	1.03	0.20	100.80
85.29	0.99	9.94	1.98	0.23	0.66	0.11	99.20
61.09	0.82	35.06	0.85	0.24	0.22	0.06	98.34
70.92	1.38	24.04	1.49	0.35	0.57	0.06	98.81
85.86	2.06	8.40	1.45	0.32	0.58	0.05	98.72
90.50	1.32	6.25	1.15	0.27	0.29	0.05	99.83
94.93	0.96	2.32	1.21	0.12	0.40	0.05	99.99
94.80	0.91	1.80	0.83	0.22	0.16	0.04	98.76
93.60	1.47	2.68	1.00	0.20	0.20	0.04	99.19
94.24	0.95	2.41	1.20	0.28	0.23	0.05	99.36
95.08	0.63	2.43	1.13	0.25	0.20	0.07	99.79
92.32	1.01	3.55	1.79	0.37	0.40	0.09	99.53
93.95	0.74	2.13	1.44	0.23	0.18	0.05	98.72
87.20	1.86	6.52	3.20	0.81	0.68	0.09	100.36
90.01	1.72	4.31	2.55	0.52	0.47	0.07	99.65
89.64	1.72	4.27	2.09	0.72	0.47	0.07	98.98
88.10	1.90	5.35	2.54	0.70	0.68	0.11	99.38
93.44	1.29	2.16	0.68	0.39	0.35	0.05	98.36
97.97	0.34	0.73	0.30	0.06	0.06	0.06	99.52
98.07	0.73	0.72	0.48	0.09	0.16	0.04	100.29
98.11	0.70	0.41	0.39	0.25	0.09	0.03	99.98
97.75	0.74	0.28	0.45	0.11	0.08	0.03	99.44
97.00	1.40	0.83	0.42	0.07	0.08	0.03	99.83
96.55	1.85	0.98	0.43	0.09	0.08	0.03	100.01
96.01	2.08	1.43	0.60	0.13	0.19	0.03	100.47
96.17	2.01	1.39	0.66	0.10	0.22	0.03	100.58
96.99	1.55	1.37	0.53	0.11	0.15	0.03	100.73
96.80	0.86	1.76	0.85	0.13	0.38	0.03	100.81
94.57	2.90	1.87	0.76	0.50	0.28	0.04	100.92
91.40	2.91	3.19	1.19	0.39	0.53	0.05	99.66
92.80	2.62	3.15	1.20	0.36	0.50	0.12	100.75
92.41	2.71	2.51	0.68	0.27	0.30	0.06	98.94
94.40	2.09	1.69	0.43	0.17	0.17	0.04	98.99
96.39	1.90	1.39	0.38	0.14	0.14	0.04	100.38
92.01	3.50	3.01	1.04	0.67	0.55	0.07	100.85
85.90	3.56	6.73	2.14	0.82	0.70	0.09	99.94
86.93	3.22	5.54	1.78	0.67	0.68	0.07	98.89
88.62	1.57	6.27	1.60	0.35	0.87	0.07	99.35
97.42	1.27	1.34	0.51	0.16	0.20	0.03	100.93

Sampled and Described By: Warren H. Anderson and Lance S. Barron
Analyzed By: Kentucky Center for Energy Research Laboratory and Kentucky Geological Survey
Date Sampled: August 10-11, 1993

Description		
Footage (feet)	*Thickness (feet)*	*Formation and Lithology*
474.4-489.4	15	**Lexington Limestone** Limestone, light- to medium- to light-olive-gray, moderately to coarsely crystalline; becomes finely to moderately crystalline in lower 6 ft.; scattered bioskeletal debris; some shale and argillaceous partings; blue porcelaneous chert at 475.4 ft.; blue porcelaneous chert with relict bioclastic texture in basal 0.6 ft.
		High Bridge Group
		Tyrone Limestone
489.4-490.4	1	**Mud Cave** Bentonite; green shale with biotite flakes.
490.4-499.7	9	Limestone, light-gray; becomes light-olive-gray in lower part; micrograined; in part moderately crystalline; floating bioskeletal debris, pellets, shell fragments, bryozoans, trilobites, scattered shale partings; stylolites.
499.7-504.6	5	Limestone, light-olive-gray to yellowish-gray; in part medium-gray; micrograined, in part with birdseye calcite; bioclastic calcilutite from 500 to 501.1 ft.; mottled with medium-gray and light-olive-green burrowing at 501.1 ft.
504.6-516.1	11	Limestone, yellowish-gray to light-olive-gray, with scattered medium-gray mottling; micrograined; birdseye calcite in upper 3 ft; some stylolites; in part with coarsely crystalline calcite veinlets; iridescent pyrite at 505.5 ft.; shale partings at 507.1 ft.
516.1-525.5	9	Limestone, yellowish-gray to light-olive-gray; in part brownish-gray; micrograined, with birdseye calcite; medium-gray burrows and mottling; numerous shale and argillaceous partings; greenish-gray, argillaceous limestone from 522.6 to 524.7 ft.
525.4-525.5	0.1	**(Pencil Cave)** Bentonite; green shale with biotite flakes.

Chemical Analysis

% $CaCO_3$	% $MgCO_3$	% SiO_2	% Al_2O_3	% Fe_2O_3	% K_2O	% Na_2O	% Total
97.00	1.21	1.75	0.30	0.12	0.10	0.03	100.51
94.16	1.65	1.56	0.38	0.37	0.11	0.04	98.27
93.66	1.95	2.25	0.54	0.36	0.16	0.04	98.96
92.02	3.75	2.67	1.02	0.39	0.22	0.05	100.12
90.01	3.85	3.04	1.17	0.38	0.25	0.05	98.75
84.77	5.80	5.56	2.03	0.68	0.55	0.06	99.45
86.56	4.46	5.77	2.04	0.72	0.50	0.09	100.14
90.20	3.56	4.53	1.62	0.55	0.42	0.06	100.94
90.25	3.50	4.46	1.66	0.55	0.40	0.06	100.88
82.10	4.01	8.22	2.73	1.00	0.64	0.10	98.80
85.50	3.47	5.98	1.96	0.71	0.51	0.08	98.21
94.00	2.50	1.80	0.60	0.21	0.10	0.03	99.24
94.03	2.25	1.64	0.57	0.20	0.10	0.03	98.82
74.90	4.45	12.00	5.11	1.39	0.87	0.16	98.88
82.25	2.65	8.50	3.50	0.90	0.64	0.12	98.56
81.40	2.85	9.01	3.75	1.07	0.74	0.13	98.95
74.71	4.02	13.56	4.09	1.65	1.00	0.19	99.22
75.69	4.15	11.90	4.53	1.37	0.85	0.17	98.66
84.45	3.85	7.50	2.40	1.00	0.65	0.10	99.95
85.09	3.12	7.00	2.08	0.79	0.58	0.10	98.76
87.82	2.73	5.41	1.72	0.75	0.51	0.09	99.03
89.95	2.10	3.97	1.32	0.56	0.20	0.07	98.17
88.75	3.30	5.20	1.66	0.77	0.50	0.08	100.26
86.41	2.79	6.75	2.04	0.84	0.62	0.09	99.54
87.34	3.34	5.41	1.60	0.67	0.50	0.12	98.98
85.00	3.46	7.20	2.00	0.84	0.70	0.15	99.35
77.40	4.89	11.60	3.70	1.36	0.86	0.17	99.98
86.65	4.20	5.60	1.74	0.72	0.58	0.10	99.59
93.57	2.69	1.43	0.40	0.26	0.12	0.05	98.52
90.45	5.27	1.80	0.55	0.33	0.23	0.06	98.69
88.20	4.53	4.06	0.85	0.49	0.45	0.07	98.65
89.98	4.39	3.21	0.42	0.30	0.28	0.07	98.65
88.99	4.54	3.66	0.60	0.31	0.33	0.07	98.50
86.83	4.80	5.09	1.42	0.73	0.51	0.11	99.49
84.30	3.99	6.95	1.96	0.67	0.57	0.12	98.56
66.45	12.40	14.86	2.66	1.64	1.12	0.19	99.32
67.90	10.57	14.00	3.98	1.57	0.94	0.19	99.15
58.61	11.98	15.99	7.74	2.00	1.63	0.21	98.16
70.18	13.50	10.50	2.00	1.35	0.70	0.22	98.45
92.07	3.57	1.60	0.36	0.18	0.23	0.07	98.08
91.93	3.65	1.66	0.60	0.20	0.24	0.06	98.34
90.97	3.60	3.06	0.68	0.25	0.39	0.06	99.01
87.14	4.31	4.80	1.18	0.54	0.48	0.08	98.53
80.60	14.40	3.56	0.89	0.44	0.35	0.08	100.32
68.90	24.77	3.00	0.38	0.86	0.32	0.07	98.30
79.45	14.50	3.12	0.56	0.43	0.35	0.08	98.49
81.02	12.80	3.25	0.62	0.44	0.37	0.08	98.58
90.14	5.11	2.25	0.36	0.17	0.11	0.04	98.18
89.66	5.19	1.91	0.44	0.86	0.20	0.04	98.30
78.49	15.00	2.78	0.76	0.48	0.43	0.07	98.01
87.49	5.10	3.87	1.45	0.49	0.62	0.08	99.10
88.80	5.25	2.76	0.94	0.44	0.50	0.06	98.75
89.40	5.20	3.50	0.99	0.40	0.60	0.07	100.16
87.84	4.76	3.60	1.08	0.43	0.73	0.06	98.50
72.97	14.39	8.50	1.83	0.72	0.90	0.09	99.40
77.28	14.57	4.46	0.94	0.47	0.57	0.06	98.35
88.25	3.85	4.65	1.14	0.42	0.58	0.07	98.96
85.20	3.03	7.79	2.08	0.52	0.97	0.06	99.65
76.60	9.50	10.00	1.75	0.63	1.32	0.09	99.89
90.70	5.66	1.99	0.34	0.17	0.22	0.02	99.10

Description

Footage (feet)	Thickness (feet)	Formation and Lithology
525.5-531.6	6	Limestone, yellowish-gray to light-olive-gray; micrograined; gray laminated and argillaceous mottling and partings; some coarsely crystalline veinlets.
531.6-539.1	8	Limestone, yellowish-gray to light-olive-gray; micrograined; in part very fine grained; mottled with shale; styolitic; irregular bodies of light-olive-gray to greenish-gray, finely crystalline dolomite; dark shale partings from 532.1 to 537.2 ft.; brownish-gray limestone, in part with moderately crystalline calcite, in basal foot.
539.1-565.7	26	Limestone, yellowish-gray to light-olive-gray to greenish-gray, micrograined to very fine-grained, in part argillaceous, with abundant dark-gray, silty shale partings; some scattered floating bioskeletal debris, in part with yellowish-gray, micrograined limestone; 0.25-in. pyrite cube at 539.5 ft.; dolomite mottling at 543.7 ft.; birdseye texture from 554.5 to 559.9 ft.; algal laminations at 561.4 ft.; varved, argillaceous, laminated, and composed of intercalated greenish-gray shale and limestone, with some birdseye calcite in basal 5 ft.
565.7-585.6	19	Limestone, yellowish-gray to light-olive to pinkish-gray, with gray and brown coloration, some black mottling in lower part; micrograined, with birdseye calcite; in part fine-grained; argillaceous laminations; pyrite at 569.5 ft.; 0.5 ft. of shaly, argillaceous partings at 569.8 ft.; scattered shale partings; stylolites in lower 2 ft.
585.6-585.9	0.3	Bentonite; green shale with some biotite flakes and iridescent pyrite.

Chemical Analysis

% $CaCO_3$	% $MgCO_3$	% SiO_2	% Al_2O_3	% Fe_2O_3	% K_2O	% Na_2O	% Total
85.60	7.75	3.90	0.49	0.26	0.51	0.05	98.56
83.01	10.01	5.60	0.83	0.49	0.71	0.04	100.69
88.53	4.99	3.85	0.66	0.32	0.57	0.07	98.99
92.04	3.25	2.06	0.40	0.20	0.31	0.04	98.30
93.90	3.54	2.30	0.30	0.16	0.18	0.05	100.43
94.14	3.50	2.15	0.30	0.13	0.20	0.13	100.55
88.69	7.97	1.87	0.32	0.16	0.23	0.05	99.29
78.20	14.78	4.50	0.79	0.52	0.56	0.09	99.44
91.70	5.57	1.55	0.32	0.30	0.14	0.05	99.63
91.50	4.76	1.70	1.40	0.21	0.25	0.04	99.86
92.47	4.40	1.58	0.27	0.14	0.26	0.06	99.18
93.90	3.69	1.50	0.28	0.13	0.25	0.23	99.98
92.38	2.79	2.50	0.40	0.14	0.32	0.05	98.58
91.58	3.87	2.60	0.45	0.21	0.30	0.06	99.07
83.73	11.02	2.07	0.41	0.28	0.95	0.23	98.69
86.56	9.10	1.98	0.25	0.25	0.24	0.08	98.46
81.62	10.47	5.39	0.36	0.39	0.20	0.07	98.50
86.01	11.30	2.10	0.32	0.24	0.29	0.06	100.32
82.56	13.05	2.40	0.40	0.35	0.47	0.09	99.32
81.94	13.75	2.04	0.40	0.24	0.19	0.17	98.73
80.55	11.26	5.10	0.28	0.34	0.87	0.09	98.49
83.59	11.29	2.42	0.47	0.17	0.34	0.23	98.51
78.90	15.40	3.01	0.50	0.24	0.30	0.09	98.44
75.64	18.15	3.51	0.59	0.53	0.31	0.06	98.79
79.20	15.90	2.27	0.26	0.23	0.16	0.05	98.07
83.30	12.76	1.76	0.21	0.21	0.13	0.03	98.40
74.01	20.25	3.36	0.43	0.30	0.28	0.09	98.72
72.14	20.41	4.50	0.64	0.38	0.50	0.10	98.67
71.94	21.09	4.11	0.60	0.36	0.37	0.14	98.61
82.47	13.15	2.40	0.34	0.26	0.22	0.05	98.89
83.49	12.12	2.73	0.26	0.17	0.16	0.08	99.01
69.70	24.54	4.50	0.68	0.38	0.36	0.06	100.22
75.92	18.24	2.99	0.38	0.29	0.23	0.08	98.13
77.97	16.30	2.91	0.54	0.21	0.30	0.07	98.30
79.89	13.78	3.56	0.51	0.26	0.31	0.06	98.37
91.95	4.79	1.97	0.56	0.14	0.18	0.06	99.65
73.96	19.00	4.21	0.68	0.35	0.46	0.09	98.75
67.58	25.40	3.97	0.55	0.35	0.37	0.08	98.30
68.56	23.94	4.45	0.59	0.37	0.48	0.08	98.47
73.17	19.60	4.13	0.57	0.37	0.45	0.08	98.37
82.97	13.03	1.50	0.34	0.20	0.23	0.09	98.36
93.69	4.70	1.98	0.21	0.16	0.15	0.04	100.93
94.15	3.95	1.46	0.17	0.13	0.12	0.05	100.03
87.12	7.84	2.67	0.42	0.18	0.29	0.07	98.59
89.84	6.03	2.88	0.62	0.28	0.33	0.10	100.08
90.60	5.81	2.73	0.60	0.23	0.32	0.13	100.42
90.30	4.30	2.46	0.57	0.61	0.24	0.06	98.54
82.84	10.04	5.60	0.49	0.27	0.25	0.05	99.54
59.65	31.10	5.26	1.15	0.76	0.56	0.12	98.60
58.01	34.04	4.45	0.77	0.58	0.45	0.12	98.42
57.70	35.56	3.68	0.55	0.35	0.34	0.10	98.28
59.00	33.74	4.05	0.66	0.41	0.44	0.11	98.41
59.80	33.15	4.04	0.51	0.49	0.44	0.12	98.55
60.70	31.97	3.95	0.62	0.54	0.43	0.09	98.30
79.12	13.20	3.94	0.89	0.48	0.46	0.09	98.18

Description

Footage (feet)	Thickness (feet)	Formation and Lithology
585.9-597.4	11	Limestone, light-olive-gray, micrograined to fine-grained, some birdseye calcite; greenish-gray dolomite mottling in upper 0.5 ft; shale partings.
597.4-604.4	7	Limestone, yellowish-gray to olive-gray, micrograined to very finely crystalline, mottled with dark-yellowish-gray, finely crystalline dolomite and black argillaceous burrows; bioclastic calcilutite-calcarenite with brownish-gray and grayish-black mottling, stylolites from 601.2 to 603 ft.
604.4-635	31	Limestone, light-olive-gray, in part with yellowish-gray and black mottling in upper 2 ft.; micrograined to very fine-grained; in part earthy porcelaneous texture and dolomitic with black argillaceous mottling; bioclastic calcilutite from 623.2 to 624.1 ft.; dark-gray to brownish-gray bioclastic calcarenite from 633 to 634.6 ft.; shaly partings at base.
635-642.4	7	**Oregon Formation** Dolomite, pale-yellowish-brown to light-olive-gray to light-gray, with dark-gray mottling; finely crystalline; in part limy; shale partings at base.

Chemical Analysis

% $CaCO_3$	% $MgCO_3$	% SiO_2	% Al_2O_3	% Fe_2O_3	% K_2O	% Na_2O	% Total
88.15	2.70	6.38	0.64	0.15	0.17	0.04	98.23
86.89	5.00	5.10	1.17	0.58	0.51	0.11	99.36
87.70	5.60	5.01	1.06	0.58	0.50	0.09	100.54
90.78	3.26	2.76	0.59	0.30	0.26	0.10	98.05
93.01	2.46	3.09	0.93	0.55	0.38	0.08	100.50
88.52	3.61	4.15	0.81	0.54	0.40	0.09	98.12
68.80	11.00	16.02	2.49	1.45	0.79	0.18	100.73
86.91	5.01	4.01	1.73	0.90	0.70	0.15	99.41
87.09	5.60	3.11	0.93	0.86	0.41	0.08	98.08
96.09	1.71	1.05	0.19	0.11	0.13	0.03	99.31
96.45	0.82	0.80	0.11	0.10	0.08	0.06	98.42
92.57	0.94	2.86	0.81	0.12	0.66	0.08	98.04
96.99	1.20	1.58	0.30	0.11	0.24	0.04	100.46
88.44	8.13	1.81	0.42	0.05	0.24	0.04	99.13
90.20	6.25	2.05	0.40	0.08	0.26	0.05	99.29
89.93	5.40	2.00	0.36	0.06	0.25	0.04	98.04
90.03	5.27	2.00	0.40	0.28	0.26	0.05	98.29
87.99	7.05	2.09	0.43	0.26	0.26	0.05	98.13
86.06	8.80	2.30	0.50	0.30	0.28	0.05	98.29
88.88	6.90	1.80	0.50	0.36	0.27	0.12	98.83
91.83	4.30	1.75	0.30	0.25	0.17	0.07	98.67
93.12	3.15	1.81	0.15	0.13	0.11	0.05	98.52
93.18	3.45	1.72	0.47	0.26	0.20	0.07	99.35
93.30	3.60	2.31	0.79	0.42	0.35	0.07	100.84
90.98	5.70	1.25	0.23	0.15	0.13	0.04	98.48
90.85	5.75	1.00	0.19	0.12	0.10	0.04	98.05
90.70	5.92	1.66	0.45	0.22	0.21	0.04	99.20
90.10	5.40	1.78	0.47	0.21	0.19	0.04	98.19
89.77	6.48	1.30	0.21	0.14	0.12	0.04	98.06
88.20	9.05	1.00	0.17	0.15	0.10	0.05	98.72
88.69	8.31	0.95	0.19	0.13	0.10	0.06	98.43
89.66	6.75	1.50	0.34	0.18	0.23	0.07	98.73
84.96	6.67	4.26	1.00	0.50	0.57	0.17	98.13
89.22	6.63	2.13	0.42	0.23	0.17	0.04	98.84
85.45	9.14	2.78	0.59	0.29	0.26	0.10	98.61
86.91	7.79	2.68	0.57	0.35	0.25	0.11	98.66
79.70	13.18	4.14	0.91	0.46	0.40	0.13	98.92
82.02	12.04	2.95	0.46	0.28	0.24	0.06	98.05
84.11	11.90	2.15	0.30	0.17	0.16	0.06	98.85
82.90	11.87	3.39	0.77	0.38	0.36	0.11	99.78
80.50	10.77	5.71	1.00	0.14	0.40	0.09	98.61
80.70	11.00	4.88	0.85	0.43	0.36	0.09	98.31

Description

Footage (feet)	Thickness (feet)	Formation and Lithology
642.4-666.7	24	**Camp Nelson Limestone** Limestone, light-olive-gray to pale-yellowish-brown, with dark-gray mottling, micrograined, with birds-eyes and veinlets of calcite; mottled with irregular bodies of greenish-gray, finely crystalline dolo mite, in part medium-light-gray calcarenite from 663 to 666.7 ft.; white agate chert at 664.4 ft.; stylolites.
666.7-684.4	18	Limestone, light-olive-gray to yellowish-gray, micrograined; with yellowish-gray to light-olive-gray to olive-gray, finely crystalline dolomite; thin zones of calcarenite, in part dark-greenish-gray, stylolites; argillaceous and shaly partings at 678.5 and 682.9 ft.

Chemical Analysis

% $CaCO_3$	% $MgCO_3$	% SiO_2	% Al_2O_3	% Fe_2O_3	% K_2O	% Na_2O	% *Total*
85.40	9.72	2.25	0.30	0.36	0.16	0.07	98.26
83.20	12.06	2.53	0.36	0.43	0.19	0.07	98.84
83.89	11.78	2.00	0.25	0.15	0.13	0.07	98.27
87.30	8.82	1.63	0.15	0.14	0.12	0.08	98.24
91.25	4.26	2.00	0.20	0.15	0.11	0.05	98.02
89.82	6.60	1.55	0.20	0.15	0.10	0.05	98.47
88.90	7.65	1.30	0.12	0.11	0.07	0.05	98.20
87.80	7.59	2.70	0.43	0.23	0.18	0.04	98.97
85.00	8.84	4.07	0.43	0.22	0.18	0.04	98.78
90.00	5.83	3.11	0.28	0.15	0.12	0.04	99.53
88.26	6.45	3.29	0.32	0.18	0.14	0.07	98.71
85.23	9.39	2.79	0.32	0.20	0.14	0.05	98.12
88.74	8.00	2.34	0.25	0.23	0.13	0.06	99.75
79.97	11.20	7.28	0.36	0.29	0.19	0.10	99.39
90.09	7.60	1.33	0.19	0.17	0.12	0.09	99.59
86.96	7.70	3.59	0.21	0.13	0.12	0.09	98.80
84.68	8.98	4.96	0.21	0.15	0.12	0.10	99.20
86.88	8.91	1.97	0.28	0.17	0.16	0.09	98.46
88.00	8.75	2.37	0.45	0.25	0.20	0.07	100.09
91.58	6.26	1.57	0.23	0.13	0.10	0.09	99.96
91.67	4.79	2.07	0.11	0.12	0.08	0.08	98.92
91.50	6.32	1.87	0.19	0.11	0.10	0.09	100.18
89.00	8.01	2.60	0.40	0.19	0.18	0.07	100.45
88.01	8.57	1.61	0.25	0.14	0.10	0.07	98.75
89.33	7.61	1.57	0.15	0.08	0.07	0.05	98.86
91.60	5.85	1.70	0.23	0.11	0.12	0.05	99.66
88.50	8.54	2.12	0.42	0.22	0.17	0.05	100.02
90.56	7.25	1.31	0.17	0.10	0.07	0.04	99.50
91.03	7.01	1.38	0.19	0.12	0.07	0.04	99.84
89.81	8.25	1.94	0.34	0.15	0.12	0.06	100.67
88.56	8.72	1.89	0.28	0.16	0.14	0.08	99.83
88.96	7.12	1.79	0.17	0.17	0.13	0.09	98.43
89.01	6.99	1.57	0.17	0.18	0.13	0.07	98.12
92.08	6.10	1.53	0.19	0.11	0.12	0.07	100.20
91.53	6.75	1.43	0.17	0.13	0.11	0.07	100.19
93.55	4.01	1.40	0.25	0.11	0.10	0.08	99.50
91.80	7.01	1.27	0.23	0.09	0.09	0.04	100.53
92.14	6.00	1.28	0.17	0.10	0.10	0.06	99.85
92.90	5.50	1.84	0.26	0.15	0.14	0.09	100.88
88.60	9.20	1.83	0.34	0.25	0.17	0.15	100.54
66.80	26.66	5.68	0.34	0.23	0.15	0.10	99.96
90.61	4.91	1.69	0.28	0.50	0.12	0.17	98.28
89.56	6.95	1.59	0.23	0.09	0.10	0.04	98.56
89.99	6.02	1.60	0.19	0.15	0.09	0.08	98.12
89.00	9.36	1.56	0.15	0.12	0.08	0.05	100.32
90.49	5.26	1.94	0.19	0.15	0.12	0.07	98.22
78.00	3.60	15.97	0.11	0.29	0.17	0.10	98.24
91.73	5.79	1.55	0.21	0.13	0.09	0.06	99.56
89.07	9.03	1.47	0.15	0.16	0.06	0.06	100.00
86.99	5.29	5.63	0.16	0.16	0.06	0.04	98.33
91.36	5.31	1.29	0.15	0.11	0.06	0.03	98.31
91.95	4.39	1.37	0.13	0.13	0.07	0.05	98.09
93.75	3.31	1.19	0.25	0.10	0.09	0.07	98.76
94.62	2.19	1.15	0.17	0.09	0.09	0.06	98.37
95.40	3.56	0.99	0.11	0.07	0.06	0.05	100.24
92.71	5.85	1.10	0.17	0.11	0.09	0.06	100.09
87.26	10.40	1.19	0.17	0.12	0.11	0.06	99.31
84.29	12.70	1.40	0.23	0.13	0.12	0.10	98.97
94.44	3.73	1.41	0.17	0.16	0.10	0.06	100.07
90.38	6.22	1.26	0.28	0.16	0.14	0.05	98.49
92.17	3.97	2.09	0.28	0.17	0.15	0.07	98.90
90.01	7.30	2.20	0.34	0.18	0.17	0.06	100.26
87.39	6.20	3.20	0.63	0.30	0.31	0.15	98.18
86.97	8.06	2.76	0.39	0.19	0.25	0.16	98.78
77.97	12.49	5.43	0.92	0.37	0.70	0.24	98.12
82.19	10.94	4.00	0.44	0.13	0.32	0.19	98.21

Description

Footage (feet)	Thickness (feet)	Formation and Lithology
684.4-743.4	59	Limestone, light-olive-gray to yellowish-gray, micrograined, birdseye calcite, in part with floating bioclastic debris; with greenish-gray to light-olive-gray dolomite; scattered tripolitic chert; birdseye calcite; stylolites, vertical fracture with argillaceous parting at 727 ft.; chert with relict bioclastic texture at 731.2 ft.; thin zones of light-brownish-gray, bioclastic calcilutite from 738 to 741 ft.; very light-gray, with dark mottling, earthy texture in basal 0.5 ft.
743.4-749.9	6	Limestone, light-olive-gray to olive-gray, fine-to medium-grained; thin zones of calcilutite with floating and bioclastic calcarenite; dolomite stringers at 743.4 and 747 ft.; mainly yellowish-gray to light-olive-gray, micrograined, with birdseye and veinlets of calcite, stylolites in lower 3 ft.; in part medium-dark-gray, fine-grained, argillaceous with floating bioclastic grains in lower 3 ft.; mottled with irregular bodies of greenish-gray, fine-grained dolomite at 749 ft.

Chemical Analysis

% $CaCO_3$	% $MgCO_3$	% SiO_2	% Al_2O_3	% Fe_2O_3	% K_2O	% Na_2O	% Total
92.48	4.91	2.18	0.29	0.08	0.26	0.16	100.36
92.39	4.11	2.13	0.39	0.12	0.30	0.14	99.58
95.15	3.50	1.15	0.15	0.09	0.09	0.08	100.21
95.83	1.50	0.89	0.13	0.09	0.09	0.06	98.59
95.55	2.91	0.75	0.10	0.09	0.10	0.06	99.56
95.00	3.37	0.77	0.21	0.11	0.12	0.07	99.65
91.90	4.35	2.96	0.70	0.12	0.36	0.11	100.50
86.40	6.90	4.51	1.33	0.13	0.65	0.19	100.11
88.06	6.30	3.80	0.90	0.47	0.43	0.22	100.18
91.95	3.79	3.25	0.49	0.28	0.27	0.12	100.15
91.40	5.30	2.71	0.30	0.24	0.36	0.14	100.45
92.16	4.50	2.50	0.38	0.22	0.34	0.11	100.21
95.67	2.40	1.61	0.25	0.14	0.23	0.09	100.39
91.03	2.26	4.85	0.87	0.42	0.87	0.29	100.59
95.14	2.18	2.12	0.36	0.18	0.31	0.13	100.42
91.26	4.47	3.43	0.68	0.38	0.49	0.27	100.98
93.18	4.13	1.88	0.26	0.18	0.22	0.09	99.94
82.16	9.55	4.96	0.80	0.39	0.75	0.36	98.97
89.48	6.00	3.40	0.53	0.25	0.50	0.27	100.43
90.08	5.90	3.30	0.44	0.23	0.37	0.19	100.51
87.58	7.50	3.45	0.70	0.47	0.35	0.23	100.28
88.02	7.29	3.47	0.80	0.41	0.37	0.20	100.56
87.07	8.06	3.44	0.70	1.00	0.33	0.17	100.77
76.80	7.20	11.59	2.55	0.50	1.71	0.47	100.82
85.99	5.00	4.97	1.26	0.26	0.73	0.29	98.50
90.03	5.75	2.26	0.47	0.17	0.63	0.21	99.52
92.09	5.09	1.38	0.26	0.27	0.74	0.26	100.09
91.57	5.08	1.01	0.19	0.24	0.07	0.05	98.21
87.84	7.59	2.47	0.42	0.13	0.10	0.06	98.61
83.64	8.80	3.94	0.91	0.22	0.43	0.17	98.11
82.20	10.97	2.97	1.34	0.49	0.56	0.27	98.80
85.29	8.97	3.00	0.70	0.79	0.29	0.19	99.23
87.23	6.81	2.99	0.61	0.49	0.30	0.17	98.60
71.73	14.29	8.94	2.26	0.50	0.36	0.19	98.27
70.75	14.63	8.28	2.17	1.15	0.80	0.53	98.31
72.69	13.25	9.51	2.25	1.17	0.90	0.41	100.18
88.42	8.04	1.80	0.47	1.11	0.13	0.06	100.03
88.77	8.16	2.10	0.30	0.21	0.16	0.10	99.80
88.94	6.99	2.13	0.26	0.29	0.26	0.14	99.01
90.34	6.57	1.30	0.17	0.24	0.12	0.07	98.81
92.89	3.77	1.19	0.09	0.19	0.07	0.09	98.29
90.60	6.00	2.09	0.25	0.15	0.17	0.12	99.38
86.99	8.68	2.33	0.47	0.23	0.27	0.17	99.14
82.48	9.65	4.03	1.02	0.39	0.56	0.34	98.47
87.31	4.14	4.59	1.02	0.40	0.59	0.37	98.42
79.88	10.25	5.71	1.40	0.54	0.65	0.41	98.84
90.79	3.49	2.47	0.59	0.26	0.34	0.19	98.13
88.22	3.28	4.29	1.02	0.41	0.60	0.43	98.25
89.95	4.25	2.60	0.50	0.30	0.27	0.20	98.07
91.95	3.65	3.26	0.25	0.17	0.13	0.11	99.52
83.36	8.05	4.60	1.15	0.53	0.40	0.30	98.39
87.31	4.31	4.71	1.30	0.59	0.53	0.36	99.11
90.50	3.00	2.98	0.75	0.34	0.30	0.21	98.08
94.35	1.60	1.75	0.34	0.17	0.16	0.08	98.45
94.07	1.36	1.89	0.34	0.18	0.17	0.11	98.12
92.87	1.81	3.00	0.30	0.20	0.23	0.11	98.52
90.49	3.29	2.97	0.75	0.20	0.26	0.10	98.06
90.01	3.08	3.19	0.87	0.41	0.37	0.24	98.17
73.70	12.36	9.53	1.59	0.50	0.84	0.42	98.94
88.53	4.43	4.74	0.81	0.31	0.59	0.39	99.80

Description

Footage (feet)	Thickness (feet)	Formation and Lithology
749.9-785.9	36	Limestone, olive-gray, fine-to medium-grained; bioclastic calcilutite to calcarenite with floating bioclastic debris, burrows, scattered shale partings, and floating brachiopod fragments; light-olive-gray, micro-grained with some birdseye calcite from 763.3 to 769 ft.; brachiopod fragments at 756.5 ft.; yellowish to greenish dolomite mottling from 769.2 to 785.9 ft.; scattered shale parting and some dark mottling in basal 4 feet; green bentonite shale from 774.5 to 774.9 ft. with biotite and some calcite.
785.9-788.1	3	Limestone, medium-gray to light-bluish-gray, fine-grained, with light-yellow dolomite mottling; with shaly partings.
788.1-812.6	24	Limestone, light-olive-gray to yellowish-gray, micrograined; fossiliferous; with irregular bodies of yellow dolomite; thin zones of calcarenite; some gastropods; light-olive-gray to yellowish-gray, medium-grained with occasional shale partings from 798.6 to 805 ft.; brownish-gray to olive-gray, micrograined, with birds-eye calcite, and dark-gray dolomite-burrow mottling at base.

Chemical Analysis

% $CaCO_3$	% $MgCO_3$	% SiO_2	% Al_2O_3	% Fe_2O_3	% K_2O	% Na_2O	% Total
77.02	9.51	9.49	1.32	0.40	0.89	0.61	99.24
80.28	6.26	8.28	1.32	0.48	0.80	0.58	98.00
81.21	8.50	7.07	1.25	0.41	0.65	0.44	99.53
90.56	2.85	3.09	0.72	0.28	0.44	0.21	98.15
84.46	5.44	6.16	1.06	0.35	0.66	0.25	98.38
84.64	5.96	6.23	1.17	0.39	0.69	0.22	99.30
93.60	2.90	2.70	0.45	0.15	0.35	0.14	100.29
94.01	1.80	2.73	0.59	0.20	0.41	0.17	99.91
86.01	4.25	5.52	1.17	0.43	0.66	0.44	98.48
90.97	2.21	3.31	0.55	0.18	0.62	0.35	98.19
86.51	4.50	5.16	0.96	0.27	0.62	0.37	98.39
89.40	3.51	3.99	0.70	0.24	0.60	0.45	98.89
94.04	1.64	1.72	0.25	0.20	0.25	0.13	98.23
93.03	1.56	2.58	0.38	0.15	0.35	0.14	98.19
90.05	1.85	5.32	1.00	0.36	0.64	0.24	99.46
80.95	6.34	8.64	1.59	0.48	0.71	0.39	99.10
84.80	4.56	5.95	0.96	0.32	1.00	0.77	98.36
82.64	6.03	7.85	1.59	0.54	0.90	0.71	100.26
83.07	3.93	9.60	1.70	0.53	0.96	0.54	100.33
73.89	2.90	18.56	1.97	0.49	1.59	0.78	100.18
65.04	3.10	24.96	2.36	0.47	1.81	0.94	98.68
90.30	3.09	4.08	0.49	0.13	0.43	0.20	98.72
84.96	4.38	6.59	0.89	0.28	0.67	0.28	98.05
85.49	3.25	7.20	1.49	0.59	0.90	0.53	99.45
85.94	9.05	2.79	0.55	0.16	0.40	0.11	99.00
89.36	4.68	2.79	0.44	0.38	0.29	0.13	98.07

Description

Footage (feet)	Thickness (feet)	Formation and Lithology
812.6-838	26	Limestone, light-greenish-gray to brownish-gray, in part olive-black to yellowish-gray; calcilutite and bioclastic calcisiltite; scattered specks of pyrite, chalcopyrite, and veinlets of calcite; scattered shale partings; thin zones of olive-gray, with black mottling, calcilutite; 1-in. green shale with rounded calcilutite fragments at base.

Chemical Analysis

% $CaCO_3$	% $MgCO_3$	% SiO_2	% Al_2O_3	% Fe_2O_3	% K_2O	% Na_2O	% Total
88.84	6.04	2.59	0.53	0.17	0.38	0.12	98.67
90.90	5.70	1.10	0.17	0.13	0.11	0.08	98.19
92.73	3.96	0.95	0.10	0.13	0.10	0.08	98.05
93.07	5.02	0.85	0.09	0.11	0.09	0.06	99.29
79.30	14.88	2.75	0.49	0.26	0.35	0.15	98.18
86.56	9.25	1.80	0.25	0.20	0.18	0.10	98.34
94.27	2.09	1.95	0.34	0.15	0.11	0.07	98.98
93.09	3.41	2.26	0.43	0.20	0.30	0.19	99.88
83.29	9.98	3.74	0.90	0.31	0.52	0.27	99.01
83.69	11.02	3.35	0.94	0.25	0.42	0.22	99.89
89.09	6.60	2.88	0.69	0.25	0.39	0.21	100.11
84.76	5.34	5.25	1.66	0.42	0.85	0.37	98.65
86.70	4.21	4.45	1.42	0.36	0.65	0.25	98.04
83.64	3.80	7.95	2.08	0.55	0.80	0.17	98.99
85.68	3.06	6.25	1.70	0.49	0.80	0.20	98.18
89.62	2.96	3.74	0.94	0.28	0.75	0.30	98.59
85.04	6.55	4.90	1.27	0.39	0.51	0.20	98.86
92.08	3.43	2.00	0.34	0.14	0.20	0.09	98.28
90.02	4.76	2.89	0.57	0.18	0.34	0.05	98.81
87.01	6.89	3.98	1.00	0.28	0.56	0.10	99.82
87.97	5.01	3.79	0.95	0.35	0.53	0.20	98.80
86.91	4.83	3.96	1.10	0.36	0.58	0.37	98.11
82.68	6.33	7.72	2.08	0.53	0.80	0.41	100.55
84.71	5.10	5.59	1.74	0.44	0.68	0.20	98.46
73.99	8.53	10.94	3.21	0.80	1.40	0.20	99.07
86.90	4.56	4.55	1.23	0.33	0.56	0.24	98.39
90.90	5.17	2.00	0.42	0.19	0.24	0.11	99.03
90.45	5.01	2.29	0.70	0.39	0.42	0.27	99.53
92.88	5.11	1.61	0.26	0.17	0.16	0.09	100.28
89.40	6.73	2.97	0.74	0.29	0.44	0.21	100.78
86.19	5.67	4.58	1.32	0.44	0.59	0.37	99.16
86.80	5.30	5.32	1.47	0.42	0.69	0.40	100.40
90.03	3.34	4.30	1.25	0.39	0.52	0.30	100.13
81.14	4.69	9.99	2.46	0.71	1.00	0.35	100.34
83.10	5.65	7.87	1.93	0.61	0.71	0.37	100.24
90.00	2.76	4.31	1.23	0.43	0.49	0.20	99.42
92.66	2.20	2.19	0.64	0.20	0.09	0.10	98.08
84.60	3.98	6.43	2.15	0.63	0.21	0.15	98.15
83.56	6.39	6.17	1.98	0.55	0.17	0.13	98.95
88.61	2.59	5.25	1.72	0.51	0.10	0.05	98.83
88.37	2.79	4.89	1.49	0.41	0.31	0.19	98.45
84.91	6.37	4.41	1.47	0.47	0.29	0.24	98.16
85.17	11.47	0.89	0.38	0.15	0.17	0.07	98.30
86.50	11.90	0.75	0.47	0.16	0.11	0.04	99.93
84.77	11.69	1.35	0.36	0.20	0.17	0.13	98.67
83.70	11.55	2.60	0.82	0.41	0.39	0.05	99.52
91.01	6.00	2.30	0.68	0.29	0.35	0.03	100.66
89.06	5.81	2.06	0.62	0.28	0.32	0.08	98.23
89.33	5.82	3.26	1.09	0.45	0.46	0.05	100.46
91.90	5.50	1.52	0.59	0.22	0.25	0.04	100.02
89.34	7.41	2.02	0.53	0.28	0.35	0.02	99.95
86.14	6.83	4.00	0.38	0.34	0.70	0.03	98.42
88.61	4.39	3.59	1.06	0.36	0.65	0.04	98.70
87.82	10.29	1.00	1.17	0.13	0.20	0.03	100.64
NO ANALYSIS							

Description

Footage (feet)	Thickness (feet)	Formation and Lithology
838-881.3	43	Limestone, light-brownish-gray to yellowish-gray to light-olive-gray, with irregular black mottling, micro-grained; in part with irregular bodies of light-olive-gray dolomite and thin zones of bioclastic calcarenite and calcilutite with floating bioclastic grains; birdseyes and veinlets of calcite; scattered pyrite and shale partings; medium-gray to brownish-gray micrograined, with scattered shaly dolomitic zones in lower 18 ft.
881.3-892.1	10	Limestone, yellowish-gray to olive-gray, with black mottling, micrograined; in part with irregular bodies of dark-yellowish-gray dolomite; birdseyes and veinlets of calcite; stylolites.
892.1-896.1	4	Core loss.

Chemical Analysis

% $CaCO_3$	% $MgCO_3$	% SiO_2	% Al_2O_3	% Fe_2O_3	% K_2O	% Na_2O	% Total
84.02	12.01	1.70	0.44	0.21	0.33	0.05	98.76
84.13	12.17	2.14	0.59	0.30	0.40	0.07	99.80
85.49	11.08	0.98	0.18	0.14	0.17	0.07	98.11
84.81	12.05	0.80	0.09	0.29	0.12	0.06	98.22
88.70	9.70	0.83	0.08	0.10	0.09	0.05	99.55
84.18	11.28	1.61	0.75	0.11	0.11	0.07	98.11
82.74	12.98	1.88	0.17	0.14	0.16	0.05	98.12
82.43	14.39	1.90	0.49	0.24	0.36	0.11	99.92
83.36	13.48	1.53	0.50	0.18	0.09	0.05	99.19
86.15	12.08	0.85	0.15	0.13	0.14	0.04	99.54
83.68	12.98	0.98	0.10	0.15	0.10	0.07	98.06
84.51	12.45	0.93	0.08	0.13	0.09	0.05	98.24
83.99	13.15	0.66	0.06	0.11	0.08	0.04	98.09
85.09	11.86	0.75	0.09	0.13	0.09	0.06	98.07
86.20	10.12	1.24	0.25	0.15	0.25	0.07	98.28
85.20	11.30	1.59	0.08	0.19	0.28	0.04	98.68
81.17	12.40	3.39	0.16	0.35	0.61	0.11	98.19
84.87	12.03	1.52	0.31	0.16	0.23	0.09	99.21
85.55	11.49	0.89	0.14	0.13	0.12	0.07	98.39
85.72	11.66	0.58	0.08	0.11	0.11	0.05	98.31
85.97	11.13	0.59	0.09	0.11	0.10	0.07	98.06
83.64	12.95	1.60	0.45	0.12	0.25	0.10	99.11
83.22	12.58	1.55	0.21	0.13	0.29	0.09	98.07
82.82	13.15	1.04	0.39	0.22	0.27	0.19	98.08
84.25	12.36	0.70	0.16	0.13	0.30	0.13	98.03
88.01	7.89	1.63	0.07	0.21	0.31	0.19	98.31
86.89	7.87	3.26	0.11	0.09	0.05	0.05	98.32
89.24	7.99	1.13	0.08	0.24	0.05	0.10	98.83
89.31	6.83	2.07	0.09	0.24	0.36	0.23	99.13
89.08	6.53	1.90	0.20	0.17	0.12	0.15	98.15
84.48	12.62	0.68	0.18	0.10	0.07	0.10	98.23
86.55	11.62	0.39	0.08	0.10	0.07	0.03	98.84
77.39	19.80	0.50	0.06	0.13	0.11	0.07	98.06
82.23	17.07	0.52	0.07	0.15	0.11	0.05	100.20
84.98	9.95	2.28	0.11	0.32	0.30	0.15	98.09
88.02	4.78	3.68	0.17	0.49	0.59	0.34	98.07
85.41	8.25	3.73	0.11	0.25	0.22	0.14	98.11
87.31	8.10	4.03	0.03	0.18	0.17	0.11	99.93
88.75	7.03	3.36	0.05	0.11	0.06	0.05	99.41
89.01	6.62	3.55	0.03	0.10	0.10	0.06	99.47
82.05	14.03	3.57	0.02	0.12	0.11	0.04	99.94
81.77	14.65	3.59	0.02	0.17	0.09	0.02	100.31
87.65	8.01	3.45	0.04	0.08	0.07	0.03	99.33
83.75	11.45	4.03	0.03	0.16	0.18	0.10	99.70
75.46	18.82	4.11	0.04	0.18	0.20	0.10	98.91
82.88	13.68	3.50	0.04	0.14	0.15	0.03	100.42
79.40	17.60	1.71	0.07	0.16	0.10	0.03	99.07
80.83	16.03	1.37	0.04	0.07	0.03	0.03	98.40
82.30	16.77	0.42	0.03	0.10	0.06	0.05	99.73
81.93	18.08	0.54	0.02	0.13	0.07	0.05	100.82
81.64	15.59	0.59	0.09	0.13	0.08	0.05	98.17
80.49	16.57	0.77	0.09	0.14	0.11	0.10	98.27
81.36	15.83	0.69	0.05	0.11	0.08	0.05	98.17
79.15	18.26	0.47	0.04	0.14	0.05	0.05	98.16
86.38	12.21	0.36	0.03	0.11	0.03	0.01	99.13
81.15	18.08	0.54	0.02	0.15	0.08	0.04	100.06
81.55	16.92	0.79	0.03	0.16	0.10	0.07	99.62
93.20	3.21	1.04	0.10	0.23	0.15	0.09	98.02
93.86	2.06	1.59	0.08	0.37	0.09	0.06	98.11
93.92	1.72	2.00	0.09	0.23	0.27	0.10	98.33
86.31	4.80	5.90	0.05	0.65	1.34	0.67	99.72
90.06	4.24	5.23	0.04	0.53	0.59	0.13	100.82
89.99	5.07	1.76	0.08	0.57	0.46	0.16	98.09
90.48	4.87	1.89	0.06	0.49	0.19	0.09	98.07
91.39	4.65	1.46	0.06	0.21	0.18	0.15	98.10

Description

Footage (feet)	Thickness (feet)	Formation and Lithology
896.1-962.6	67	Limestone, yellowish-gray to light-olive-gray, micrograined to fine-grained with irregular bodies of yellowish-gray to greenish-gray, medium-grained dolomite; in part with floating bioskeletal debris and some birdseye calcite; stylolites; in part medium-dark-gray, micrograined with traces of organic matter from 922.5 to 925.6 ft.; brownish-gray micrograined with birdseye texture at 955.2 ft.

Chemical Analysis

% $CaCO_3$	% $MgCO_3$	% SiO_2	% Al_2O_3	% Fe_2O_3	% K_2O	% Na_2O	% Total
90.00	4.88	2.39	0.03	0.33	0.74	0.39	98.76
87.05	6.09	5.08	0.01	0.58	0.90	0.26	99.97
79.50	9.85	8.10	0.02	0.79	1.12	0.50	99.88
93.82	5.02	1.40	0.02	0.21	0.16	0.07	100.70
84.50	11.41	3.20	0.02	0.74	0.11	0.05	100.03
85.60	8.72	4.69	0.08	0.51	0.19	0.09	99.88
82.13	8.75	6.87	0.15	0.52	0.22	0.13	98.77
75.50	6.25	12.46	2.77	1.01	0.63	0.51	99.13
66.40	15.43	13.60	3.09	1.11	0.48	0.32	100.43
74.57	8.21	13.66	0.39	1.09	0.32	0.24	98.48
75.75	8.42	12.71	0.27	1.09	0.25	0.11	98.60
85.86	5.72	6.79	0.10	0.66	0.09	0.07	99.29
70.94	8.86	13.99	3.49	1.39	0.79	0.53	99.99
95.01	3.40	1.84	0.02	0.26	0.05	0.03	100.61
94.91	3.52	1.57	0.04	0.30	0.05	0.04	100.43
95.95	2.20	1.50	0.09	0.22	0.04	0.03	100.03
93.20	4.18	1.11	0.30	0.17	0.00	0.00	99.00
92.00	4.71	1.40	0.36	0.17	0.00	0.00	98.70
93.40	3.02	1.50	0.47	0.17	0.00	0.00	98.60
88.20	5.41	2.86	0.82	0.27	0.00	0.00	97.60
55.80	12.00	16.20	2.79	1.67	0.00	0.00	88.50
92.20	3.73	1.89	0.49	0.18	0.00	0.00	98.50
85.50	5.91	4.34	1.17	0.42	0.00	0.00	97.30
67.60	11.30	11.20	2.60	1.04	0.00	0.00	93.70
76.80	8.86	7.47	1.84	0.64	0.00	0.00	95.60
91.90	3.69	1.82	0.45	0.17	0.00	0.00	98.00
66.30	12.50	11.20	2.36	1.00	0.00	0.00	93.40
59.80	14.80	13.50	2.40	1.22	0.00	0.00	91.70
61.90	9.62	14.10	2.48	1.20	0.00	0.00	89.30
65.80	8.64	13.30	2.84	1.24	0.00	0.00	91.80
85.80	4.25	4.57	1.12	0.38	0.00	0.00	96.20
85.70	4.25	4.96	1.15	0.37	0.00	0.00	96.40
87.70	3.83	4.11	0.95	0.29	0.00	0.00	96.90
76.80	6.72	8.10	1.76	0.62	0.00	0.00	94.00
85.50	4.33	5.14	1.01	0.29	0.00	0.00	96.30
81.40	5.35	7.20	1.30	0.43	0.00	0.00	95.70
76.00	9.66	7.84	1.40	0.54	0.00	0.00	95.40
62.30	25.30	7.57	1.07	0.53	0.00	0.00	96.70

Description

Footage (feet)	Thickness (feet)	Formation and Lithology
962.6-999.9	38	Limestone, light-olive-gray to brownish-gray, with black mottling, micrograined; in part laminated with thin shale partings, interbedded with several 2- to 4-in. green dolomitic shales; dolomitic in basal foot.

Chemical Analysis

% $CaCO_3$	% $MgCO_3$	% SiO_2	% Al_2O_3	% Fe_2O_3	% K_2O	% Na_2O	% Total
52.20	22.10	14.80	2.18	1.20	0.00	0.00	92.50
28.30	4.34	5.32	15.90	1.55	0.00	0.00	55.40
47.90	30.60	13.90	1.49	1.02	0.00	0.00	94.90
44.40	29.90	15.90	1.61	1.45	0.00	0.00	93.30
51.80	32.90	11.10	1.21	0.68	0.00	0.00	97.70
53.70	34.90	9.04	0.99	0.66	0.00	0.00	99.30
56.10	34.40	7.53	0.78	0.57	0.00	0.00	99.40
50.40	36.90	10.00	1.01	0.78	0.00	0.00	99.10
47.50	32.50	12.90	1.48	1.19	0.00	0.00	95.60
53.30	35.10	8.81	1.07	0.71	0.00	0.00	99.00
45.90	28.40	16.00	1.62	1.44	0.00	0.00	93.30
55.40	31.80	9.73	1.01	0.76	0.00	0.00	98.80
60.90	32.10	5.22	0.59	0.49	0.00	0.00	99.20
53.40	31.90	11.60	0.88	0.67	0.00	0.00	98.50
55.80	32.00	8.66	0.70	0.56	0.00	0.00	97.70
52.40	34.10	9.62	1.19	0.86	0.00	0.00	98.20
50.40	36.00	9.22	1.30	0.91	0.00	0.00	97.80
41.80	28.10	17.50	1.54	2.03	0.00	0.00	91.00
50.60	33.70	10.40	1.49	0.93	0.00	0.00	97.10
47.50	29.50	13.90	1.73	1.18	0.00	0.00	93.90
47.40	30.00	14.20	1.81	1.27	0.00	0.00	94.80
49.50	31.30	12.90	1.67	1.18	0.00	0.00	96.60
50.80	32.50	12.40	1.32	0.96	0.00	0.00	97.90
51.00	31.40	13.10	1.03	0.84	0.00	0.00	97.40
50.90	31.60	11.30	1.43	0.82	0.00	0.00	96.10
49.40	31.80	12.70	1.62	1.07	0.00	0.00	96.70
49.80	32.70	11.10	1.34	0.89	0.00	0.00	95.80
53.40	32.60	10.50	0.85	0.67	0.00	0.00	98.00
49.90	32.30	11.30	1.37	0.91	0.00	0.00	95.80
47.20	30.90	13.40	1.60	1.13	0.00	0.00	94.30
51.00	31.80	11.90	1.14	0.80	0.00	0.00	96.70
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
47.70	31.50	13.50	1.68	1.19	0.00	0.00	95.50
38.40	25.10	19.60	1.02	2.61	0.00	0.00	86.70
46.10	30.70	15.10	1.72	1.48	0.00	0.00	95.10
51.00	34.80	10.90	1.09	0.87	0.00	0.00	98.60
43.60	26.60	17.70	1.75	1.77	0.00	0.00	91.30
40.70	22.70	20.90	1.50	2.18	0.00	0.00	88.00
48.80	29.20	15.90	1.53	1.22	0.00	0.00	96.60
47.90	26.00	17.30	1.85	1.44	0.00	0.00	94.40
46.70	26.60	16.60	1.86	1.38	0.00	0.00	93.20
46.80	28.60	15.90	1.86	1.44	0.00	0.00	94.60
42.90	24.10	19.10	1.71	1.86	0.00	0.00	89.70
46.30	27.90	15.20	1.62	1.13	0.00	0.00	92.20
46.30	30.80	14.00	1.62	1.34	0.00	0.00	94.00
43.10	27.00	17.30	1.65	1.84	0.00	0.00	90.80
49.40	31.10	13.30	1.39	0.92	0.00	0.00	96.20
47.10	32.00	14.80	1.60	1.20	0.00	0.00	96.60
45.50	29.50	15.80	1.65	1.30	0.00	0.00	93.70
42.80	26.80	17.10	1.52	1.65	0.00	0.00	89.90
41.20	28.30	18.30	1.54	2.17	0.00	0.00	91.50
46.40	31.20	14.90	1.71	1.27	0.00	0.00	95.50
50.20	33.90	11.80	1.17	0.90	0.00	0.00	98.00
50.10	34.40	12.10	1.16	0.90	0.00	0.00	98.60
47.20	30.40	14.90	1.47	1.11	0.00	0.00	95.10
43.30	27.60	17.40	1.63	1.62	0.00	0.00	91.50
45.50	32.90	14.40	1.75	1.49	0.00	0.00	96.00
48.00	32.40	13.00	1.65	1.32	0.00	0.00	96.30
47.10	31.80	13.90	1.48	1.33	0.00	0.00	95.60
41.50	28.90	18.50	1.44	2.03	0.00	0.00	92.30
34.10	21.30	23.20	0.07	3.15	0.00	0.00	81.80
46.80	33.10	13.70	1.34	1.29	0.00	0.00	96.20
45.20	31.60	15.20	1.51	1.33	0.00	0.00	94.90

Description

Footage (feet)	Thickness (feet)	Formation and Lithology
999.9-1073.5	73	**Wells Creek Formation** Dolomite, light-gray to olive-gray to greenish-gray to light-bluish-gray, with black mottling, micrograined to fine-grained, earthy, porcelaneous chert, irregularly laminated with shale and argillaceous partings; dolomite of upper 1.75 ft. grades downward into green shale from 1001.9 to 1003.3 ft.; in part intercalated with green silty shales; interbedded with several 2- to 12-in. green silty shales; scattered quartz sand from 1037 to 1038 ft.; argillaceous with scattered quartz sand in lower 4 ft.; clasts of Knox dolomite and abundant quartz sand in basal foot.

Chemical Analysis

% $CaCO_3$	% $MgCO_3$	% SiO_2	% Al_2O_3	% Fe_2O_3	% K_2O	% Na_2O	% Total
43.50	28.50	17.20	1.74	1.58	0.00	0.00	92.50
45.30	30.30	15.70	1.63	1.41	0.00	0.00	94.40
45.40	31.60	14.80	1.48	1.19	0.00	0.00	94.50
44.20	28.00	16.30	1.74	1.32	0.00	0.00	91.50
44.70	29.10	15.90	1.61	1.23	0.00	0.00	92.50
47.20	32.60	13.10	1.37	0.98	0.00	0.00	95.30
44.80	30.00	15.20	1.52	1.19	0.00	0.00	92.70
46.20	32.10	13.80	1.29	1.11	0.00	0.00	94.50
44.10	31.40	15.40	1.71	1.29	0.00	0.00	93.90
47.70	32.60	13.30	1.03	0.71	0.00	0.00	95.40
53.80	42.30	3.02	0.53	0.46	0.00	0.00	100.10
53.60	41.30	3.19	0.69	0.48	0.00	0.00	99.30
51.10	36.70	8.93	0.91	0.61	0.00	0.00	98.30
48.30	32.70	13.10	1.12	0.65	0.00	0.00	95.90
51.50	38.60	7.48	0.70	0.44	0.00	0.00	98.70
50.40	34.10	12.00	0.90	0.53	0.00	0.00	98.00
50.40	33.90	11.30	0.97	0.50	0.00	0.00	97.10
51.60	39.10	6.98	0.77	0.51	0.00	0.00	98.90
51.50	38.20	8.46	0.77	0.54	0.00	0.00	99.50
52.60	36.80	7.73	0.92	0.48	0.00	0.00	98.50
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
53.70	42.90	2.37	0.66	0.48	0.00	0.00	100.10
52.60	40.70	4.83	0.84	0.49	0.00	0.00	99.40
50.60	35.50	11.40	0.81	0.52	0.00	0.00	98.80
49.00	34.50	12.80	0.74	0.48	0.00	0.00	97.60
47.30	29.20	17.80	1.00	0.61	0.00	0.00	95.90
48.70	31.20	14.20	0.94	0.52	0.00	0.00	95.50
49.90	33.50	12.00	0.73	0.50	0.00	0.00	96.70
50.90	34.60	10.30	0.79	0.41	0.00	0.00	97.00
50.70	35.10	9.95	0.94	0.38	0.00	0.00	97.00
51.20	37.10	7.49	0.81	0.28	0.00	0.00	96.80
51.40	36.00	7.95	0.75	0.32	0.00	0.00	96.50
50.70	33.20	10.50	0.86	0.38	0.00	0.00	95.70
48.60	33.70	13.10	0.98	0.58	0.00	0.00	96.90
47.80	32.20	14.10	1.09	0.69	0.00	0.00	95.90
48.80	31.80	14.90	0.95	0.63	0.00	0.00	97.20
50.70	34.20	12.20	0.69	0.41	0.00	0.00	98.20
48.30	30.00	17.90	0.87	0.72	0.00	0.00	97.80
52.80	40.80	4.25	1.13	0.52	0.00	0.00	99.50
52.90	40.60	3.70	0.94	0.32	0.00	0.00	98.50
52.30	39.30	4.92	1.04	0.33	0.00	0.00	97.90
51.90	39.60	6.23	0.83	0.41	0.00	0.00	99.00
53.20	41.40	3.02	0.49	0.19	0.00	0.00	98.20
54.10	41.30	1.55	0.24	0.16	0.00	0.00	97.30
53.80	39.80	2.94	0.33	0.18	0.00	0.00	97.10
53.10	38.00	5.25	0.28	0.19	0.00	0.00	96.80
51.80	37.70	8.08	0.29	0.24	0.00	0.00	98.10
51.00	34.30	11.60	0.42	0.32	0.00	0.00	97.40
48.90	31.40	16.10	0.45	0.47	0.00	0.00	97.32

Bottom of sampled interval

Description

Footage (feet)	Thickness (feet)	Formation and Lithology
		Wells Creek Formation (continued)
1073.5-1113.6	40	**Knox Group** **Kingsport Formation** Dolomite, very light-gray to light-gray, in part light-olive-gray, finely crystalline; scattered quartz sand; abundant quartz sand in upper 2 ft.; tripolitic chert with dolomoldic texture; clasts of Wells Creek and Knox dolomite at top; stylolites; in part vuggy and fractured; some oil staining and pyrite; scattered shale laminations at 1089.2, 1099, and 1101.4 ft.

Fly Ash Facts for Highway Engineers

Chapter 3 - Fly Ash in Portland Cement Concrete

- Introduction
- Mix Design and Specification Requirements
- Fly Ash Properties
- Other Constituents
- Construction Practices

Introduction *TOP*

The use of fly ash in portland cement concrete (PCC) has many benefits and improves concrete performance in both the fresh and hardened state. Fly ash use in concrete improves the workability of plastic concrete, and the strength and durability of hardened concrete. Fly ash use is also cost effective. When fly ash is added to concrete, the amount of portland cement may be reduced.

Benefits to Fresh Concrete. Generally, fly ash benefits fresh concrete by reducing the mixing water requirement and improving the paste flow behavior. The resulting benefits are as follows:

- **Improved workability.** The spherical shaped particles of fly ash act as miniature ball bearings within the concrete mix, thus providing a lubricant effect. This same effect also improves concrete pumpability by reducing frictional losses during the pumping process and flat work finishability.

Figure 3-1: Fly ash improves workability for pavement concrete.

- **Decreased water demand.** The replacement of cement by fly ash reduces the water demand for a given slump. When fly ash is used at about 20 percent of the total cementitious, water demand is reduced by approximately 10 percent. Higher

More Information

- Pavement Publications

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fly ash contents will yield higher water reductions. The decreased water demand has little or no effect on drying shrinkage/cracking. Some fly ash is known to reduce drying shrinkage in certain situations.

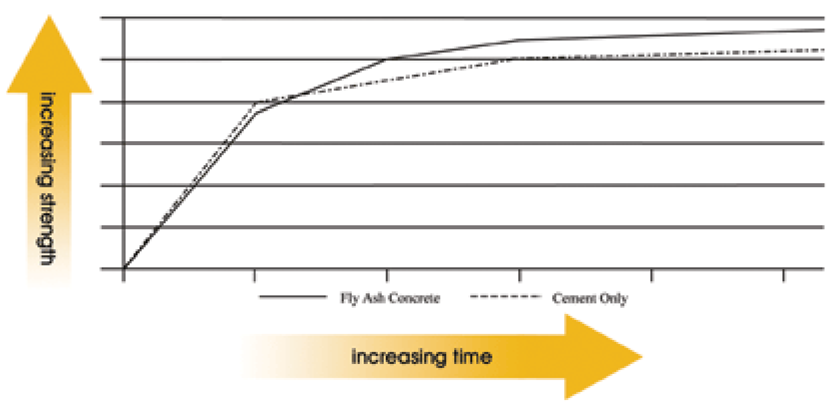
- **Reduced heat of hydration.** Replacing cement with the same amount of fly ash can reduce the heat of hydration of concrete. This reduction in the heat of hydration does not sacrifice long-term strength gain or durability. The reduced heat of hydration lessens heat rise problems in mass concrete placements.

Benefits to Hardened Concrete. One of the primary benefits of fly ash is its reaction with available lime and alkali in concrete, producing additional cementitious compounds. The following equations illustrate the pozzolanic reaction of fly ash with lime to produce additional calcium silicate hydrate (C-S-H) binder:

		(hydration)
Cement Reaction:	C_3S +	H → C-S-H + CaOH
Pozzolanic Reaction:	CaOH +	S → C-S-H
		silica from ash constituents

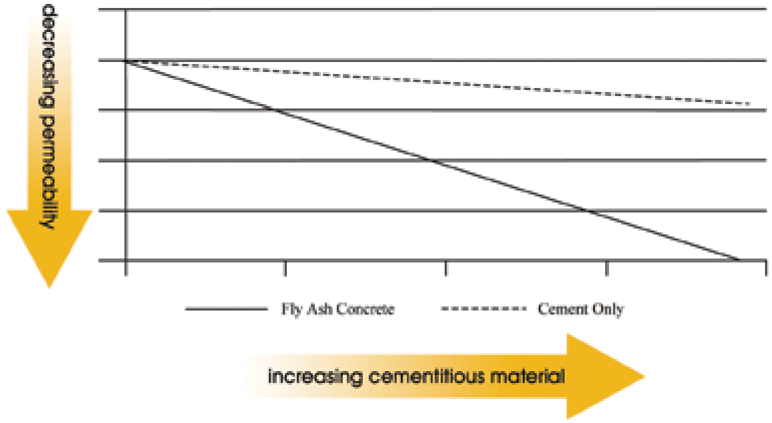
- **Increased ultimate strength.** The additional binder produced by the fly ash reaction with available lime allows fly ash concrete to continue to gain strength over time. Mixtures designed to produce equivalent strength at early ages (less than 90 days) will ultimately exceed the strength of straight cement concrete mixes (see Figure 3-2).

Figure 3-2: Typical strength gain of fly ash concrete.



- **Reduced permeability.** The decrease in water content combined with the production of additional cementitious compounds reduces the pore interconnectivity of concrete, thus decreasing permeability. The reduced permeability results in improved long-term durability and resistance to various forms of deterioration (see Figure 3-3)

Figure 3-3: Permeability of fly ash concrete.



- **Improved durability.** The decrease in free lime and the resulting increase in cementitious compounds, combined with the reduction in permeability enhance concrete durability. This affords several benefits:
    - Improved resistance to ASR. Fly ash reacts with available alkali in the concrete, which makes them less available to react with certain silica minerals contained in the aggregates.
    - Improved resistance to sulfate attack. Fly ash induces three phenomena that improve sulfate resistance:
        - Fly ash consumes the free lime making it unavailable to react with sulfate
        - The reduced permeability prevents sulfate penetration into the concrete
        - Replacement of cement reduces the amount of reactive aluminates available
    - Improved resistance to corrosion. The reduction in permeability increases the resistance to corrosion.

Figure 3-4: Fly ash concrete is used in severe exposure applications such as the decks and piers of Tampa Bay's Sunshine Skyway Bridge.

Mix Design and Specification Requirements TOP

Procedures for proportioning fly ash concrete (FAC) mixes necessarily differ slightly from those for conventional PCC. Basic guidelines for selecting concrete proportions are contained in the American Concrete Institute (ACI) Manual of Concrete Practice, Section 211.1. Highway agencies generally use variations to this procedure, but the basic concepts recommended by ACI are widely acknowledged and accepted. There is very little on proportioning in ACI 232.2.

Fly ash is used to lower the cost and to improve the performance of PCC. Typically, 15 percent to 30 percent of the portland cement is replaced with fly ash, with even higher percentages used for mass concrete placements. An equivalent or greater weight of fly ash is substituted for the cement removed. The substitution ratio for fly ash to portland cement is typically 1:1 to 1.5:1.

A mix design should be evaluated with varying percentages of fly ash. Time versus strength curves can be plotted for each condition. To meet specification requirements, curves are developed for various replacement ratios and the optimum replacement percentage ratio is selected. A mix design should be performed using the proposed construction materials. It is recommended that the fly ash concrete being tested incorporates local materials in performance evaluation.

Cement Factors. Because fly ash addition contributes to the total cementitious material available in a mix, the minimum cement factor (portland cement) used in the PCC can be effectively reduced for FAC. The ACI acknowledges this contribution and recommends that a water/(cement plus pozzolan) ratio be used for FAC in lieu of the conventional water/cement ratio used in PCC.

Fly ash particles react with free lime in the cement matrix to produce additional cementitious material, and thus, to increase long-term strength.

Fly Ash Properties ▲TOP

Fineness. The fineness of fly ash is important because it affects the rate of pozzolanic activity and the workability of the concrete. Specifications require a minimum of 66 percent passing the 0.044 mm (No. 325) sieve.

Specific gravity. Although specific gravity does not directly affect concrete quality, it has value in identifying changes in other fly ash characteristics. It should be checked regularly as a quality control measure, and correlated to other characteristics of fly ash that may be fluctuating.

Chemical composition. The reactive aluminosilicate and calcium aluminosilicate components of fly ash are routinely represented in their oxide nomenclatures such as silicon dioxide, aluminum oxide and calcium oxide. The variability of the chemical composition is checked regularly as a quality control measure. The aluminosilicate components react with calcium hydroxide to produce additional cementitious materials. Fly ashes tend to contribute to concrete strength at a faster rate when these components are present in finer fractions of the fly ash.

Sulfur trioxide content is limited to five percent, as greater amounts have been shown to increase mortar bar expansion.

Available alkalis in most ashes are less than the specification limit of 1.5 percent. Contents greater than this may contribute to alkali-aggregate expansion problems.

Carbon content. LOI is a measurement of unburned carbon remaining in the ash. It can range up to five percent per AASHTO and six percent per ASTM. The unburned carbon can absorb air entraining admixtures (AEAs) and increase water requirements. Also, some of the carbon in fly ash may be encapsulated in glass or otherwise be less active and, therefore, not affect the mix. Conversely, some fly ash with low LOI values may have a type of carbon with a very high surface area, which will increase the AEA dosages. Variations in LOI can contribute to fluctuations in air content and call for more careful field monitoring of entrained air in the concrete. Further, if the fly ash has a very high carbon content, the carbon particles may float to the top during the concrete finishing process and may produce dark-colored surface streaks.

Other Constituents ▲TOP

Aggregates. As with any concrete mix, appropriate sampling and testing are needed to ensure that the aggregates used in the mix design are of good quality and are representative of the materials that will be used on the project. Aggregates containing reactive silica may be used in the FAC.

Cement. Fly ash can be used effectively in combination with all types of cements: portland cement, performance cement, and blended cements. However, special care should be taken when using fly ash with high early strength or pozzolanic cements. Appropriate mix design and testing should be conducted to evaluate the impact of fly ash addition on the performance of high early strength concrete. Blended or pozzolanic cements already contain fly ash or other pozzolan. Additional cement replacement would affect early strength development. Characteristics of cement vary, as do fly ashes, and not all combinations produce a good concrete. The selected portland cement should be tested and approved on its own merit, as well as evaluated in combination with the specific fly ash to be used.

Air Entraining Admixtures (AEAs). The higher the carbon content in the fly ash, the more difficult it is to control the air content. Further, if the carbon content varies, air content must be closely monitored and admixture dosage rates changed to insure proper levels of air entrainment.

Retarders. Adding fly ash should not appreciably alter the effectiveness of a chemical retarder. Some fly ashes may delay the time of set and may reduce the need for a retarder.

Water reducers. Fly ash concrete normally requires less water, but it can be further improved with the use of a water-reducing admixture. The effectiveness of these admixtures can vary with the addition of fly ash.

Construction Practices ▲TOP

Fly ash concrete mixes can be developed to perform essentially the same as PCC mixes with minor differences. When mixing and placing any FAC, some minor changes in field operation may be desirable. The following general rules-of-thumb will be useful:

Plant Operations. Fly ash requires a separate watertight, sealed silo or holding bin for storage. Take care and clearly mark the loading pipe for fly ash to guard against cross-contamination when deliveries are made. If a separate holding bin cannot be provided, it may be possible to divide the cement silo. If available, use a double-walled divider to prevent cross-contamination. Due to its particle spherical shape, dry fly ash is more flowable than dry portland cement. The angle of repose of fly ash is typically less than that of cement.

As with any concrete mix, mixing time and conditions are critical to producing quality concrete. The increase in paste volume and concrete workability (ball bearings effect) associated with the use of fly ash typically improve mixing efficiency.

Field Practices. Beginning with the first concrete delivery to the job site, every load should be checked for entrained air until the project personnel are confident a consistent air content is being obtained. After that, periodic testing should continue to ensure consistency. Concrete should be placed as quickly as possible to minimize entrained air loss by extended agitation. Normal practices for consolidation should be followed. Excessive vibration should be avoided to minimize the loss of in-place air content.

FAC mix workability characteristics allow it to be placed easily. Many contractors report improved smoothness of FAC pavements over those constructed with conventional PCC. FAC contains more paste than conventional PCC, which is beneficial to the finishing. The slower early strength development of FAC may also result in longer moisture retention.

Figure 3-5: Fly ash concrete finishing

Troubleshooting. First-time users of fly ash in concrete should evaluate the performance of proposed mixes prior to construction. All concrete ingredients must be tested and evaluated to develop the desired mix design.

Air content. The fineness of fly ash and the improved workability of FAC make it naturally more difficult to develop and hold entrained air. Also, residual unburned carbon in ash adsorbs some of the air entraining agent and make it more challenging to develop the desired air content. Higher carbon content ashes naturally require higher AEA contents. Quality assurance and quality control testing of ash at the source must ensure that the fly ash used maintains a uniform carbon content (LOI) to prevent unacceptable fluctuations in entrained air. New technologies and procedures to address unburned carbon in fly ash are described in Chapter 10.

Lower early strength. Fly ash concrete mixes typically result in lower strengths at early ages. The slower strength gain may require forms to be strengthened to mitigate hydraulic loads. It should be noted that form removal and opening to traffic may be delayed due to the slower strength gains. Lower early strengths can be overcome by using accelerators.

Seasonal limitations. Construction scheduling should allow time for FAC to gain adequate density and strength to resist de-icing applications and freeze-thaw cycling prior to the winter months. Strength gain of FAC is minimal during the colder months. Although pozzolanic reactions are significantly diminished below 4.4 degrees C (40 degrees F), strength gain may continue at a slower rate resulting from continued cement hydration. Chemical admixtures can be utilized to off-set seasonal limitations.

Design and Construction References

See Appendix C.

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Practical techniques to improve the air quality in underground stone mines

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ABSTRACT: Researchers working for the National Institute for Occupational Safety and Health (NIOSH) at the Pittsburgh Research Laboratory are developing ways to protect the health of miners. Part of that effort is devoted to improving the air quality in underground stone mines by developing ventilation techniques that can be used in these types of operations. The air quality in these large opening nonmetal mines can be significantly improved by using diesel particulate matter (DPM) controls along with sufficient ventilation quantities to remove contaminants. Practical methods of ventilating these underground stone mines can be accomplished by using mine layouts that course and separate ventilation air through the use of stoppings. The design, construction, and maintenance of effective stoppings in large openings have been a real challenge to mine operators. Several different types of stoppings have and can be used for this application. The choice of stopping design, material used, and construction techniques should be dependent upon a number of factors such as the intended life and effectiveness desired.

1 INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) conducts research into various mining health and safety issues to provide the basis for improvements to U.S. miners' health and safety. As part of this role, researchers at the NIOSH Pittsburgh Research Laboratory (PRL) are developing methods and technologies to improve the air quality for large opening underground metal/nonmetal mines. This paper discusses NIOSH/PRL research dealing with ventilation techniques that will be applicable to large opening mining operations. Furthermore, the paper describes concepts that can be incorporated into the overall ventilation design of these mines. The most common underground large opening mines are underground stone mines followed by underground rock salt mines. Surveillance data from the Mine Safety and Health Administration (MSHA) for the year 2000 shows that there were 162 active nonmetal underground mines in the United States, of which, 117 were stone mines and 13 were rock salt mines.

The continuing and emerging air quality issues in metal/nonmetal mines include silica dust, diesel particulate, fog and fumes. The concentration of these contaminants can be effectively reduced by utilizing various control technologies along with adequate air quantities and proper ventilation methods. A growing concern by various health agencies is the health risks associated with exposure to diesel particulate matter (DPM). It is generally accepted by various regulatory agencies, ACGIH (2001), NIOSH (1988), EPA (2000), and confirmed by the United States Congress, as to the health hazards of exposure to diesel particulate matter. As this concern grows, the mining community is confronted with new DPM regulatory exposure limits. MSHA recently addressed these health concerns by promulgating underground diesel regulations for coal and metal/nonmetal mines, MSHA (2001). The standard was developed to reduce the health risks associated with exposure to DPM. Our view is that the metal/nonmetal DPM exposure limits proposed by the regulations of 400 $_{tc}$ µg/m^3 on July 19, 2002 and a more stringent limit on January 12, 2006 to 160 $_{tc}$ µg/m^3 will impel the use of diesel emissions control technology, and in many cases, some form of ventilation improvement to meet these new air quality standards. The most common ventilation knowledge and techniques that are utilized in coal and some metal mines are not readily adaptable to large opening mines. The large openings in many mines offer little ventilation resistance to air flow. However, this low resistance permits large air quantities to move through the large opening mines at extremely small mine (fan) pressures. From an engineering design prospective, this large air quantity, small pressure scenario should play an integral part in the overall mine ventilation design scheme.

2 FUNDAMENTALS OF IMPROVING VENTILATION IN LARGE OPENING MINES

Previous literature (Head 2001; Grau 2002) has documented the necessity for the large air volumes that are required to effectively dilute DPM concentrations to meet the proposed regulatory standards established by MSHA. In addition to the large air requirements, effective planning for the placement of ventilation equipment and control devices, such as fans and stoppings are necessary to effectively ventilate the large opening mines. Determining the required air quantity throughout the mine is the first and most important elements for planning effective underground mine ventilation. Although many mining activities produce contaminants that enter the mine air, the greatest concern is with the DPM created from the diesel engines used to power the equipment operating in these U.S. mines. Most likely, if the DPM concentrations are reduced or diluted to concentrations that comply with the proposed regulatory standards, the other contaminant concentrations will also be in compliance. The research at NIOSH indicates that there is no single fix or approach to reduce DPM concentrations within these large opening mines, however, providing at least the minimum ventilation quantities to areas with operating diesel equipment plays a crucial role in diluting DPM concentrations. Therefore, we believe, that for the foreseeable future, the eventual DPM regulatory exposure limits will be the dominant parameter driving ventilation requirements for these mines.

3 DESIGNING EFFICIENT VENTILATION SYSTEMS

The fundamental principle of mine ventilation is that air movement is caused by differences in air pressure. The pressure difference results from either natural ventilation pressures or a mechanical fan(s) or a combination of both. There are currently large variations in the methods used by U.S. underground large opening mine operators to develop air movement. The methods vary from reliance on natural ventilation forces to the use of main mine fan(s) or combinations of both. In addition, auxiliary jet fans (free standing) are often used in most of these systems for local areas or to assist and direct the main mine currents. Since natural ventilation is a product of the differences in densities of air columns in and around mine openings, natural ventilation is largely variable and uncontrolled. The direction and magnitude of natural ventilation will change frequently, often several times in a day and certainly seasonally in temperate climates. Therefore, mines that rely solely on natural ventilation as the primary source of ventilation have a highly uncontrolled ventilation system. It should be noted that natural ventilation is better than no ventilation and natural ventilation may provide satisfactory air exchanges in some circumstances or in some parts of the mine. Natural ventilation has been helpful in some large opening drift stone mines with multiple entries and in parts of mines that have been extensively benched. Even with small differences in elevation, natural ventilation alone can promote large volume air movement and mine air exchanges, although in an uncontrolled manner. In areas that have become extensively benched, the large void created may actually create an "air reserve." Although this air reserve can become be gradually contaminated with DPM, the natural ventilation does provide some ventilation relief during working hours and clean out the system during off shift times. Jet fans positioned in proper locations may enhance this exchange process. However, jet fans in other portions of the mine are often positioned working against the natural ventilation flow direction. This results in inadequate air flow and uncontrolled recirculation. In most cases, using natural ventilation as a primary ventilation source is a haphazard affair usually with unknown results.

To effectively improve the air quality in these underground mines, sound ventilation planning needs to be incorporated into the overall mine planning process. For instance, mechanical main mine fans, auxiliary fans, stoppings, and a general ventilation concept should to be integrated into mine layouts and mining sequences. Also, special ventilation considerations, such as production faces, shops, benching areas, and haulage routes should be considered in this mine planning process. Criteria for proper fan selection, installation and operation for both main mine fans and auxiliary fans should be considered. Fan characteristics of pressure and quantity should be matched for the operation. Fan effectiveness is increased dramatically when used in conjunction with stoppings. Utilizing stoppings to build air walls helps control the mine ventilation flow, i.e., efficiently directing the air to where it's needed the most. The air walls also separate the intake and return airways. Stoppings can be made from man-made materials, leaving areas of intact rock to act as stoppings, or by filling an opening with waste material.

Fan and stopping locations need to be an integral part of the mine layout. Stopping and air wall locations will often need to be built, taken down or moved with changes in mining areas and/or in concert with a predetermined sequence of a mining and accompanying ventilation scheme. This would include methods to ventilate the active faces, while providing adequate ventilation to any special needs area noted above. The overall ventilation concepts for these types ventilation concepts are discussed more fully in Grau (2002). Other important factors that reduce DPM at the face area are selecting cleaner burning diesel engines and planning the truck haulage routes. Effective planning of haulage routes will reduce DPM from truck haulage which is the single largest source of DPM in many underground stone mines.

4 DETERMINING SUFFICIENT AIR REQUIREMENTS

The first step to designing an effective ventilation system in underground stone mines is to determine the total air quantity that is needed for effective dilution of DPM and other contaminants. As previously noted, although many different mining activities emit noxious contaminants and require dilution, the result of the new DPM regulations will be that the overriding ventilation design parameter is for the dilution of DPM. In addition, even though the total theoretical air quantity needed to dilute these contaminates can be estimated for adequate dilution, sufficient quantities of air must be distributed to areas where contaminates are being generated. Therefore, certain mining operations may require auxiliary fans to adequately dilute the DPM at the source. Methods to determine the mine air requirements for DPM dilution are described by both Haney (1998); Grau (2002). Grau (2002) reported that the estimated air quantity required for the equipment currently operating in an underground stone mine producing 113 million metric tons (1.25 million tons) is 401 m^3/s (850,000 cfm) to dilute to a 400 $_{tc}$ $\mu g/m^3$ concentration and 990 m^3/s (2,100,000 cfm) to dilute to a 160 $_{tc}$ $\mu g/m^3$ concentration. These conclusions were based on the current equipment, controls, etc being used. The air quantities may be too high for practical mine ventilation, however the required air quantity is highly dependent upon the engines in use and as previously described, the extremely large volume of the bench area may reduce the air flow required. It should be noted that engines of an older vintage are less efficient. As an engine ages, the combustion process degrades, which lowers the fuel economy and promotes higher emissions. Mine operators can dramatically decrease air requirements by selectively replacing the engines with a lower DPM emissions or by adding control measures to engines that emit the most DPM. This significant difference defines why additional research is needed to define more accurate estimates of air requirements.

The goal for many mine operators in the near future will be to have their mine be in compliance with the DPM regulations. We expect that, over time, this will be a process of implementing both DPM control measures and ventilation techniques. Operators are looking at different scenarios in both areas to determine where the most DPM reduction can be achieved in the best practical way. As they move through this iterative process, they will likely make ventilation changes to their mine and also gradually replace the older high DPM emitting engines with new cleaner burning engines. The operators should factor these scenarios into their mine planning process.

5 FAN SELECTION

Many underground limestone mines are drift mines developed from previous quarry operations. Typically, these room and pillar mines have entries that are 6.1 m (20 feet) or higher and at least 12.2 m (40 feet) wide. These large dimensions lead to a very small pressure loss, even when significant air quantities move through the mine. This is especially true of the drift mine operations where our observations found that pressure differences of less than a 24.9 Pa ((0.1 in of water gauge, (w.g.)) are not uncommon, no matter whether these mine are ventilated by natural ventilation, a mechanical fan(s) or combinations of both. Our observations also indicate that the underground stone mines with slope/decline and shaft operations that are less than 70 m (200 ft) in depth, have small mine pressure differences, usually less than 746 Pa (3 in w.g). These differences are or could be much lower if the proper consideration was given to the contribution that the slope/decline and shaft provide to the overall mine resistance.

The low pressure loss present in these large opening mines is actually an advantage compared to other type mines and should be treated as such. The ventilation principles, concepts and techniques used to ventilate these mines are different from the techniques used in mines with larger pressure losses. For example, axial vane fans have predominately been used where higher pressures are required. However, in large opening mines with low pressure requirements, propeller fans offer an alternative. The propeller fans can develop large air volumes under low pressure conditions. Propeller fans can be used as either main mine fans or as free standing auxiliary (jet) fans. Free-standing fans are commonly used to promote air movement as shown in Figure 1.

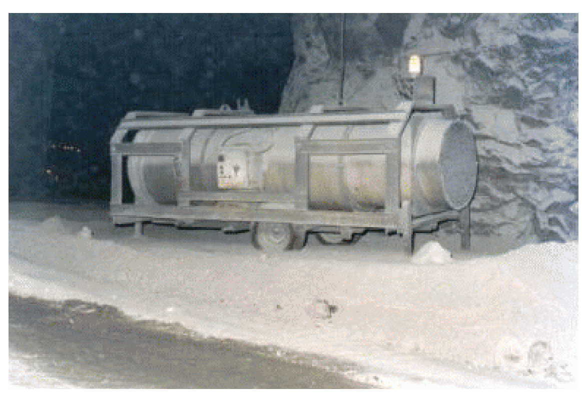

Figure 1. Jet fan.

Ventilation studies by Matt et al. (1978), Agaipito (1985), Goodman (1992) and Foster-Miller (1980) have measured the performance of jet fans (usually axial vane free standing) either in single headings or ventilating portions of the main airways. The research found that the most important aspect for jet fan performance is that the jet fan should be positioned in the intake incoming main air stream so that there is sufficient intake air for the fan. Other important results from these tests showed that the performance of these fans was enhanced by adding a nozzle to the fan. Results were also significantly improved by angling the fan upward and located against a rib when ventilating a dead-ended opening.

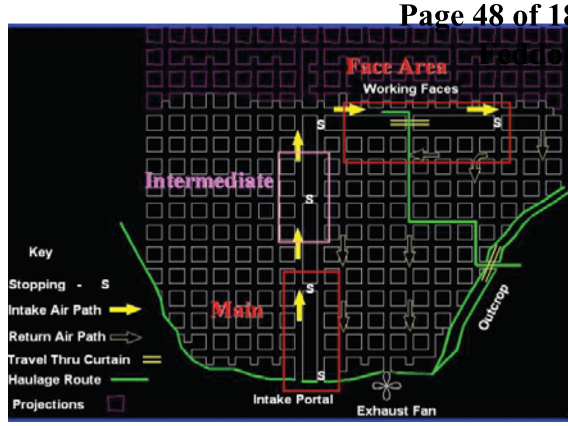

Figure 2. Stopping locations in a typical room and pillar stone mine.

6 VENTILATION CONTROLS (STOPPINGS)

In order to adequately deliver proper air flows to the face areas, good air controls in the form of stoppings are necessary. Stoppings are physical barriers that separate the intake air from the return air. Since air flows through a mine due to differential pressure between travel points, a pressure difference always exits between the intake and return airways. The stoppings act as a barrier allowing for this pressure differential to exist and circumvent short circuiting of intake air to return air. Currently, in most U.S. large opening mines, stoppings and fans are the only control measures used. Most of these operations are currently using or strive to produce a primary, single mine air current to the active mining faces. However, there are a number of variations, especially for drift operations where natural ventilation and sometimes a number of openings, yields secondary air currents. This single split concept currently eliminates the need for other control measures such as overcasts, regulators and air doors. In many underground mines with large openings, the auxiliary fans are the only control devices used to distribute the air to the face working area.

Stoppings have not been widely used in large opening stone mines. Unfortunately, capital expense, construction, and maintenance problems have impeded this segment of the mining industry from building stoppings. This is particularly problematic in the larger, more established mines. In those mines, stoppings were never incorporated into the mining plan. Retrofitting the mines with stoppings to course the air requires building many stoppings with a corresponding investment in time and construction cost.

Design criteria for stoppings include minimizing the leakage between the intake and return air, withstanding the fan pressure differentials and withstanding or relieving the pressure from face production blasting. Table 1 shows the criteria that are the most important in different parts of the mine. There are three main areas of the mine to consider in determining the type or quality of stopping, the main, intermediate, and the face areas. These areas are shown in Figure 2 for a typical underground stone mine. The stoppings in the main airways will typically have less blast pressure, but since they are usually located near the main mine fan, they are subject to the highest constant pressure differential and thus have the potential for the highest leakage. The stoppings in the main entry will also need to survive the life of the mine, hopefully requiring little maintenance. Minimizing leakage in the main airways prevents a direct short circuit of air to or from the fan. For these reasons, the stoppings located in the main areas of the mine should be substantially constructed. For these stoppings, some form of pressure relief may be needed from production face shots, especially early in their life. This need will often diminish as the active mining advances further away, causing the blast pressures to dissipate with ventilation relief (other openings) and distance.

Table 1 - Stopping criteria for locations in an underground stone mine.

Location in the mine	Fan pressure difference	Blast pressure	Acceptable leakage
Main	Greatest	Little	Low
Intermediate	Significant	Some	Intermediate
Face Area	Lowest	Greatest	Moderate

For underground large opening stone drift mines with multiple entries, the pressure across intake and return air is generally less than 62 Pa (0.25 inch w.g.) as found by Grau (2002). From theoretical ventilation calculations, this pressure differential is greatest near the fan.

Pressures from face production blasts far exceed the ventilation pressure. Tests performed by NIOSH, (Mucho, 2001) found pressures from two different production face shot, ranged from 8.2738 kPA (1.20 psi) to 9.3769 kPA (1.36 psi) at distances of 200-500 ft from the face shot as shown in Figure 3. The face shots were generated with 400 lbs of ANFO, 169 lb of dynamite and 50 lb of Datagel. Research is continuing at NIOSH to further bracket expected blasting pressures that stoppings could be expected to experience in these types of mines and to define the controlling parameters such as distance and the impact of venting to adjacent openings.

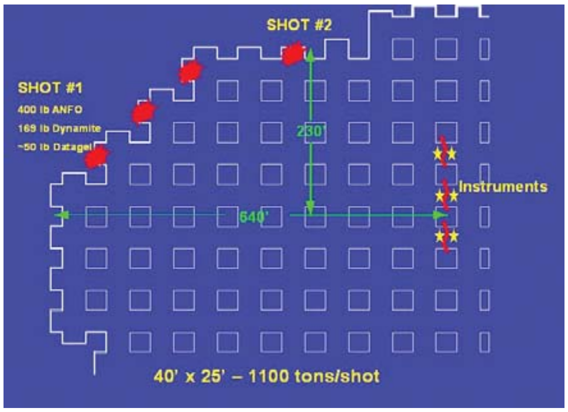

Figure 3. Schematics of tests for measure pressure from face production shots.

Some mines have had success in developing stoppings designed to provide relief from blast pressure. Techniques such as leaving the brattice loose at the floor (and sometimes ribs), using tear away VELCRO strips (Timko 1987), creating openings in the stoppings prior to blasting, and using a combination of used mine belt and brattice have been used. The brattice left loose at the floor simply allows the brattice to fly up when the face shot pressure passes by and returns to the floor when the pressure is through. This technique has been used in some mines near face areas where leakage is not as critical and pressure differentials are lower. Brattice stoppings sealed with VELCRO strips have been developed and used on brattice stoppings in oil shale mines (Timko 1987) and in the NIOSH Lake Lynn Laboratory (Mayercheck 2002). The VELCRO strips separate during the impact of the face shot but they immediately reseal. If sealing is not immediately accomplished, the VELCRO strip seals are manually reconnected after the mine blast. Although they exhibited good success in the Lake Lynn conditions, at least one mine has discontinued their use because of mud and dirt filling the VELCRO and reducing the sealing effectiveness.

7 TYPES OF LARGE OPENING STOPPINGS

Stoppings are built from a variety of construction materials. The construction materials are chosen based upon the desired performance, construction time and ease, and material cost. Construction materials that have typically been used in these mines for stoppings include steel sheeting, cementious-covered fiber matting, mine brattice cloth, used mine belting and piled waste stone.

Used conveyor belting that is no longer useful for material transport can be used to make stoppings. The combination of used belting and brattice have been used effectively in stoppings for both sealing, production face shot relief, and flyrock or other physical damage protection. It has been successfully used as blast relief in a main mine fan bulkhead. Prior to utilizing the mine belt as shown in Figure 4, the mine had several stoppings blown over during production face shots. The mine belt weight and strength allow it to be strong enough to withstand the pressure wave from the face shot but flexible enough to give and act as a pressure relief. Belting hung in this manner should be hung in an overlapping concave pattern to promote interlocking of belting. This technique will minimize air leakage. Figure 5 shows used mine conveyor belt supplementing conventional mine brattice in a stopping. This combination minimizes leakage while providing protection, blast relief, and a more substantial stopping. Conveyor belts could also be used to shield conventional brattice stoppings from the fly rock damage shown in Figure 6.

Figure 4. Used mine belt used pressure relief.

Certainly one of the most durable, but also the most costly, for both construction and materials are the corrugated steel panels reinforced with a steel frame as shown in Figure 7. This is the most durable stopping and can be effectively sealed on roof and rib by making a template of the rib and cutting the corrugated sheet to match. The remaining spaces can be filled with expanding foam. One advantage of this stopping is that a swing door can be incorporated into it. This allows for personnel and equipment passage, as well as for blast relief. Besides the cost and time required to install, a disadvantage of this door is that leakage can occur at the door bottom. This might be corrected by adding some type of door sweep.

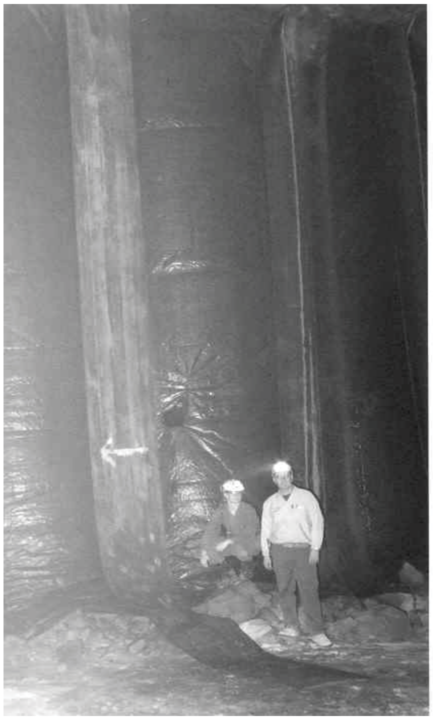

Figure 5. Used mine conveyor belt supplementing conventional mine brattice in a stopping.

Figure 7. Stopping made for corrugated steel panels reinforced with a steel frame.

Figure 6. Fly rock damage in brattice cloth.

A less elaborate, but still rigid, stopping is a fiber/mesh covered with cementious grout as shown in Figure 8. This type of stopping is currently being evaluated in an operating underground limestone mine. This stopping is installed by hanging fabric backed by grid and then sealed by spraying with a water-based cementious grout on both sides using high pressure grout pumps. Stoppings of this type are still being evaluated for effectiveness by NIOSH researchers.

A prototype stopping being researched by NIOSH is a tension brattice stopping. The stopping is similar to the tension membrane construction methods used to create various fabric covered, large dome stadiums throughout the country. In this stopping, currently being installed and tested at NIOSH's Lake Lynn Laboratory, a brattice material is tensioned and attached to the various steel framework supports, thereby increasing the strength of the structure.

Figure 8. Fabric-grid material sprayed with cementious material.

8 NATURAL ROCK STOPPINGS

Leaving rock in place to form natural rock stoppings has several advantages. By using the natural rock stopping, leakage, construction, and maintenance costs are eliminated. The rock stoppings are created by leaving at least the last face shot that would normally break through two adjoining openings. This keeps a natural rock integrity between the two adjoining pillars. Similar to constructed stoppings, natural rock stoppings between future independent pillars can be strategically oriented to direct the ventilation air. In order to direct the air, the rock stoppings are oriented parallel to the ventilation flow. Stone production may be temporarily compromised because the stone in the rock stopping is not immediately mined. However, the rock stoppings can be pre-drilled and mined through at a later time for stone recovery, or for other reasons when the particular stopping line is no longer required to course the air.

When using lines of rock stoppings to separate and course the air, openings need to be created every few crosscuts to meet practical mining needs. However, often the natural rock can be left in place along the ribs and back of the final cut that creates these long pillars to serve as a natural framework for the stoppings and to minimize the size of the stoppings. These too can be pre-drilled for future enlargement to normal opening size when the stopping line is no longer needed and/or the area is to be benched. A caution when using this method is the mining horizon for the top or back rock must be carefully chosen so that a ground control problem is not created.

9 CONCLUSIONS

NIOSH is researching various ways to improve ventilation in large opening mines in an effort to assist with methods and techniques to improve the air quality in these mines and therefore the health of miners. NIOSH is currently focusing on fan applications, air coursing, intake and return airway separation using stoppings, and implementing mine ventilation techniques and concepts into the mine planning to accomplish this goal.

Many U.S. underground stone mines are large opening mines that generally feature small ventilation head losses compared to other types of underground mining. Propeller fans are generally well suited to efficiently produce large air quantities under low pressure requirements. Stoppings are necessary to direct and control the mine air. A variety of stopping choices exist for these types of applications and depend upon the quality of the stopping needed. Different portions of the mine may be better suited to different types of stoppings. The use of stone stoppings is being investigated, especially as it relates to their deployment in various stages of the mine layout. Operators of all underground stone mines should find that this information will improve their ventilation in the underground workings.

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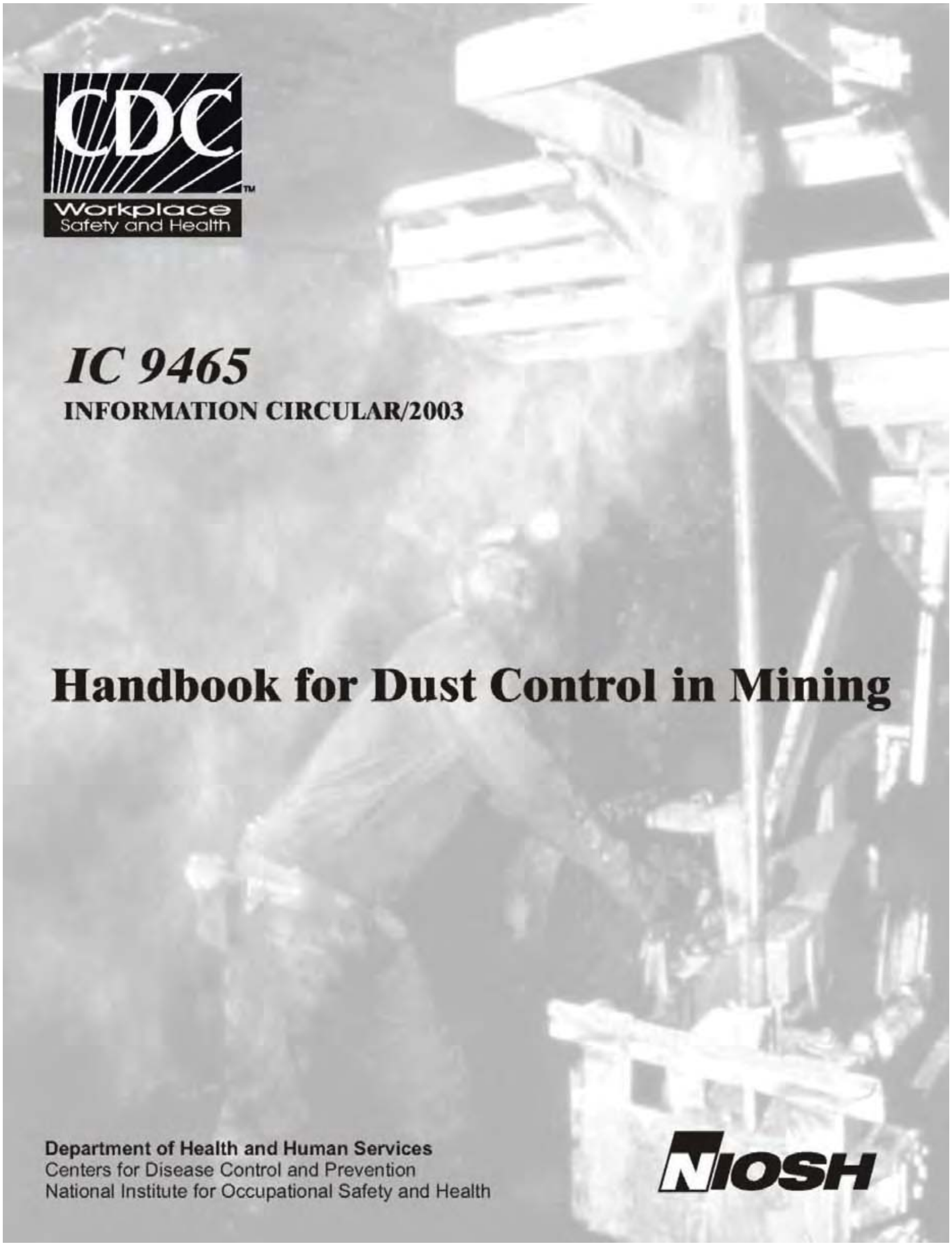

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Handbook for Dust Control in Mining

Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

NIOSH

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Handbook for Dust Control in Mining

By Fred N. Kissell, Ph. D.

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cfm	cubic foot per minute	m	meter
ft	foot	m^3	cubic meter
ft^2	square foot	mg	milligram
ft/min	foot per minute	mg/m^3	milligram per cubic meter
gpm	gallon per minute	mg/sec	milligram per second
hr	hour	min	minute
in	inch	mm	millimeter
in w.g.	inch water gauge	µm	micrometer
lb	pound	psi	pound (force) per square inch
L/min	liter per minute	sec	second

HANDBOOK FOR DUST CONTROL IN MINING

Fred N. Kissell, Ph.D.,[1] Editor

ABOUT THIS HANDBOOK

This handbook describes effective methods for the control of mineral dusts in mines and tunnels. It assumes the reader is familiar with mining. The first chapter deals solely with dust control methods, regardless of the application. It is a brief tutorial on mining dust control and will be of help to the reader whose dust control problem does not conveniently fit any of the mining equipment niches described in later chapters.

The subsequent chapters describe dust control methods for different kinds of mines and mining equipment. This includes underground coal and hard-rock mines, as well as surface mines, stone mines, and hard-rock tunnels. Because dust sampling has so many pitfalls, a chapter on methods used to sample dust is included. For those occasions when there is no practical engineering control, a chapter on respirators is also included.

Except for those listed as “future possibilities” in the longwall chapter, the dust control methods described are practical and cost-effective for most mine operators.

If controlling dust were a simple matter, dust problems in tunnels and mines would have been eradicated years ago. Unfortunately, most underground dust control methods yield only 25% to 50% reductions in respirable-sized dust. Often, 25% to 50% reductions are not enough to achieve compliance with dust standards. Thus, mine operators must use several methods simultaneously, usually without knowing for sure how well any individual method is working. In fact, given a 25% error in dust sampling and day-to-day variations in dust generation of 50% or more, certainty about which control methods are most effective can be wanting. Nevertheless, over the years, some consensus has emerged on the best dust control practices. This handbook summarizes those practices.

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CHAPTER 1.—DUST CONTROL METHODS IN TUNNELS AND UNDERGROUND MINES

By Fred N. Kissell, Ph.D.[2]

In This Chapter

- ✓ Ventilation: dilution and displacement
- ✓ Water sprays: wetting and airborne capture
- ✓ Water additives: foam and wetting agents
- ✓ Dust collectors: filtration efficiency and inlet capture efficiency
- ✓ Reducing the generation of dust for cutting, drilling, blasting, crushing, and conveying

This chapter will give you a general perspective on what works or doesn't work. The chapter will also help if your dust control problem doesn't fit any of the circumstances described in later chapters.

This chapter describes the three major control methods used to reduce airborne dust in tunnels and underground mines: ventilation, water, and dust collectors. It also describes methods to reduce the generation of dust, so less has to be removed from the mine air.

The ventilation methods provide the best use of air in the vicinity of workers and in the vicinity of dust sources. In this sense, the methods described are local ventilation methods. Most of the emphasis is on so-called displacement ventilation because it is the most effective dust control technique available.

The section on water sprays outlines the dual role of sprays—wetting and airborne capture—and describes why wetting is more important. It also corrects some of the misconceptions about spray effectiveness and describes circumstances where sprays can actually *increase* the dust exposure of workers.

The section on dust collectors outlines the circumstances under which dust collectors can be expected to function effectively. It also describes some common design and maintenance problems.

The final section describes how to reduce the amount of dust that gets into the air in the first place, since once the dust is airborne it is always harder to control.

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VENTILATION

Ventilation air reduces dust by dilution and by displacement. Displacement ventilation is far more effective, but it is harder to implement. Several examples of displacement ventilation are provided.

This section describes local ventilation methods for dust control. Ventilation air reduces dust through both dilution and displacement. The dilution mechanism operates when workers are surrounded by a dust cloud and additional air serves to reduce the dust concentration by diluting the cloud. The displacement mechanism operates when workers are upwind of dust sources and the air velocity is high enough to reliably keep the dust downwind.

Dilution Ventilation. The basic principle behind dilution ventilation is to provide more air and dilute the dust. Most of the time the dust is reduced roughly in proportion to the increase in airflow, but not always. The cost of and technical barriers to increased airflow can be substantial, particularly where air already moves through ventilation ductwork or shafts at velocities of 3,000 ft/min or more.

Displacement Ventilation. The basic principle behind displacement ventilation is to use the airflow in a way that confines the dust source and keeps it away from workers by putting dust downwind of the workers. Every tunnel or mine passage with an airflow direction that puts dust downwind of workers uses displacement ventilation. In mines, continuous miner faces or tunnel boring machines on exhaust ventilation use displacement ventilation. Enclosure of a dust source, such as a conveyor belt transfer point, along with extraction of dusty air from the enclosure, is another example of displacement ventilation.

Displacement ventilation can be hard to implement. However, if done well, it is the most effective dust control technique available, and it is worth considerable effort to get it right. The difficulty is that when workers are near a dust source, say, 10 to 20 ft from the source, keeping them upwind requires a substantial air velocity, typically between 60 and 150 ft/min. There is not always enough air available to achieve these velocities.

To compensate for the lack of air, two techniques are used. The first is to reduce the cross-sectional area of the air course between the worker and the dust source. This confines the dust source by raising the air velocity. Second, the turbulence of the dust source is reduced. A turbulent dust source creates dusty eddy currents of air that back up against the airflow and push upwind toward the worker. When the dust source is less turbulent, less air is required to confine the dust cloud. The best way to illustrate displacement ventilation is to consider four specific mining examples.

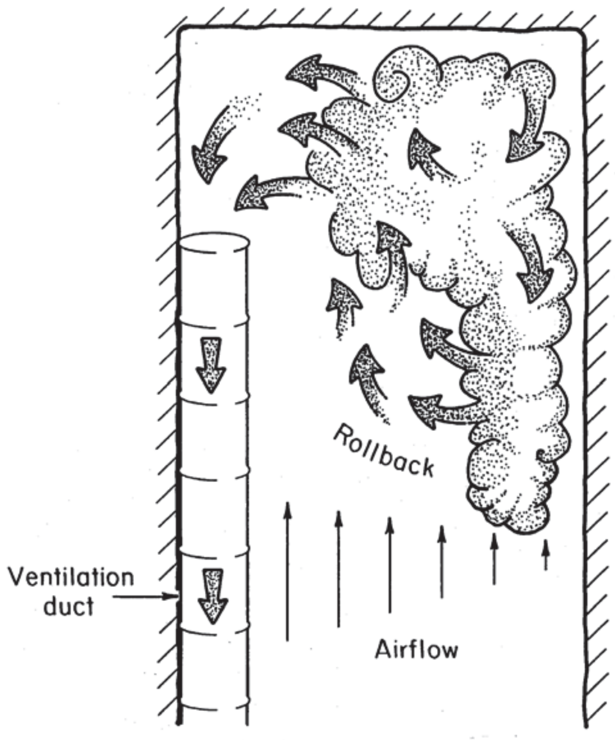

Figure 1-1.—Rollback of dust resulting from non-uniform airflow.

Example No. 1: Continuous miner faces on exhaust ventilation.—To confine the dust cloud at continuous miner faces, U.S. coal mine ventilation regulations require an average air velocity of 60 ft/min. This velocity is based on the entry cross-section without considering the area blocked by the equipment. However, 60 ft/min is a bare minimum, as it has been shown that 120 ft/min is required for good dust control [USBM 1985]. This relatively high air velocity is required because a typical coal mine entry is about 18 ft wide, and over this width the air velocity is not uniform. The air velocity is much higher on the side next to the ventilation duct, as shown in figure 1-1. Air turbulence created by the machine water sprays causes the dust cloud at the cutting face to expand and back up against the weaker airflow on the side opposite the ventilation duct. In mining, this is called rollback. It is surprising how far dust can roll back to contaminate the incoming air breathed by mine workers.

Rollback can be reduced by increasing the airflow. The air turbulence that causes rollback can be reduced by lowering the spray water pressure and aligning spray nozzles so that they are confined only to spray on the broken coal. Also, in high coal where the cross-sectional area is very large, a half-curtain in the entry is helpful. This curtain, shown in figure 1-2, is placed between the mining machine and the right or left rib, whichever is farthest from the mining machine [Jayaraman et al. 1986]. A half-curtain reduces the cross-sectional area of the entry and raises the air velocity to confine the dust cloud.

In addition to the half-curtain, there are many possible mining applications where a temporary curtain or screen can be used to channel airflow or raise the air velocity to keep nearby workers upwind of a dust source.

Example No. 2: Closed-face tunnel boring machine (TBM).—Cutter heads of hard-rock tunnel boring machines operate in what most would regard as an enclosed space. However, Myran [1985] has published recommended air quantities needed to confine dust to the cutter head space, and they are high. For example, a 20-ft-diam TBM requires 12,000 to 17,000 cfm. Why such high airflow for what is presumably an enclosed space? First, the stirring action of the large rotating cutter head creates a considerable amount of air turbulence. Second, there is far less enclosure of the cutter head than a casual inspection of a TBM would indicate. Depending on the TBM design, the entire belt conveyor access space can be open. Also, there is considerable open space when the grippers at the head expand to press out against the tunnel walls. Dust reduction efforts have focused on reducing the open space available for dust leakage by

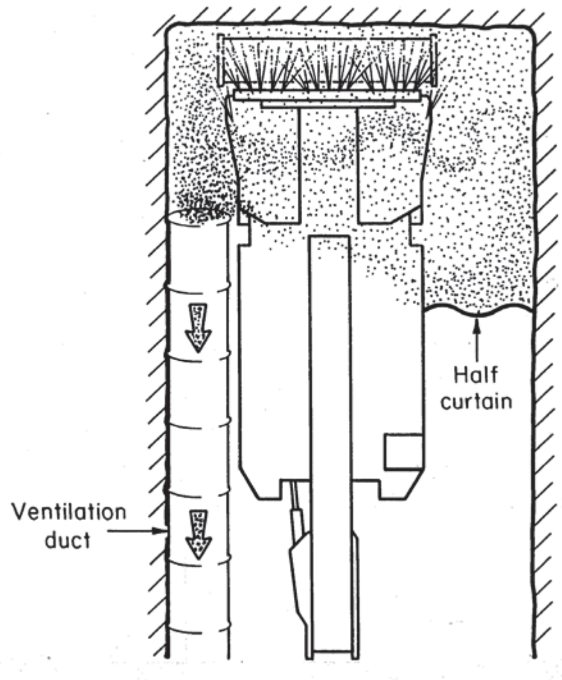

Figure 1-2.—A half-curtain raises the air velocity to confine the dust cloud.

enclosing the conveyor tunnel and by installing single or even double sets of rubber dust seals between the grippers and TBM body.

Example No. 3: Conveyor belt transfer point enclosure.—In addition to maintaining high airflow, sometimes it is necessary to extract the air at the right location in order to adequately confine dust. Figure 1-3 shows a conveyor transfer point enclosure. The design of this and similar enclosures used in materials transport has been well worked out [Goldbeck and Marti 1996; Swinderman et al. 1997]. In principle, a high degree of enclosure is possible, so even moderate airflow extracted from the enclosure should keep dust inside. However, the falling material drags air with it, creating an unbalanced pressure in the enclosure that pushes dust out of the high pressure end of the enclosure. The most effective designs address this issue by locating the exhaust port at the high-pressure end and exhausting sufficient air. Other designs incorporate steps to break the fall of the rock and thus diminish the amount of air moved. However, if the dust seals along the belt and the rubber flaps at the end of the enclosure are worn or missing, even the best designs available will leak dust.

Example No. 4: Dust avoidance measures.—Dust avoidance refers to moving either the dust cloud or the workers so that the workers are upwind of the dust. The use of remote control on coal mining machinery is the best example of dust avoidance in mining. On longwall shearers, remote control has enabled the shearer operators to move upwind 15-20 ft and avoid direct contact with the dust cloud coming off the headgate-end shearer drum, which reduces their dust exposure by 68% [USBM 1984]. On continuous miners, remote control has enabled the operator to step back toward the intake by about 12 ft and reduce his or her dust exposure level by 50% or more [Divers et al. 1982].

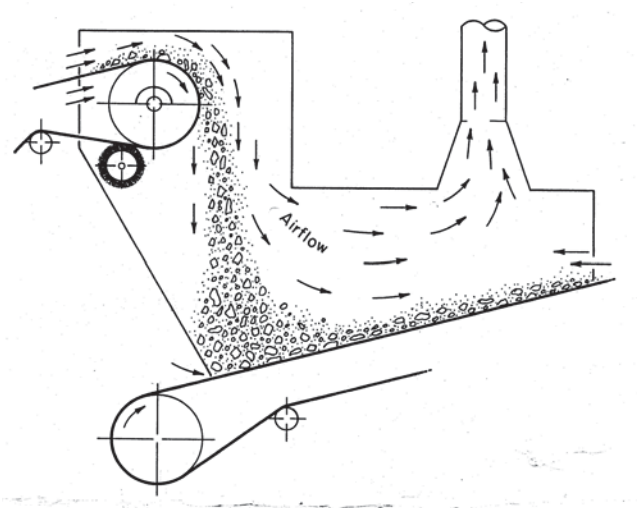

Figure 1-3.—Falling material drags air with it, so air must be extracted at the high-pressure side of the transfer point.

Sometimes, it is possible to move the dust cloud or at least its outer edge. On longwall shearers, the so-called “shearer-clearer” system uses the air-moving capacity of water sprays to hold the dust cloud against the face and prevent it from moving out into the walkway. This can reduce worker dust exposure by 50% [Shirey et al. 1985].

When workers are at the edge of a dust cloud, a small shift in the location of the workers or the location of the cloud can yield large benefits. However, if workers are in the middle of a dust cloud, dust avoidance has less chance of success because the distance moved must be greater.

WATER SPRAYS

When using water sprays, focus on uniform wetting more than airborne capture.

The role of water sprays in mining is a dual one: (1) wetting of the broken material being transported and (2) airborne capture. Of the two, wetting of the broken material is far more effective.

Wetting. Adequate wetting is extremely important for dust control. The vast majority of dust particles created during breakage are not released into the air, but stay attached to the surface of the broken material [Cheng and Zukovich 1973]. Wetting this broken material ensures that the dust particles stay attached. As a result, adding more water can usually (but not always) be counted on to reduce dust [Jankowski and Organiscak 1983; Ruggieri and Jankowski 1983; Zimmer et al. 1987]. For example, coal mine operators have been able to reduce the dust from higher longwall production levels by raising the shearer water flow rate to an average of 100 gpm [Colinet et al. 1997]. Compared to the amount of coal mined, on a weight basis, this 100 gpm is equivalent to 1.9% added moisture from the shearer alone. Unfortunately, excessive moisture levels can also result in a host of materials handling problems, operational headaches, and product quality issues, so an upper limit on water use is sometimes reached rather quickly. As a result, an alternative to simply adding more water is to ensure that the broken material is being wetted uniformly.

Uniformity of wetting was recognized as an important issue long ago by Hamilton and Knight [1957], who measured the amount of dust generated by dropping coal. By far the best dust reductions came from prespraying the coal with water and then mechanically mixing the coal and water together to achieve a uniformity of wetting. Subsequent mining experience has confirmed this. For example, releasing water at the cutting picks of rotating shearer drums has proven to be far more effective at suppressing longwall dust than using external sprays on the shearer body. This is because water released at the cutting picks gets mixed in with the broken coal, whereas water from external sprays usually provides just surface wetting.

Increasing the number of sprays is another way to promote uniformity of wetting. Bazzanella et al. [1986] showed that dust suppression is improved by increasing the number of sprays on a shearer drum even when the total water flow and nozzle pressure were held constant with the use of smaller orifice nozzles. When 46 smaller orifice nozzles were substituted for the 17 original nozzles, dust was reduced by 60%. This is better than the dust reduction given by most dust control techniques.

The benefits of improved mixing and uniformity of wetting have also been obtained with foam, with far greater effectiveness when the foam was mechanically mixed in with the coal [Mukherjee and Singh 1984] or mechanically mixed with silica sand [Volkwein et al. 1983].

The lessons from this knowledge about the use of water are twofold. First, it is best to wet the material fully during the breakage process. This is when most mechanical mixing is likely to take place. Wetting during breakage ensures that the benefits will carry over to any downstream secondary handling operation. Second, uniformity of wetting is best achieved by using more nozzles at lower flow rates and ensuring that the nozzles are aimed at the broken material rather than just spraying into the air and wetting an adjacent metal or rock surface.

While it is always best to aim sprays at broken material, circumstances dictate the impracticality of locating spray nozzles where they might be easily damaged. For example, spray nozzles under the boom of a continuous miner are more effective than those on the top of the boom [Matta 1976]. However, top nozzles are more commonly used because sprays under the boom are damaged more often and are harder to maintain.

Airborne capture. Under actual mining conditions, the typical water spray operating at 100 psi and 1-2 gpm gives no more than 30% airborne capture of respirable dust[3] [Courtney and Cheng 1977]. This is not as good as lab tests [Tomb et al. 1972] would lead one to believe. In lab tests, the

[3] The author is aware of one notable exception to this 30% rule: water blast sprays in metal mines. These sprays, using a combination of water and compressed air, were first used many years ago to reduce dust in metal mine headings after blasting. Brown and Schrenk [1938] saw dust reductions of 90%-99% from water blast sprays within 15 min after blasting. The reason for the difference (90%-99% instead of 30%) is that the water blast sprays had 15 min to work on a single-event dust cloud confined to the end of the heading. Most of the dust in the cloud recirculated through the sprays again and again, whereas in most modern mining applications the dust cloud is generated continuously, and the dust only gets one pass of a few seconds through the sprays. This explains the 30% spray effectiveness in modern mining applications. In more recent years, McCoy et al. [1985] measured the effectiveness of water spray nozzles using a closed chamber in which a single-event dust cloud was recirculated again and again through a spray. In a few minutes, the dust level was reduced by 90%, confirming the earlier observations of Brown and Schrenk, and others [van der Bank 1977].

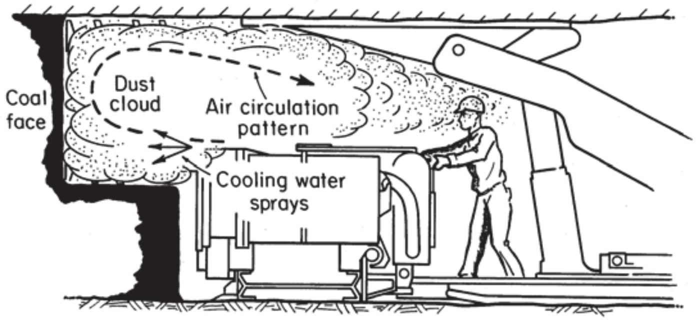

Figure 1-4.—Spray-generated airflow carries dust back to the shearer operator.

sprays were usually confined in a duct, and all of the dust was forced to pass through the spray. However, under actual mining conditions, dust clouds are unconfined. In all sprays, the moving droplets exert drag on the adjacent air; thus, sprays act to move the air. Because of this air entrainment effect, if a spray is aimed at an unconfined dust cloud, it will carry in air that spreads the cloud, thus making capture by the spray less efficient.

Aside from making sprays less efficient, the air entrainment of sprays can create other problems. Figure 1-4 shows how some sprays on a longwall shearer actually raise the shearer operator=s dust level. For many years, it was a common practice to discharge the motor-cooling water by aiming it at the coal face under the theory that it would capture some airborne dust. Although some dust was captured, a considerable airflow toward the coal face was also created. That airflow, upon reaching the coal face, simply turned around and carried the rest of the dust cloud, formerly confined to the face, back over the operator. Perhaps one-fourth of the cloud was captured, but the remaining three-fourths was blown back over the operator, raising the operator's dust level threefold [USBM 1981].

Air entrainment of sprays can also lead to overrating their effectiveness. Figure 1-5 shows a conceptual example. A dust cloud is generated by a dust source, such as a belt transfer point, and the cloud surrounds much of the dust source (figure 1-5, left). A water spray is aimed at the cloud, and a dust sampler located on or near the source shows a substantial dust reduction when the spray is turned on. Most of this dust reduction is actually caused by the air currents induced by the water spray, which dilute and blow away much of the dust cloud (figure 1-5, right). Normally, this dust reduction would be misinterpreted as airborne capture by the spray droplets.

A flawed spray application that appears in all types of mines is the so-called "water curtain." It is based on the incorrect notion that dust particles passing across a barrier row of sprays will always be captured.

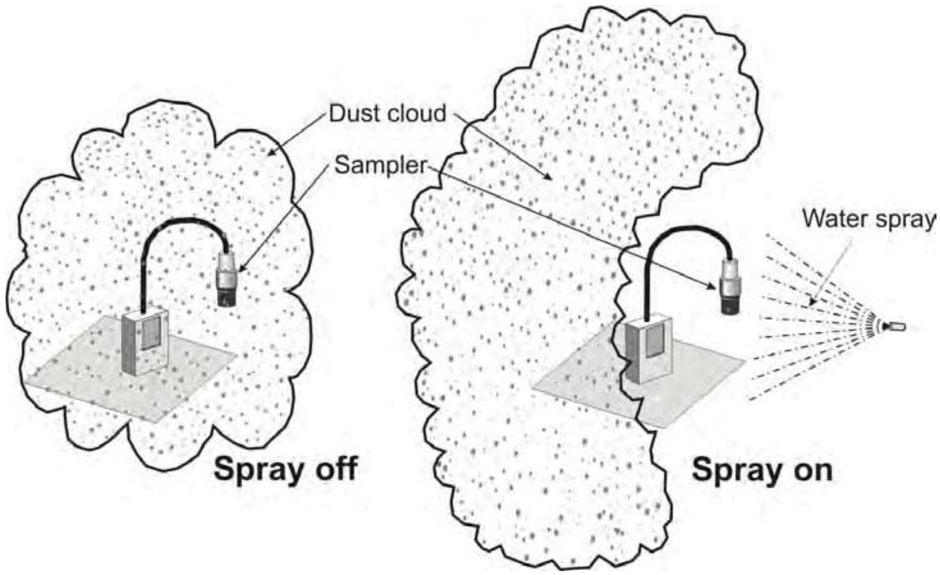

Figure 1-5.—Water spray test that can lead to overrating spray effectiveness.

Attempts to improve the airborne capture efficiency of sprays have not met with practical success. One approach has been to reduce droplet size, based on the notion that capture by smaller droplets is more efficient. This effort has included atomizing or fog sprays, steam, sonically atomized sprays, compressed air-atomized sprays, and electrically charged atomized sprays [Bigu and Grenier 1989; McCoy et al. 1983]. These methods usually offer somewhat better dust capture and some economy in the use of water, but have many disadvantages that prevent their use in mining. Nozzles with very small orifices are more prone to clogging. Fine droplets are likely to evaporate quickly and release captured dust along with the minerals that had been dissolved in the water [McCoy et al. 1983].

Sprays that use less water fall short in the more important role of wetting the broken material.

Despite the limitations of sprays, proper nozzle selection can enhance their use. Figure 1-6 shows the airborne capture performance of some common spray nozzle types at different pressures. Atomizing sprays are the most efficient. Hollow-cone sprays are a close second and are the best choice for practical mining applications because they have larger orifice nozzles and are less likely to clog. Flat fan sprays are more appropriate for spraying into a narrow rectangular space because less water is wasted by spraying against an adjacent rock or metal surface.

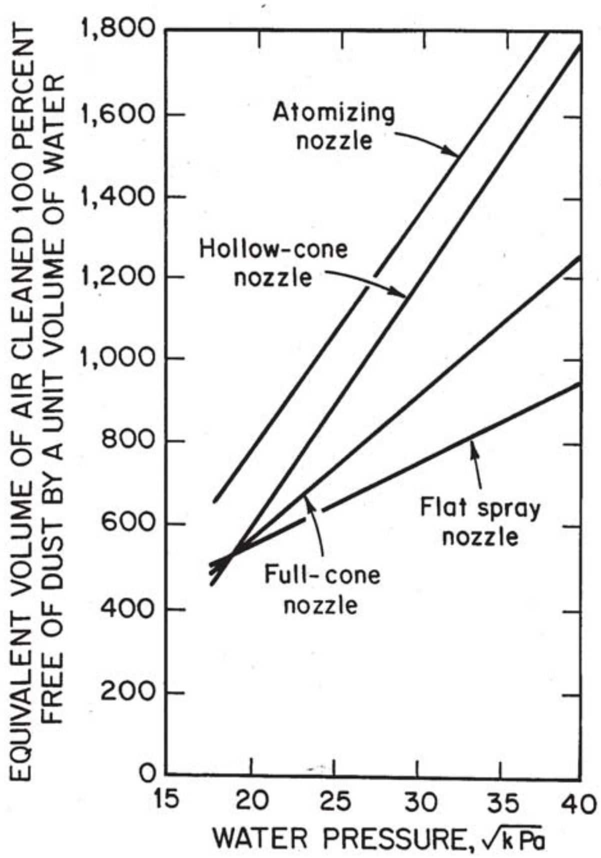

Figure 1-6.—Airborne capture performance of four types of spray nozzles.

High-pressure sprays. One way to improve sprays is to raise the water pressure. This raises the efficiency per unit use of water, as shown in figure 1-6. Jayaraman and Jankowski [1988] tested the airborne capture of both conventional and high-pressure sprays at a full-scale model continuous miner face. A conventional spray system on the miner (100 psi, 19 gpm) gave 30% respirable dust reduc-tion. A high-pressure system (2,500 psi, 3 gpm) gave the same reduction, but with much less water. The two systems operating together (22 gpm) gave 59% dust reduc-tion. The dual system would be the choice for underground use, providing both airborne capture and sufficient wet-ting of the broken material.

A marked disadvantage of high-pressure sprays is that they entrain large volumes of air, often leading to more dispersal of dust than is captured. Because of this secondary dispersal, their application is limited to enclosed or semienclosed spaces, such as under the boom of a con-tinuous mining machine.

Aside from efforts to improve sprays, the most helpful action you can take is to provide an automatic feature that turns sprays on and off as needed. This allows sufficient wetting while helping to avoid the problems associated with overuse of water.

Foam. For dust control, foam works better than water. It provides dust reductions of 20% to 60% compared to water. Foam also can produce similar results at lower water use, that is, the amount of water needed to make the foam is less than the equivalent water spray.

Seibel [1976] compared high-expansion foam to water sprays at a belt transfer point. Compared to water, the foam averaged an additional 30% dust reduction. Mukherjee and Singh [1984] found that foam released from a longwall shearer drum cut the dust an additional 50% compared to conventional water sprays on the drum. Also, the system used one-half the water of the conventional sprays. The drawback of the foam was high cost. Like water, foam works best when it is mechanically mixed with the broken material. A comprehensive review of foam for dust control in mining and minerals processing has been given by Page and Volkwein [1986].

Wetting agents. Wetting agents receive a disproportionate amount of attention, perhaps because they seem to offer an easy fix to dust problems. Most interest has been in coal mining because of the hydrophobic nature of coal. The effectiveness of wetting agents has been the subject of considerable research over the years, without much of a definitive answer on how well they work. Various studies have shown a respirable dust control effectiveness compared to plain water, averaging about 25% and ranging from zero [MRDE 1981; Chander et al. 1991] to 25%-30% [Kost et al. 1980] to more than 40% [Meets and Neethling 1987]. It seems that wetting agent effectiveness depends on the type of wetting agent, type of coal, dust particle size, dust concentration, water pH, and water mineralogy [Hu et al. 1992; Kim and Tien 1994; Tien and Kim 1997]. However, no general formula or methodology has emerged that would allow a mine operator to select a wetting agent appropriate for its specific coal (or rock) type. The only alternative is to try out a prospective wetting agent and discontinue its use if there is no clear benefit. However, given that the average effectiveness of a wetting agent is 25%, about the same as the accuracy of dust sampling methods, a wetting agent choice is never easy.

DUST COLLECTORS

Dust collectors can play a valuable role in dust reduction—if space is available to locate the collector and if the collector efficiency is high. Dust collectors range from low-volume filtration systems used in the cabs of mining equipment [Organiscak et al. 2000] to high-volume wet collectors used on continuous miners in coal mines [Volkwein et al. 1985].

The most difficult dust collector application occurs when the dust has a high percentage of silica and the air passing through the collector is reused. Then, any minor collector malfunction or design flaw will lead to excessive dust levels.

It is important to recognize that the efficiency of a dust collector is the filtration efficiency of the unit times the capture efficiency of its inlet. For collectors properly designed to trap respirable dust, the filtration efficiency is usually quite high, in the 90%-95% range. The inlet capture efficiency is much more variable. The inlet capture efficiency is high, 80% or better, when the collector extracts air from an enclosed or semienclosed space, such as the cutter head space of a hard-rock TBM or the crusher on a longwall stageloader. If the coalbed is not too high, capture efficiency is also reasonable at continuous miner faces, which are dead-end spaces crammed with equipment. However, where there is less enclosure, such as in continuous miner faces in high coal, roadheader faces, or longwall shearer faces, inlet capture efficiency is poor, 50% or less, unless the collector air quantity is unreasonably high.

Collectors also exhibit many design and maintenance problems, as follows:

Design problems. The designers of dust collection systems take many shortcuts to cut costs and reduce the amount of maintenance required, some of which also reduce the efficiency. For example, some of the fiber filters on cab filtration systems [Organiscak et al. 2000] and the flooded-bed panels on continuous miners [Colinet and Jankowski 2000] have been found to be too porous. A porous filter permits more airflow and allows for a smaller fan, but exhibits a poor collection efficiency for hard-to-trap respirable dust. Also, in recent years, continuous miner booms have been redesigned to move the collector inlets from the boom to the hinge point. This has had many benefits in cost and maintenance, but this location is farther from the dust source and thus has lowered the inlet capture efficiency [Jayaraman et al. 1992b].

Maintenance problems. Dust collectors in mines and tunnels can be high-maintenance equipment. Screens and filters clog often, sometimes more than once per shift. Gaskets disappear and access doors leak. Often, filters are not seated properly, and dusty air leaks around them. Filters also develop holes from mishandling and from abrasion by larger-sized particulate. Ductwork leading to the collector fills with coarse particulate, cutting off the airflow. Fans located on the inlet side of the collector suffer rapid erosion of their blades and are usually not designed for convenient blade replacement. High dust levels are the result. A major reason for excessive silica exposure during coal mine roof bolting is lack of maintenance on the bolting machine dust collector.

REDUCING THE AMOUNT OF DUST GENERATED

When less dust is generated, less has to be removed from the mine air.

Dust is generated by extraction, drilling, blasting, dropping, crushing, and conveying. Usually, there is some opportunity for improved control.

Extraction. The machines that produce extraction dust are longwall shearers, continuous miners, tunnel boring machines, and roadheaders. For these, the deeper the cut and the larger the chips, the less the dust produced per pound of material removed [Ludlow and Wilson 1982]. Of the factors that impact cut depth, the one under the control of the mine operator is the sharpness and the lacing pattern of the cutting tools. Lab studies on conical cutting bits have shown that significantly worn bits without their carbide tips produce much more dust [Organiscak et al. 1995].

Aside from using sharper cutting bits, water can be applied as described above. Another application of water that reduces cutting dust is water infusion of coal seams. Although it has been largely abandoned because of high cost, water infusion of coal seams will reduce dust by about 50%. To infuse a coal seam, boreholes are drilled into the coal seam ahead of mining and large volumes of water are pumped in under high pressure to wet the coal [McClelland et al. 1987].

Somewhat analogous to cutting is the grinding action of longwall shields as they are pressed against the coal mine roof. This dust is released into the air as the shields are lowered and moved forward. The factors affecting dust generated by longwall shields and the methods used to control this dust have been discussed by Organiscak et al. [1985].

Drilling. In coal mines, the most common method of drill dust control is a dry collector with the intake at the tip of the drill bit. This arrangement provides excellent dust control if the collector is maintained properly [Divers and Jankowski 1987].

In hard-rock mines and tunnels, water injection through the drill steel has been effectively used to control dust for many years [ILO 1965; Page 1982]. Foam injection through the drill steel also can be used in those applications where excessive water can create a problem [Page 1982]. Problems with wet drills usually result from maintenance difficulties such as failure to clean out clogged lines or refill water tanks. Dry dust collectors with the inlet located at the collar of the drill hole have also worked [Page and Folk 1984], but not as well as water or foam.

Blasting. Blasting is done at a time when workers are not expected to enter the affected area of the mine for the next hour or so [Knight 1980]. This allows some dust to settle out and the rest to be carried away by the ventilation system. Water can help control dust by wetting down the blast area.

Dropping. In removing and transporting mined material, the broken material is inevitably dropped. At longwall faces, the broken coal can fall 6 ft or more to the panline. At tunnel-boring machines, rock removed at the crown can drop 25 ft or more. At conveyor belts, the dropping of material from one belt to another can be a major dust source. Where it is possible to do so, dust from falling material, whether at ore passes or at conveyor transfer points, is usually controlled by enclosure and exhaust ventilation [Marshall 1964].

Crushing. Crushers in mines range from small roll types used in coal mines to large gyratory types used in hard-rock mines and mills. Whatever the size and method of crushing, dust is controlled by water sprays and local exhaust ventilation. The amount of water and air needed to do the job is hard to specify. It depends on the type of material being crushed and the degree to which the crusher can be enclosed. Jayaraman et al. [1992a] obtained substantial reductions in crusher dust at a longwall by enclosing the entire stageloader-crusher unit, using 18 gpm of water inside the enclosure, and extracting 2,500 cfm of air from the enclosure. Rodgers et al. [1978] described how dust from a 5-ft gyratory crusher was reduced by using a 75,000-cfm exhaust ventilation system and a control booth for the operators.

Conveying. Conveying by railcar usually generates little dust. Rubber-tired vehicles will kick up dust if the mine floor is dry. This dust from the floor can be reduced by wetting, by calcium chloride, or by any of the chemical preparations used to control dust at surface mines [ILO 1965; Kissell 1992].

A conveyor belt can generate large amounts of dust from several sources. Dust originates at transfer points. It is also shaken from the belt as the belt passes over the idlers. Spillage of material from the belt can also be a big contributor. Further, a high velocity of ventilation air will assist the release of dust by drying the material and releasing settled particulate.

Methods to deal with belt dust are well known [Goldbeck and Marti 1996; Swinderman et al. 1997]. If belt dust is high, the relevant questions to address are the following:

1. Are transfer points enclosed? A simple enclosure with a spray or two inside of it may be adequate. If this is not enough, the air inside must be exhausted to a dust collector, with all of the leakage points on the enclosure sealed properly [Swinderman et al. 1997].

2. Is the material being conveyed adequately wet, but not so much that it leaves a sticky mud residue on the belt? When this residue dries, dust is released; thus, an end result of excessive wetting can be an increase in belt dust.

3. Are the undersides of both the top and the bottom belts being wet [Ford 1973] so that dust sticking to the belt is not shaken loose by the idlers? Does the belt stay wet or is it drying out and releasing dust?

4. Are the belt scrapers working properly? Is a second set of scrapers being used? Has a belt-washing system been tried [Bennett and Roberts 1988; Stahura 1987]?

5. Is the belt running true and not spilling its contents [Swinderman et al. 1997]?

Chapter 6 on hard-rock mines contains more information on conveyor belt dust control. See page 86.

SUMMARY

<u>DUST CONTROL METHOD</u>	<u>EFFECTIVENESS</u> (Low is 10%-30%, moderate is 30%-50%, high is 50%-75%)	*COST AND DRAWBACKS*
Dilution ventilation	Moderate	High – more air may not be feasible
Displacement ventilation, including enclosure with extraction of dusty air	Moderate to high	Moderate – can be difficult to implement well
Wetting by sprays	Moderate	Low – too much water can be a problem
Airborne capture by sprays	Low	Low – too much water can be a problem
Airborne capture by high pressure sprays	Moderate	Moderate – can only be used in enclosed spaces
Foam	Moderate	High
Wetting agents	Zero to low	Moderate
Dust collectors	Moderate to high	Moderate to high – possible noise problems
Reducing generated dust	Low to moderate	Moderate
Enclosure with sprays	Low to moderate	Moderate
Dust avoidance	Moderate	Low to moderate

Many methods have been tested to control dust in tunnels and underground mines. Poor results and difficult operating conditions have ruled out a high proportion. Those that have remained will reliably reduce dust if one makes a determined effort to deal with the problem. Inevitably, there is cost and inconvenience involved. However, the proper consideration and use of ventilation, water, and dust collectors can usually achieve a satisfactory result.

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CHAPTER 2.—CONTINUOUS MINER AND ROOF BOLTER DUST CONTROL

By Fred N. Kissell, Ph.D.,[5] and Gerrit V. R. Goodman, Ph.D.[6]

In This Chapter

- ✓ Design and operation of machine-mounted scrubbers
- ✓ Dust control with scrubbers and blowing ventilation
- ✓ Dust control with scrubbers and exhaust ventilation
- ✓ Dust control with exhaust ventilation and no scrubber
- ✓ Dust control methods common to all continuous miner sections
- ✓ Dust control for roof bolters

This chapter explains how to control dust at continuous miner sections in coal mines where the main dust sources are continuous miners and roof bolters. In relation to dust, there are three categories of continuous miner faces depending on the type of ventilation and whether or not a machine-mounted dust scrubber is used. These are—

1. Mining machines with dust scrubbers used with blowing face ventilation
2. Mining machines with dust scrubbers used with exhaust face ventilation
3. Mining machines without scrubbers used with exhaust face ventilation

The approach to dust control is somewhat different in all three of these. However, there are many dust control features (such as the need to provide adequate airflow) common to all continuous miner sections.

For workers at roof bolter faces, there are two dust sources:

1. Dust from the continuous miner when it is upwind.
2. A malfunctioning dust collector on the bolter, which allows dust to escape

DESIGN AND OPERATION OF MACHINE-MOUNTED SCRUBBERS

Almost all new continuous miners are equipped with scrubbers. When the dust is excessive, it is possible that the scrubber needs some maintenance.

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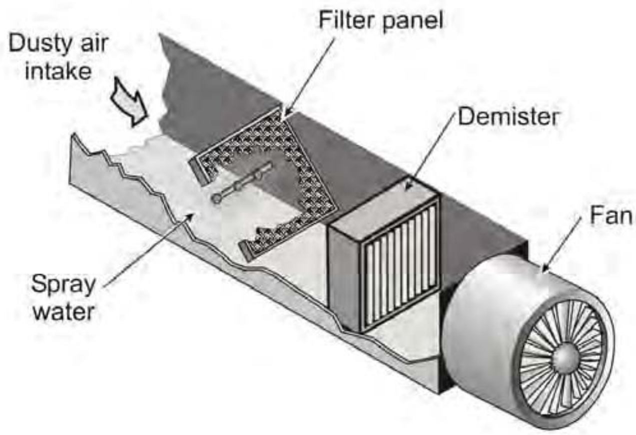

Figure 2-1.—Machine-mounted scrubber design.

Machine-mounted scrubbers, which are installed on continuous miners, collect dust-laden air through one or more inlets near the front of the miner and discharge cleaned air at the back of the miner. Figure 2-1 shows a typical design.

Inside the scrubber, the dust-laden air passes through a knit wire-mesh filter panel that is wetted with water sprays, which causes the dust particles to be captured by the water. After passing through the filter panel, the airstream then enters a demister, which removes the dust-laden water droplets from the airstream. The cleaned air passes through the fan and is then discharged at the back of the scrubber unit. Some scrubber designs have ductwork on the rear of the miner, which permits the discharge of air on either side of the machine.

Overall scrubber efficiency. The overall efficiency of the scrubber is determined by the fraction of face air that is drawn into the scrubber inlet (inlet capture efficiency) multiplied by the fraction of respirable dust removed from the captured air (filter efficiency). Overall efficiency ranges from 60% to 75% in most instances. However, several factors can cause the efficiency to decline. The most common is clogging of the filter panel.

Inlet capture efficiency. In practice, the inlet capture efficiency can be reduced by both working factors and machine design factors. The main working factors causing loss in inlet capture efficiency are entries that are large, spray pressures that are too high, and the use of blowing ventilation systems. Ideally, a dust scrubber should function like an exhaust ventilation system, drawing clean air forward over the miner and confining the dust cloud to that part of the miner that is forward of the inlet. When the entry is large, however, the scrubber capacity may not be adequate to maintain sufficient forward airflow over the miner.[7] The result is a rollback of dust, as depicted in figure 1-1. Excessive spray pressure or poorly aligned sprays also can cause rollback because of the turbulence and air movement they create. When air is delivered via blowing ventilation, and particularly with blowing duct, the amount of air delivered[8] to the face can exceed that removed by the scrubber. When this happens, dust-laden air is no longer confined to the front of the miner, but rolls back over the miner, contaminating the return air and the air breathed by workers. Specifics on how to deal with rollback are given later in this chapter.
The machine design factors that impact inlet capture efficiency are the scrubber air quantity and the location of the inlets. The air quantity should always be as large as possible and the inlets as

[7]When the entry size increases, the open area increases by a greater proportion because some of the entry is blocked by the miner.
[8]The amount of air delivered to the face includes both the airflow (the air jet) from the duct and that portion of the surrounding air induced into the jet.

far forward and close to the cutting drum as practical [Jayaraman et al. 1992]. On high-coal machines, the inlets are usually distributed under the cutting boom, which is a good location because it is where the dust cloud is thickest. On low-coal machines, the inlet is usually at the boom hinge point, which is not as good because it is farther from the cutting drum. However, since low-coal machines usually work in entries where the clearance over the machine is less, the rollback of dust that might result from using a hinge point inlet may be offset by higher forward air velocities through a narrower space over the miner. Mines in high coal that use a hinge point inlet never reach adequate capture efficiencies, even with very high scrubber airflows [Hole and Von Glen 1998].[9]

One frequently asked question is what the airflow ratio should be, that is, the ratio of ventilation airflow to scrubber airflow. The most recent research [Fields et al. 1990] shows that this ratio is not particularly important for dust control, assuming there is enough ventilation airflow to dilute dust (and gas) and assuming that blowing systems are not used in a way[10] that overpowers the scrubber and causes a loss in inlet capture efficiency.

Filter efficiency. The thickness of the filter panel controls the filter efficiency. The original filter panel was made with 40 layers of stainless steel mesh knit from 85-micrometer stainless steel wire. Today, thinner filter panels containing 30, 20, and 10 layers of stainless steel mesh are available. The reduced filter thickness allows larger quantities of air to be moved by the scrubber, potentially improving inlet capture efficiency. However, thinner filters are less efficient at trapping dust. In a study by Colinet and Jankowski [2000], the 30-layer panel displayed a filter efficiency above 90% for respirable-sized dust, but the filter efficiency dropped too much when the thinner 20- and 10-layer panels were tested.

Scrubber maintenance. When the dust is excessive, it is likely that the scrubber needs maintenance. More than likely, some cleaning of the filter panel or ductwork is required.[11] The sprays should be checked to ensure they are completely wetting the entire filter panel, and not just the center. The density of the panel should also be checked to ensure that a panel of 30 layers was purchased.

Schultz and Fields [1999] reported a method used by one mine operator to block large pieces of coal from entering the scrubber inlets under the boom. The mine had installed a flap of conveyor belt about 8 inches inby each inlet and the flaps extended downward about 8 inches. The flaps forced the air to make an extra turn before entering the inlet, blocking the larger particles flying from the cutting drum. These flaps worked so well that the scrubber lost only 10% of its airflow capacity after an entire shift of operation.

[9]Hole and Von Glen [1998] tested a scrubber for which the distance between the inlet and outlet was only about 8.2 ft. Air entrainment into the outlet jet produced a low-pressure region on the side of the machine that caused air at the front of the machine to bypass the inlet, further reducing the inlet capture efficiency.
[10]This is described in more detail in the next section.
[11]Schultz and Fields [1999] have noted that some scrubbers lose as much as one-third of their airflow after just one cut. Scrubber airflow can be monitored by measuring the filter differential pressure, the fan inlet pressure, or the fan motor current [Taylor et al. 1996].

DUST CONTROL WITH SCRUBBERS AND BLOWING VENTILATION

Dust scrubbers are most often used with blowing ventilation. When operator dust levels are too high, the most likely reason is that the operator is not spending enough time standing in front of the blowing line curtain.

With blowing face ventilation, fresh air is directed behind the line curtain or through ventilation duct and then discharged from the end of the line curtain/duct toward the face. This fresh air dilutes and entrains dust at the mining face, and the dust-laden air then passes out of the immediate face area and into the dust scrubber. After the dust is removed from the air, the air is discharged backwards from the rear of the mining machine on the side of the machine opposite the line curtain. A typical scrubber-blowing ventilation arrangement is shown in figure 2-2.

Remote placement of the mining machine operator. Although sections using blowing face ventilation use machine-mounted scrubbers, the operator can still be exposed to some of the respirable dust escaping the scrubber. This includes dust that escaped being drawn into the intake, as well as dust drawn into the intake but not collected by the filter panel. As a result, it can make a difference where the remote operator is located while operating the miner. A study by Jayaraman et al. [1987] in an Illinois mine measured the dust reduction benefits from positioning the operator in intake rather than return air, as shown in figure 2-2. The average intake level was 0.2 mg/m^3 and the average return level was 3.1 mg/$m.^3$ This shows that a 94% reduction in operator exposure could be obtained by moving the operator to a

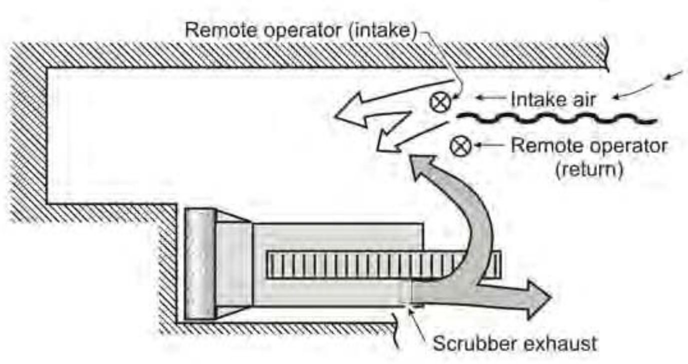

Figure 2-2.—Dust scrubber used with blowing ventilation.

position in front of the line curtain.[12] More recently, Goodman and Listak [1999] measured 0.79 mg/m^3 on a remote operator who spent most (but not all) of the time in front of the line curtain. The actual dust concentration of the intake air was 0.13 mg/m^3. Still, the dust reduction was 73% when compared to the return dust level of 2.9 mg/m^3.

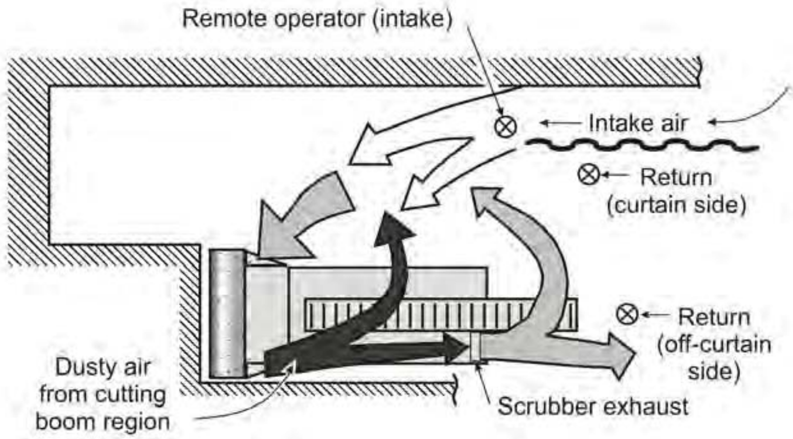

Figure 2-3.—Excessive air blown toward the face will cause dust to bypass the scrubber inlets.

Factors causing high dust levels. When remote operator dust levels are too high, the most likely reason is that the operator is not spending enough time standing in front of the blowing line curtain.[13] When downwind dust levels are too high,[14] it is likely that the scrubber needs maintenance. More than likely, some cleaning of the ductwork or filter panel is required. If the scrubber is operating properly, then the ventilation and the sprays should be checked. If the amount of air directed into the cutter boom region exceeds the amount of air withdrawn by the scrubber, then much of the dust cloud around the cutter boom will bypass the scrubber and move outby to contaminate the return (figure 2-3). This is the rollback of dust described earlier in this chapter. This excess air may be reduced by winging out the line curtain at the end to lower the velocity of the air emerging from behind it [Schultz and Fields 1999] or to pull the line curtain back slightly. Jayaraman et al. [1988] described successful experiments in a mine where the operator erected a short line curtain during the slab cut to shield the miner from the air jet emerging from a blowing duct.[15] However, the ability to use these techniques will depend on the amount of methane gas present, since limiting the fresh air may increase methane levels.

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[12] Gas emissions, MSHA guidelines regarding line curtain setback, and roof control plans may limit the selection of the best location from a dust exposure standpoint.

[13] Some mines position the operator on the return side of the line curtain but very close to the line curtain. If the line curtain has a high leakage rate, this leakage air can reduce the operator's dust level. Occasionally, a mine will slit the line curtain and position the operator in the clean air emerging from the slit. How well this works is not known.

[14] The miner helper, the shuttle car operator, or other positions downwind.

[15] Dust problems caused by blowing too much air at the face are more prevalent when ventilation duct is used in place of blowing line curtain. This is because the jet of air from the duct is moving at a much higher velocity. Due to the higher velocity, the reach of the jet is extended and the amount of surrounding air entrained by the jet and pushed forward is much greater. The problem is common in Germany, where coal mine face ventilation systems use a blowing duct in combination with an exhaust system. The usual approach to reduce dust is to use a diffuser at the end of the blowing duct [Noack et al. 1989; Graumann and Gastberg 1984].

The dust cloud also can bypass the scrubber when the spray pressure is too high[16] or when directional sprays, such as in the "spray fan" system, are used. The resulting turbulence and air movement also will cause much of the dust cloud to bypass the scrubber inlet and move outby toward the operator.

DUST CONTROL WITH SCRUBBERS AND EXHAUST VENTILATION

As with blowing ventilation, the position of the operator is crucial for good dust control.

When exhaust ventilation is used with a scrubber, fresh air is drawn through the mine entry toward the face. This air then passes into the scrubber where it is cleaned of dust and discharged back toward the line curtain. From the line curtain, the air passes to the return. Figure 2-4 shows a typical scrubber-exhaust ventilation arrangement with the miner operated by remote control. As with blowing ventilation, the location where the mining machine operator stands greatly changes his or her dust level. However, dust levels in exhaust ventilation sections can be lower than those in blowing ventilation sections because the mining machine operator has more options as to where to stand and stay out of the dust cloud. Also, the shuttle car operator is working in fresh air.

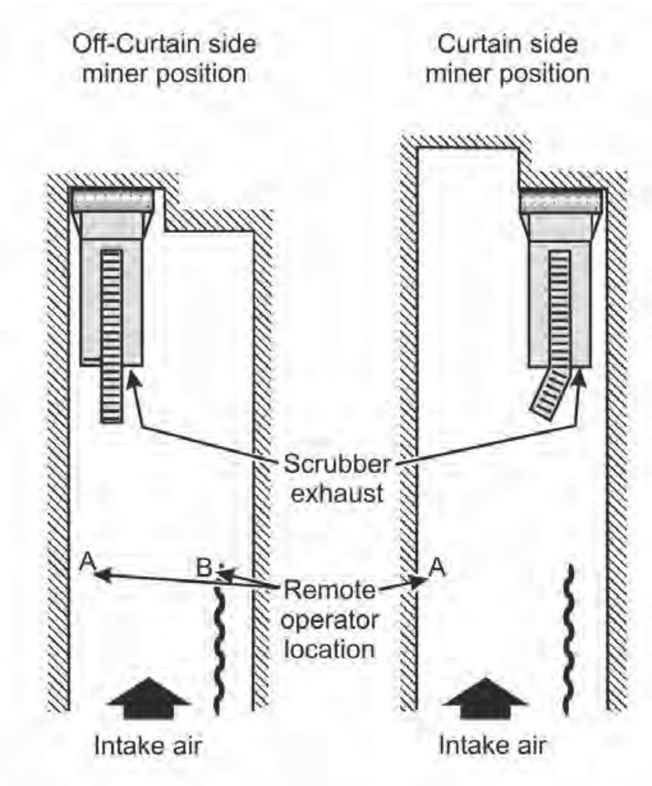

Figure 2-4.—Dust scrubber used with exhaust ventilation.

In a mine using a machine-mounted scrubber and exhaust ventilation, Goodman and Listak [1999] measured dust levels at the mining machine and at the remote operator location. The entry size was 10 ft by 20 ft. The scrubber flow was 9,500 cfm, and the air quantity exhausted by the line curtain was 15,000 cfm. For the box cut (figure 2-4, left), the remote operator stood at locations A or B; for the slab cut (figure 2-4, right), at location A only. Both locations were parallel with the end of the line curtain. The dust level at the

[16]Remedies include lowering the spray pressure to under 100 psi. The spray pressure is measured by removing a nozzle and attaching a hose that leads to a pressure gauge. See the section in this chapter on the antirollback spray system.

right rear corner of the miner (the cab location on nonremote machines) was 4.3 mg/m^3; the dust level for the remote operator location was 0.79 mg/m^3, about 80% lower than the cab location.

Goodman and Listak also found that when the remote operator positioned himself at location A, he could move a few feet inby toward the face without his dust level increasing much. However, when he stood at location B and moved a few feet inby, his dust level rose significantly because he had moved out of the intake air zone.

In another study of scrubbers and exhaust ventilation, Colinet and Jankowski [1996] used a full-scale lab model to assess the dust impact of moving the location of the remote operator while changing the distance from the end of the line curtain to the face, the line curtain airflow, and the water pressure. The entry size was 9 ft by 18 ft, and the scrubber flow was 7,800 cfm. Tests were done with the airflow ranging from 3,000 to 13,000 cfm, the line curtain-to-face distance from 30 to 40 ft, and the water spray pressure from 60 to 200 psi. Dust was measured at location A shown in figure 2-4, 5 ft inby location A, and 5 ft outby location A. Colinet and Jankowski found higher dust levels at the inby location and recommended that operators always position themselves either at location A, parallel to the end of the line curtain, or outby. At these recommended locations, changing the water pressure and line curtain-to-face distance had no effect on dust levels. Changing the airflow from 3,000 to 13,000 cfm produced a modest[17] 0.5 mg/m^3 decrease in dust. Colinet and Jankowski also point out that the scrubber exhaust must be on the same side of the entry as the line curtain and that this may require a crossover air duct at the rear of the miner.

When the dust level is too high, the first thing to check is whether the operator is standing parallel to or outby the end of the line curtain. Other factors to check are whether the jet from the scrubber exhaust is on the same side of the entry of the line curtain, whether the line curtain end is outby the scrubber exhaust, and whether the air in the jet is all passing behind the line curtain rather than backing up against the intake air. To test if the air in the jet is all passing directly behind the line curtain, the contents of a dry powder fire extinguisher should be released into the scrubber exhaust stream. Then, observe whether all of the powder goes behind the line curtain.

DUST CONTROL WITH EXHAUST VENTILATION AND NO SCRUBBER

Exhaust ventilation alone can be a very effective way to control dust. The quantity of ventilation air is the most important factor in controlling dust exposure.

With exhaust ventilation, fresh air is drawn up the mine entry to the face to dilute and entrain dust. Dust-laden air is then pulled from the face area and carried behind the line curtain or into ventilation duct and out of the face area.

[17]This amount is modest considering such a huge change in the airflow.

Over 15 years ago, the U.S. Bureau of Mines (USBM) surveyed 12 continuous miner sections that were at or below 0.5 mg/m^3 during the previous 18 months [USBM 1985b]. Three features were common in all or most of the sections: good ventilation, good spray systems, and a modified cutting cycle. The last two of these are discussed later in this chapter. The first, good ventilation, is discussed here.

Good ventilation. At all mines surveyed, the quantity of face ventilation air was the most important factor in controlling dust exposure.[18] The mean entry air velocity ranged from 63 to 335 ft/min and averaged 122 ft/min. In all cases, the distance from the face to the end of the line curtain/duct was 15 ft or less. Eight of the mines used exhaust duct with an auxiliary fan. At the other mines, the exhaust line curtain was very well maintained, and leakage was minimized by sealing the floor/line curtain interface. The high entry air velocity, averaging 122 ft/min, reduced dust rollback significantly. Rollback takes place when turbulence from the water sprays causes the dust cloud to spread toward the miner operator. Because of the high air velocity, dust generated by coal extraction was usually confined to the face area, and any operator exposure was usually from intake sources such as shuttle car loading and haulage.

Unfortunately, achieving a high ventilation air velocity is not always possible. Mine operators who cannot supply a high air velocity have three alternatives: a half-curtain, antirollback sprays, and remote control. The last two of these are discussed in the section on common dust control methods. The first, a half-curtain, is discussed here.

Half-curtain. Mines in high coal may have difficulty achieving adequate air velocities because the cross-sectional area of the mine entry is larger than normal. Although the quantity of air delivered may be large, inadequate air velocities will permit the dust cloud at the face to roll back over the miner operator. The half-curtain [Jayaraman et al. 1986] is a piece of brattice cloth supported by two pogo sticks. It is placed perpendicular to the rib just inby the operator's position and extends from roof to floor (figure 2-5).[19] The half-curtain reduces the cross-sectional area of the entry, thus increasing the air velocity in the region between the operator and the dust source. Results of a lab study show that the half-curtain performance depends largely on placement. The greatest improvement (86%) was achieved when the half-curtain was outby the end of the line curtain and just inby the operator. Underground tests show that with the half-curtain, the respirable dust exposure of the operator was reduced by 50%.

In gassy mines, caution must be used to ensure that hazardous accumulations of methane do not build up behind the half-curtain during the box cut. Jayaraman et al. [1986] also give procedures to follow when gas is present.

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[18]A full-scale lab study by Colinet et al. [1991] reached the same conclusion.
[19]The half-curtain shown in figure 2-5 is on the off-curtain (duct) side of the entry. It also can be placed on the curtain (duct) side of the entry. Some mines using exhaust duct have placed a narrow curtain at the end of the duct to enlarge the capture area of the duct. This might be described as a quarter-curtain rather than a half-curtain, since the area blocked is much less. Nevertheless, it can reduce dust for the same reason, particularly if the air velocity is in the critical 40-60 ft/min range, where minor differences in air velocity can make large differences in the dust level.

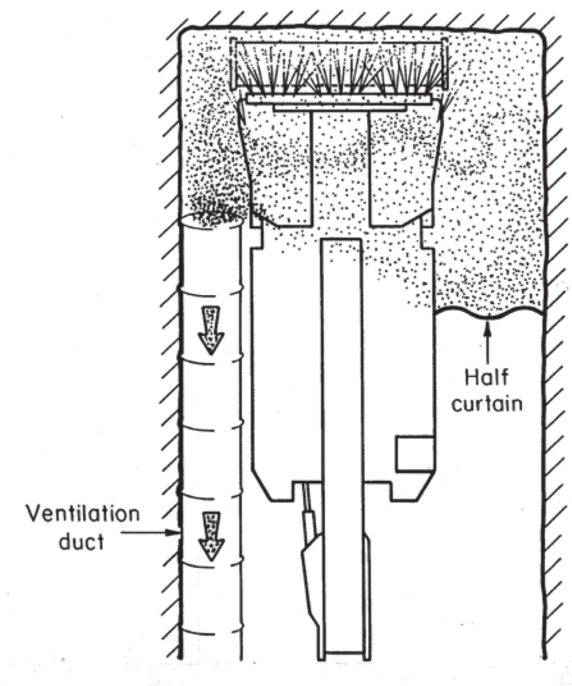

Figure 2-5.—Half-curtain location.

When dust levels are too high, the air velocity and the distance from the face to the end of the line curtain or duct should be checked. These are both critical.[20] Studies have shown that dust levels are much lower when the end of the line curtain or duct[21] is located close to the face. For this reason, the end of the exhaust line curtain or duct should be maintained within 10 ft of the face. Also, when using exhaust ventilation, mean entry air velocities above 60 ft/min have been shown to minimize dust. Both the 10-ft and 60-ft/min criteria are required by Mine Safety and Health Administration (MSHA) regulations. If these ventilation changes are not possible or if dust levels are still too high, the methods described in the next section should be considered.

DUST CONTROL METHODS COMMON TO ALL CONTINUOUS MINER SECTIONS

Many dust control methods are common to all continuous miner sections. These include good spray systems, a modified cutting cycle, remote control, good water filtration, and regular bit replacement.

The first two dust control methods in this section, good spray systems and a modified cutting cycle, originated in the USBM survey [USBM 1985b] of continuous miner sections with dust levels of 0.5 mg/m^3 or less, as discussed in the last section.

Good spray systems. All spray systems in the USBM survey were well maintained and completely functional. Water flow to the miners in the survey averaged 29 gpm. Also, sprays

[20]See figure 6-5 on page 92.
[21]When ventilation duct is used, a convenient way to keep the end close to the face is to incorporate a smaller diameter sliding section into the last fixed segment.

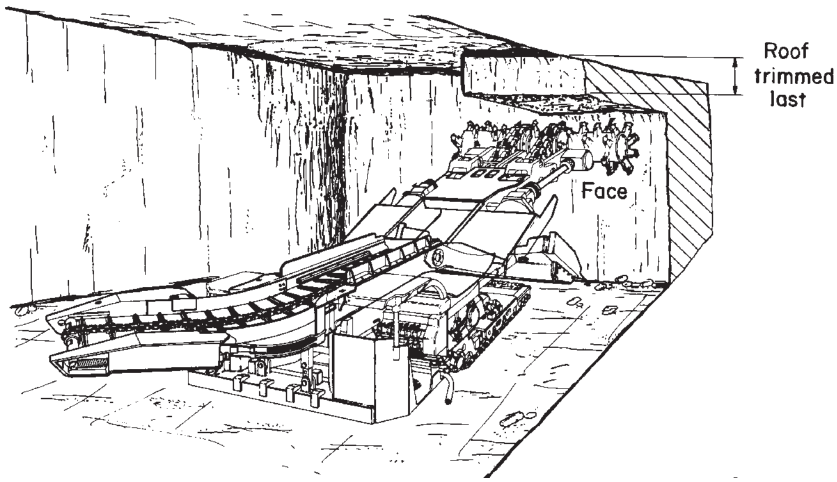

Figure 2-6.—Modified cutting cycle. In this cutting cycle, the roof is trimmed last.

were mounted on the flight conveyor with a flow averaging 5 gpm. These flight conveyor sprays served to add water to the cut material before discharge onto the shuttle car, thereby reducing the operator's exposure to this intake dust source.

Field studies by Matta [1976] and by Courtney et al. [1978] have shown that sprays under the boom are somewhat more effective than sprays on top.

Modified cutting cycle. The USBM survey of low-dust continuous miner sections also found that two-thirds of the surveyed mines used a modified cutting cycle (figure 2-6). The usual cutting cycle is to sump in at the roof and then shear down to the floor. With the modified cutting cycle, the machine sumps into the coal face a foot below the roof and then shears down to the floor. This is continued for at least two sump/shear sequences. The miner then backs up and trims the remaining rock and coal from the roof.

This modified cutting cycle leaves the roof rock in place until it can be cut out to a free face, generating less dust (and particularly less quartz dust).[22] Also, some operators have found that the modified cutting cycle provides better machine control. They reported that it prevents the machine from climbing into the roof when sumping high.

Remote control. If machine operators can avoid dusty areas and remain in uncontaminated air, their dust exposure will be much lower.[23] Remote control of the miner is the way to accomplish this. With exhaust ventilation, dust is avoided by moving away from the face and back into intake air. With blowing ventilation that uses a line curtain, dust is avoided by stepping in front of the line curtain. In either case, dust reductions of 90% are possible. Remote control allows the operator to step back and get away from the dust cloud that surrounds the machine. Several studies have shown how effective remote control can be [Divers et al. 1982; Jayaraman et al. 1987; Goodman and Listak 1999].

[22]Jayaraman et al. [1988] describe experiments at a mine where the operator used a modified cutting procedure to deal with a high level of quartz dust that originated from cutting a sandstone floor. The miner sumped into the coal face about 6 inches above the floor and sheared upwards. The bench on the floor was then trimmed separately. This change, combined with a curtain to confine the dust cloud during removal of the slab, cut the dust concentration in half and also cut the quartz percentage in half.

[23]A downside of remote control is that it may remove the operator from a location that is protected from roof falls, such as the cab of a continuous miner.

Remote control is one of the best, if not *the* best, dust control available for all kinds of mining machinery.

Antirollback water spray system. A way to counter rollback resulting from low air velocity is to use an antirollback spray system (figure 2-7) [Jayaraman et al. 1984]. Most conventional spray systems consist of multiple nozzles (15 to 30) located across the top and along the side of the miner boom. Jayaraman et al. [1984] showed that many water spray systems produce enough air turbulence to overwhelm the primary airflow, causing dust rollback. Spray system characteristics that promote rollback are:

(1) High spray pressure (over 100 psi), which increases air turbulence at the face more than it suppresses dust. Tests have shown that a moderate spray pressure of 100 psi, measured at the nozzle, is a practical maximum pressure. However, water flows should be as high as possible. The spray pressure is measured by removing a nozzle and attaching a hose that leads to a pressure gauge.

(2) Top and side sprays with wide-angle cones that purposely overspray the cutter head or are set on the boom too far back from the cutter head. The longer the spray path, the more air is set in motion, and this air movement stirs up dust. A typical miner spray does most of its airborne dust collection in the first 12 inches; thus, top and side nozzles should be arranged for “low” reach and no overspray (figure 2-7, *A* and *B*). Flat fan sprays delivering about 1 gpm per nozzle are best suited for this application since the entire flow from the nozzle can be directed onto the cutter head. Underneath the boom, deluge-type nozzles delivering about 5 gpm per nozzle should be used to wet the broken coal. These nozzles should be mounted in a protected location close to the edge of the boom to ease servicing.

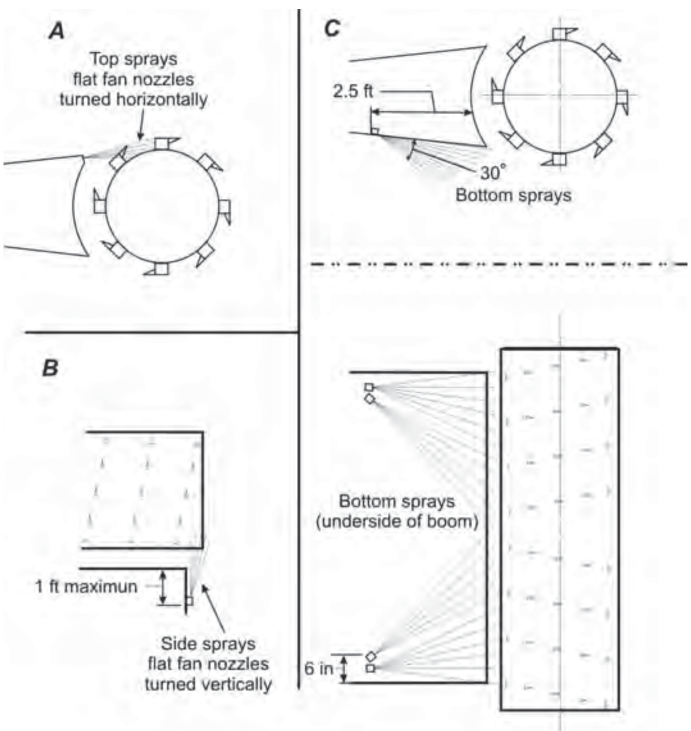

Figure 2-7.—Antirollback water spray system.

In underground trials, the antirollback spray system reduced dust levels at the operator’s position by 40%[24] compared to conventional sprays.

Good water filtration. Dirt and rust particles in the water line cause frequent clogging of spray nozzles. A simple, nonclogging water filtration system is available to replace conventional spray filters [Divers 1976]. The system consists of an in-line Y-strainer to

[24]Without using the underboom sprays.

remove the plus 1/8-in material, a hydrocyclone to remove most of the remaining particles, and a polishing filter to remove the few particles that are not trapped by the hydrocyclone during startup and shutdown of the spray system. A new type of removable manifold that facilitates the quick changing of clogged sprays can also be used. To construct it, obtain a piece of 0.5-in wall pipe that is 0.5- to 2-ft long, depending on the intended location. Cut a lengthwise slot in the pipe. Weld the pipe to the miner with the slot facing forward. Fabricate a conventional spray bar from a second piece of pipe that slides into the slotted heavy wall pipe with the nozzles keyed into the slot and aimed out of the slot. Devise some means to hold the smaller pipe in place so that it can be removed to service the nozzles.

Regular bit replacement. Routine inspection of the cutting drum and replacement of dull, broken, or missing bits improves cutting efficiency and helps to minimize dust. Also, Organiscak et al. [1996] showed that bits designed with large carbide inserts and smooth transitions between the carbide and steel shank typically produce less dust.

Reduction of intake dust. Intake dust is often overlooked as a source of dust overexposure. Intake sources may include movement of outby equipment on dry roadways, feeder-breakers, and conveyor belts. Methods to reduce conveyor belt dust are described in chapter 6 on hard-rock mines. Methods to reduce haul road dust are described in chapter 5 on surface mines. Potts and Jankowski [1992] measured the dust level impact of using belt air for face ventilation, both on continuous miner and longwall sections.

Bolter dust collector maintenance. Occasionally, a malfunctioning bolter dust collector upwind of the miner will produce enough quartz dust to raise the exposure of the continuous miner operator. This is more likely to create a compliance problem on sections that are on reduced (more stringent) standards because of quartz in the coal. In such instances, additional quartz from the bolter, even in small amounts, will have significant impact. As much as 25% of the continuous miner operator's quartz dust exposure can be attributed to dust from the bolting operation. The problem is usually a lack of maintenance on the bolter dust collector.

DUST CONTROL FOR ROOF BOLTERS

Dust at bolter faces originates from the continuous miner if it is upwind or from a malfunctioning dust collector at the bolter itself. In most instances, high dust exposures are easily remedied.

Dust from upwind sources. If the bolter dust collection systems are operating properly, most of the bolter operator's dust exposure is generated by the continuous miner when it is upwind. The best way to reduce this bolter exposure is to use double-split ventilation. If single-split ventilation is being used, then the cutting sequence must be designed to limit the amount of time that the continuous miner is upwind.

If the continuous miner has a scrubber and the bolter dust exposure is still high, the scrubber should be checked to ensure that it is operating properly. Other techniques for reducing the dust level of personnel downwind of a continuous miner have been described by Jayaraman et al. [1989].

Dust from the bolter. While most of the roof bolter operator's dust exposure comes from upwind sources (e.g., the continuous miner), some bolting machines allow a significant amount of dust to escape the dust collector system, thus contaminating the region around the bolter. Such contamination is more likely when an insufficient amount of clean air is available to dilute the dust.

When dry dust collection systems are leaking, dust emission from the blower exhaust is the most common problem. It is usually caused by damaged or improperly seated filters. Also, many roof bolter dust collectors show accumulations of dust between the filters and blower, which results from past or current filter leaks. With the filters removed and the access door open, this dust can be removed by back-flushing the system with compressed air or by running the blower for several minutes.

Proper disposal of the dust that accumulates in the dust collector box can be important, since this dust is easily stirred up by mine traffic if just dumped onto the middle of the mine floor. Goodman and Organiscak [2002] compared two methods of cleaning the dust collector box. One was the common practice of using a metal rake to scrape the cuttings out of the collection box onto the mine floor. A second method was to collect the dust in a bag contained within the largest compartment of the dust box. When full of dust, the bag is carried to the rib and gently dumped. Comparisons of the bag versus the metal rake for cleaning the dust box showed that respirable coal dust and respirable silica dust exposures for the bolter operators dropped by a factor of two when the bag was used. Disposable bags are now available for some bolters.

Dust from the drill hole can also pose a problem. A visible plume from the collar of the drill hole is a sign of inadequate airflow to the chuck or bit. The air leaks that cause inadequate airflow occur mainly at loose hose connections, through the pressure relief valve, and through poorly fitting dust collector access doors. It is common to find as much as 50% leakage.

The bit type also makes a difference in the dust escaping from the drill hole. In one study, shank-type bits allowed from 3 to 10 times more dust to escape from the drill hole collar than "dust hog" bits [USBM 1985a]. Most of this dust escaped during the first few inches of bit penetration. Typically, the dust hog bits generate one-fifth of the dust generated by the shank bits in the initial 12 inches and one-third of the dust over the full length of the hole.

Some years ago, MSHA did a survey to evaluate the effectiveness of improved maintenance on dry dust collection systems [Thaxton 1984]. During the survey, the mine operators replaced all duct hoses, filters, and the blower muffler, repaired the vacuum system and dust box seals, and cleaned the blower unit. Results showed major improvements in both the quartz percentages and the dust levels.

A small proportion of roof bolters use wet systems to control dust. In wet systems, hollow drill steels are used to deliver low-pressure water (2 gpm per chuck) to the bits. These systems offer improved bit life, faster drilling, and excellent dust control. However, wet drilling can create problems in coal mines that cannot tolerate additional water on the mine floor. Also, leaking water seals can splash water over the bolter operators, making for unpleasant working conditions. As a result, good maintenance of all seals is important.

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CHAPTER 3.—LONGWALL DUST CONTROL

By Fred N. Kissell, Ph.D.,[25] Jay F. Colinet,[26] and John A. Organiscak[27]

In This Chapter

- ✓ Which dust source to address first
- ✓ How much air and water are needed
- ✓ Keeping dust out of the walkway
- ✓ Moving workers upwind
- ✓ Dealing with the stageloader-crusher
- ✓ Gob and wing curtains to aid airflow
- ✓ The shearer-clearer system
- ✓ Modified support movement practices

and

- ✓ Dust control for future longwalls

Controlling longwall dust is not easy. Longwall production levels are high, and there are several different sources of dust to contend with. If dust levels are high, the initial effort should be devoted to finding which source is the cause. Then, efforts to reduce dust can be concentrated where they will have the most impact.

To control dust at longwalls, a large amount of ventilation air and spray water must be used. The water must be sprayed correctly so as not to blow dust into the walkway. Techniques to change local airflow patterns can be helpful. The shearer-clearer, as well as gob and wing curtains, are examples of such techniques.

DECIDING WHICH DUST SOURCE TO ADDRESS FIRST

If a longwall is out of compliance with dust standards, knowing where the extra dust is coming from helps to get back in compliance quickly.

The four major sources of dust at longwall faces are (1) the shearer, (2) the shields, (3) the stageloader-crusher, and (4) the intake. Finding the source of the extra dust involves two tasks.

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First, the dust from each source must be measured. Second, these measurements must be compared to previous samples or to results from other longwalls in order to discover which dust source is causing the problem.

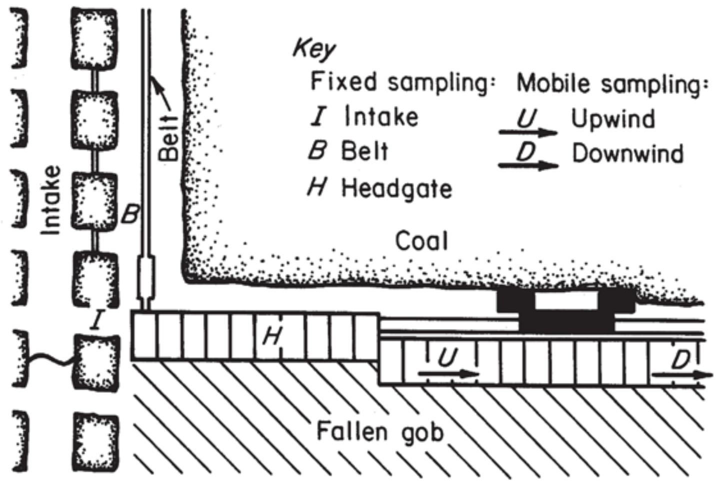

Figure 3-1.—Longwall dust sampling locations.

Finding the amount of dust from each source. The first task is to take dust samples to measure the amount of dust from each source. Initially, fixed-site on-section[28] dust samples should be taken at locations I and H shown in figure 3-1. Location I gives the intake dust level. Location H is at shield 10 and includes the intake dust in addition to the stageloader-crusher dust. The stageloader-crusher dust is obtained by subtracting the dust level at I from the dust level at H. To ensure reasonable accuracy, a package of at least two samplers should be used for three shifts.

If belt air is used to ventilate the longwall face, the belt air dust concentration at location B should be measured. If the airflow at both B and I is measured, a corrected average concentration from the two locations can be calculated.[29] The concentration at H then reflects[30] the addition of the stageloader-crusher dust[31] to the intake and belt dust.

Separating out shearer dust is a harder task. It requires two people who follow the shearer as it cuts. Each person carries several dust samplers. One stays upwind of the shearer (location U in figure 3-1); the other stays downwind of the shearer (location D in figure 3-1). The shearer dust contribution is the difference between the upwind and the downwind dust concentration values,[32] locations U and D.

Shield dust is measured in the same way, using upwind and downwind measurements, except that the sampling pumps are turned on only during the head-to-tail pass to minimize background dust levels. One person stays 25 ft upwind of shield movement; the other stays 25 ft downwind[33]

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[28]On-section means that sampling is done while the shearer is operating, not portal to portal.

[29]If the concentration and airflow at I are C_I and Q_I and at B are C_B and Q_B, then the corrected average concentration is $[(C_I\ Q_I) + (C_B Q_B)] / [Q_I+Q_B]$.

[30]The reason that concentration (mg/m^3) is used instead of dust make (mg/sec) is that the dust make value is subject to error caused by air loss into the gob, which takes place between locations I and H.

[31]The concentration measured at H will contain a small amount of shearer dust from the cutout at the headgate. This error can be eliminated by turning off the sampling pump when the shearer is upwind of shield 10.

[32]This assumes that shield movement is far enough from the shearer to be subtracted out.

[33]The 25-ft value is approximate and may vary slightly depending on circumstances. If the downwind person gets too close to the shearer, the samplers will be biased upwards by shearer dust. If the downwind person gets too close to the moving shields, the samplers will be biased upwards because the shield dust, which falls mostly into the walk-

of shield movement. This "mobile sampling" has been described more fully by Colinet et al. [1997] and Srikanth et al. [1995].

Source comparison with other longwalls. Once sampling is completed, the results should be compared to earlier results obtained at the same mine or to other longwalls. Colinet et al. [1997] give dust source contributions obtained from a survey of 13 longwalls (table 3-1). The average percent values reflect the average contribution of a given source. For example, on average, intake sources account for 9% of the dust at the longwalls that were surveyed.

The concentration values in table 3-1 reflect dust levels measured *only when the shearer was operating*, using the sampling locations shown in figure 3-1 and explained in the accompanying text. Except for the intake, the values shown represent the difference between the upwind and downwind dust concentration values. They are *not* personal exposure values.

Any dust source showing a contribution greater than the median value of table 3-1 is a likely source of the extra dust that has caused the longwall to go out of compliance.

Table 3-1.—Dust source contribution values from 13 longwalls [Colinet et al. 1997]

SOURCE	AVERAGE PERCENT	CONTRIBUTION MEDIAN	CONTRIBUTION RANGE
Intake	9	0.33 mg/m^3	0.07-1.1 mg/m^3
Stageloader-crusher	15	0.78 mg/m^3	0.29-1.3 mg/m^3
Shields	23	1.8 mg/m^3	0.67-2.3 mg/m^3
Shearer	53	3.5 mg/m^3	0.7-8.8 mg/m^3

BASIC LONGWALL DUST CONTROL TECHNIQUES

Basic techniques are those widely used to control dust, applicable at every longwall. Mine operators can use high water and airflows and take measures to avoid blowing dust into the walkway. They can also move workers upwind, reduce dust from the stageloader-crusher, use a gob curtain, and use a shearer-clearer system.

Raising airflow to control dust. Raising the airflow provides some benefit when the existing face air velocity is below 600 ft/min [Organiscak and Colinet 1999]. Over the years, longwall air quantities have risen to compensate for higher production levels [Haney et al. 1993; Ondrey et al. 1994]. A survey by the Mine Safety and Health Administration in 1999 showed that longwalls

way, has not fully mixed into that portion of the airflow moving through the shield legs and down the panline. See figure 3-5 and the accompanying explanation.

had an average intake air quantity of 71,000 cfm[34] and an average headgate-end face velocity of 650 ft/min. Eighteen percent of longwalls exceeded 100,000 cfm in the intake airways. This high air quantity helps to control respirable dust by providing better dilution of dust sources.[35]

For many years, there has been a concern that high air velocities would entrain settled dust. However, 10% of longwalls now have face air velocities exceeding 1,000 ft/min without experiencing any evident[36] entrainment problems. This lack of dust entrainment is probably due to high water application rates in conjunction with shield washing.

Using water to control dust. Dust generated by the shearer is reduced by increasing the quantity of water *supplied to the shearer drums*, so it is important to supply as much water as possible to the drums. In two separate studies, water flow to the shearer drums was increased about 50% and dust levels at the shearer were reduced about 40% [Shirey et al. 1985]. In a survey of 13 longwalls, Colinet et al. [1997] report an average shearer water flow of 100 gpm, almost all of it to the drums.

The number of sprays and the type of spray nozzle chosen are important for best dust control performance. For example, pick-point sprays at the outer edge of the vanes, now commonly used, are superior to the old cavity-filling sprays that were mounted on a pipe welded to the side of the vane [Jankowski et al. 1987]. Also, the greater the number of sprays, the more thoroughly water is mixed with the broken coal. In a test that varied the number of sprays, Bazzanella et al. [1986] showed that dust suppression is improved by increasing the number of sprays on a shearer drum, even when the total water flow and nozzle pressure were held constant with the use of smaller orifice nozzles. When 46 smaller orifice nozzles were substituted for the 17 original nozzles, dust was reduced by 60%. This finding shows that there should be at least one spray for each pick on the drum.

Design of the water supply system is an important consideration if sprays are to be effective. Each water split should have its own flow meter and pressure gauge for convenient monitoring. All of the system components must be sized for the anticipated water flows, with particular attention devoted to the size of the pipe that goes through the ranging arm and connects to the feed lines in the drum spiral. Water filtration is often a source of headaches. The coarsest filter mesh size that can normally be used is 50 micron, and the stream of water should not bypass the filter mesh when it plugs up.

Avoiding the migration of dust into the walkway. Since water sprays are known to entrain air and generate their own local air currents, they must be used in a way that allows dust from the drums to hug the face and not be blown out into the walkway. Figure 1-4 illustrates how sprays

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[34]For mines in coal under 8 ft, the average was 66,000 cfm; for mines 8 ft or more, 87,000 cfm.

[35]While increases in airflow are applicable at every longwall, it does not follow that such increases are always feasible. Depending on the age of the mine and the design of the ventilation system, major ventilation increases are not always practical. Such mines will have to depend more on the other dust controls.

[36]Evident from underground measurements, at least. Recently, Listak et al. [2001] conducted lab studies to assess the impact of higher face velocities on shield dust. Dry (1% moisture) mixed-size particulate was dropped into an airstream flowing in a horizontal wind tunnel. Surprisingly, airflow increases resulted in much higher dust concentration levels.

on the body of a longwall shearer can actually *raise* the shearer operator=s dust level by blowing dusty air into the walkway. Because of this air-entrainment effect, it is generally better not to have sprays mounted on the shearer body, unless they are part of a "shearer-clearer" configuration as described below.

Despite the need to keep sprays off of the shearer body, the motor cooling water must be discharged somewhere. The recommended location for these sprays is low on the end of the shearer, pointed straight down onto the panline so that they wet the coal on the panline and cause little air entrainment [Jankowski and Hake 1989].[37]

Excessive pressure on the drum sprays also blows dust into the walkway. In two separate studies [Pimentel et al. 1984; Kok and Adam 1986], the water pressure of the drum sprays was increased from 75 to 115 psi and 80 to 150 psi, respectively. In both instances, dust exposure of the shearer operators increased by 25% because the higher pressures on the trailing drum blew the dust into the walkway. Thus, the best drum spray pressure is in the range of 80 to 100 psi. Because of the tendency of high-pressure sprays to blow dust into the walkway, the water flow rate should always be raised by increasing the nozzle orifice size rather than the operating spray pressure.[38] However, when the nozzle pressure is below 80 psi, the sprays may plug with coal particles pushed in from the outside.

Moving workers upwind. Although measures can be taken to reduce the migration of dust into the walkway, the shearer-generated dust cloud at the face soon spreads from the panline to envelop the entire longwall face cross-section. Because of this dust cloud spreading, any mining practice or technology development that moves workers upwind of the shearer drums and moving supports is helpful. For example, use of remote control on shearers can significantly reduce dust exposure of the machine operators. A survey by the U.S. Bureau of Mines [1984] showed that exposure was reduced 68% by moving the operator just 20 ft upwind of the shearer body. Particular attention should be paid to the location of the tailgate-end shearer operator, who should always be positioned upwind of the tailgate-end drum to reduce dust exposure.

Shearer operators can further reduce their dust exposure by moving as far upwind at the headgate as possible as the shearer cuts out at the headgate.

Reducing dust from the stageloader-crusher. The stageloader-crusher can be a major dust source on longwall faces. To reduce this dust, the stageloader-crusher is enclosed with steel plates and strips of conveyor belting. All seals and skirts must be carefully maintained to ensure that dust stays inside the stageloader-crusher enclosure. Several sprays are mounted on internal spray bars, which usually span the width of the conveyor. Recommended spray bar locations are the mouth of the crusher, the discharge of the crusher, and at the stageloader-to-belt transfer point. Water pressure should be maintained below 60 psi, since high-pressure sprays may actually force dust out of gaps in the enclosure and into the intake air. During underground trials, covering the stageloader and adding spray manifolds to boost the water flow from 10 to 20 gpm yielded dust reductions of 79% at the headgate operator and 41% at support 20 [Organiscak et al.

[37]Some mines use the cooling water to wash the shearer haulage track.
[38]The spray pressure is measured by removing one spray nozzle and attaching a hose that leads to a pressure gauge.

1986; Kelly and Ruggieri 1990b].[39] The most important spray bar is the one located on the discharge side of the crusher [Jayaraman et al. 1992].

A few operators have attached dust collectors to the stageloader enclosure. This yielded no better results than just covering the stageloader and adding internal spray manifolds [Jayaraman et al. 1992]. Still, if enclosing the stageloader and adding internal sprays are not sufficient, a dust collector attached[40] to the stageloader is the next step.

Reducing dust from the intake. While the intake is usually the least significant source of longwall dust, it cannot be ignored. Reductions in intake dust from using homotropal ventilation, cleaning the panel belt, and adding water to the intake roadway have been discussed by Organiscak et al. [1986]. Other methods to reduce roadway dust are discussed in chapter 5 on surface mining. For mines that use belt air, the reduction of conveyor belt dust is discussed in chapter 6 on hard-rock mines. Work crews in the intake will often stir up dust, and rescheduling of work may be necessary.

Using a gob curtain to aid airflow. A gob curtain is a brattice curtain installed from the roof to the floor between the first support and adjacent rib in the headgate entry. It prevents air from leaking into the gob, forcing more of the ventilation airflow to make a 90º turn and stay on the face side of the supports (figure 3-2). This permits more dilution of dust in the region of the face near the headgate. Without a gob curtain, a substantial portion of intake air will pass into the gob, moving laterally behind the supports. During underground trials, the average face air velocity with the curtain installed was 35% greater than that without the curtain [Jankowski et al. 1993]. The most significant improvement was seen for the first 25 to 30 supports.[41]

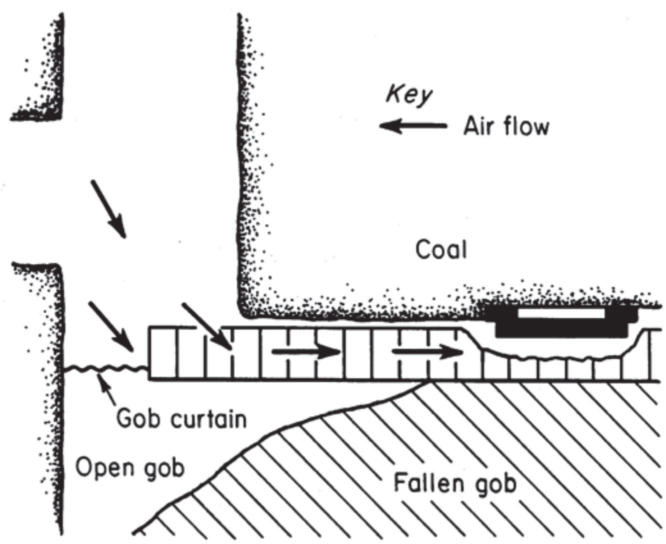

Figure 3-2.—Gob curtain forces air to stay on longwall face.

Gob curtains also have a secondary benefit. When less air enters the gob, then less air returns to the face halfway down the shield line. Therefore, dust generated by gob falls is less likely to be entrained and carried back onto the face.

Using the shearer-clearer system. A large portion of U.S. longwalls use a water spray system called a shearer-clearer, specifically designed to hold shearer-generated dust against the face. The shearer-clearer

[39]These were old studies done at low (by today's standards) production levels. Much higher water flows are necessary for today's longwalls.
[40]A dust collector on the stageloader will see a very high particulate load, so horizontal ductwork should be avoided and access doors for cleanout should be provided.
[41]Some operators use curtains or conveyor belt strips to seal the gaps between the first few shields. No data are available on how well this works to keep air on the face.

takes advantage of the air-moving capabilities of water sprays to direct the dust cloud downwind along the panline, which prevents it from spreading out into the walkway (figure 3-3). The system consists of several shearer-mounted water sprays, oriented downwind, and one or more passive barriers, which split the airflow around the shearer into separate clean and contaminated air streams (figure 3-4).

The air split in the shearer-clearer system is started by a splitter arm, with a strip of conveyor belting hanging from the splitter arm down to the panline. This belting extends from the top gobside corner of the shearer body to the cutting edge of the upwind drum. A spray manifold mounted on the splitter arm confines the dust cloud generated by the cutting drum, further enhancing the air split. The dust-laden air is drawn over the shearer body and held against the face by spray manifolds positioned between the drums on the face side of the machine. The air is then redirected around the downwind drum by a set of sprays located on the downwind end of the shearer. Operating pressure must be about 150 psi,[42] measured at the nozzle, to ensure effective air movement. Total water flow rate with all sprays operating is about 12 gpm.

In underground tests, the shearer-clearer reduced operator exposure from shearer-generated dust by at least 50% when cutting against the ventilation and 30% when cutting with the ventilation [Ruggieri et al. 1983; Jayaraman et al. 1985].[43]

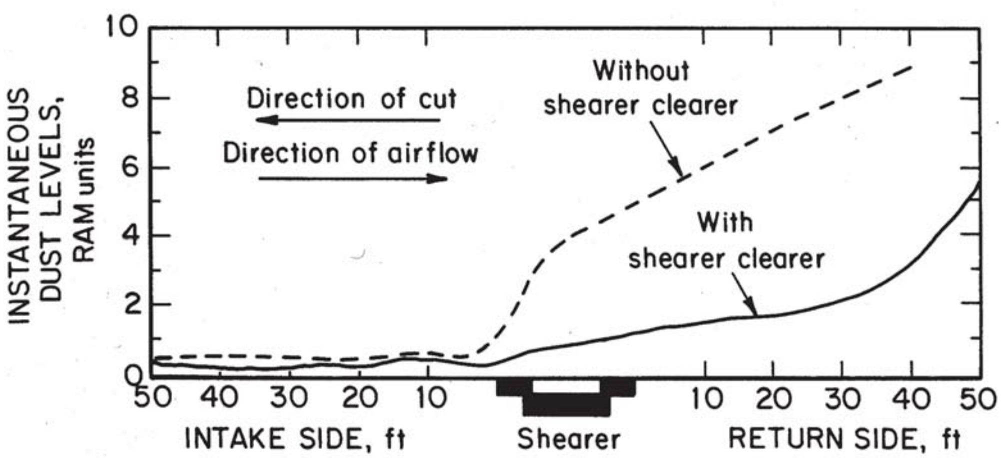

Figure 3-3.—Typical respirable dust concentration profile around the shearer during the tail-to-head pass.

[42]Proper pressure and spray placement are important if the expected reduction in dust is to be realized [Ruggieri et al. 1983].

[43]Other experiments have been done to test a shearer-clearer in conjunction with passive barriers mounted on the shearer. The passive barriers gave no improvement in dust when added to the shearer-clearer. However, the passive barriers alone (without the shearer-clearer) gave a 25% reduction in shearer dust compared to the baseline (no barriers, no shearer-clearer) [Jankowski and Babbitt 1986; Kelly and Ruggieri 1990a].

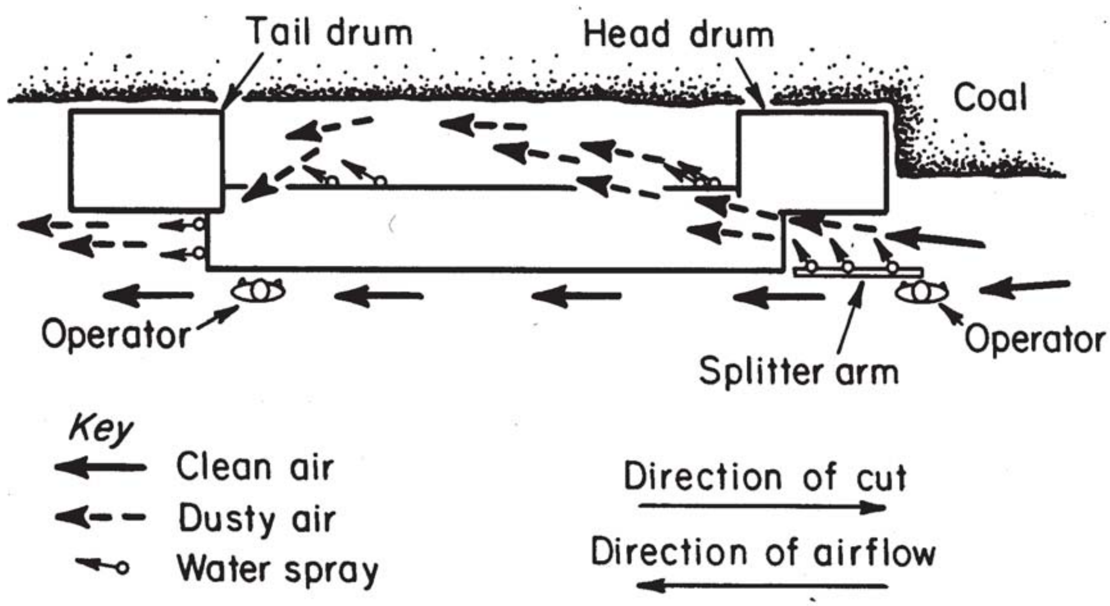

Figure 3-4.—Air currents when using the shearer-clearer system.

A helpful installation manual for the shearer-clearer is available [Ruggieri and Babbitt 1983].

Cutter drum maintenance. Routine replacement of badly worn, broken, or missing bits improves cutting efficiency and helps reduce dust. Also, bits designed with large carbide inserts and smooth transitions between the carbide and steel shank typically produce less dust [Organiscak et al. 1996a]. The water sprays should be serviced along with the bits, since the number of operating drum sprays greatly impacts the amount of dust generated [Bazzanella et al. 1986].

SITE-SPECIFIC LONGWALL DUST CONTROL TECHNIQUES

Site-specific techniques can be effective when allowed by the local geology and suitable to the type of equipment used. Mines can use unidirectional cutting, modify their support movement practices, and use a wing curtain to aid airflow.

Using unidirectional cutting. Some mines in very high coal use a unidirectional cutting sequence because it offers operational advantages. Unidirectional cutting allows somewhat greater flexibility to place workers upstream of dust sources than bidirectional cutting. If the primary cut takes place as the shearer moves in the head-to-tail direction, the leading drum that cuts most of the coal is downwind of both shearer operators and roof support movers. Dust surveys [USBM 1984] have shown that cutting in the head-to-tail direction yields dust levels about 40% less[44] than cutting in the tail-to-head direction.

On the other hand, if the primary unidirectional cut is in the tail-to-head direction, supports can be advanced just downwind of the shearer, keeping both shearer and support dust away from face workers. This cut direction works well when a shearer-clearer system is used to hold the dust against the face.

Whether unidirectional cutting can be done depends on the type of equipment used and the local roof conditions. A head-to-tail cut requires most of the coal and rock to pass under the shearer, and sufficient clearance under the shearer is required to prevent clogging. Also, a head-to-tail cut may not be necessary if shearer dust has been avoided in some other way, such as remote control. When the supports are advanced during the cycle will depend on how much the supports are adding to the overall dust problem and how long the freshly cut roof can stand without falling.

The downside of unidirectional cutting is that it may result in some loss in productivity by virtue of the reduction in cutting time. However, the cost of any expected productivity loss must be balanced against the cost of alternative dust controls.

The most common unidirectional sequence is to cut coal on the tail-to-head pass, closely following the shearer with the support advance. With this sequence, no workers are exposed to support-generated dust, and the shearer dust is held in check with a shearer-clearer system operated in conjunction with remote control.

Using modified support movement practices to reduce dust. During bidirectional cutting, support advance will occur in both cutting directions. Support movers can stay away from support dust by positioning themselves upwind of the moving supports.

During the head-to-tail cut, shearer operators are exposed to any dust generated by support movement. Support dust tends to be generated directly over the walkway, so under the moving support the concentration in the walkway will be higher than in the adjacent support legs or panline. As this support dust moves downwind, the walkway concentration declines as the walkway dust cloud mixes with the air moving down the panline and the air moving through the support legs. As a result, some mine operators find that support-generated dust can be diluted more before it reaches the shearer operators by increasing the distance between support advance and the shearer from 20 to 50 ft (figure 3-5).

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[44]The 40% figure refers only to shearer-generated dust measured at the shearer. Use of shearer remote control could increase or decrease this value.

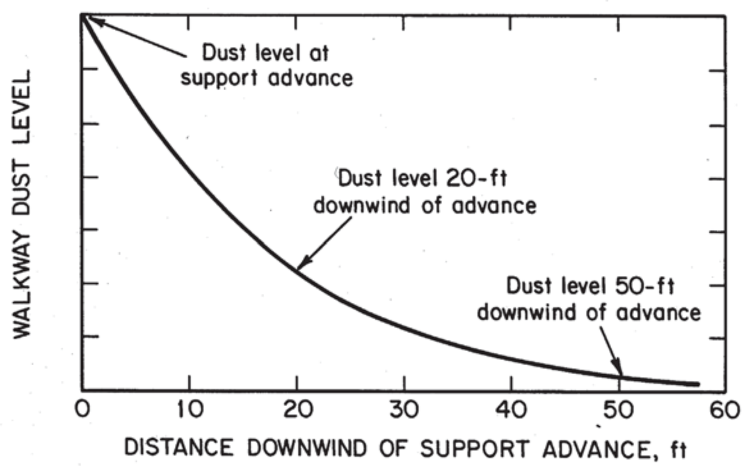

Figure 3-5.—Support dust in the walkway dilutes as it moves downwind [Organiscak et al. 1985].

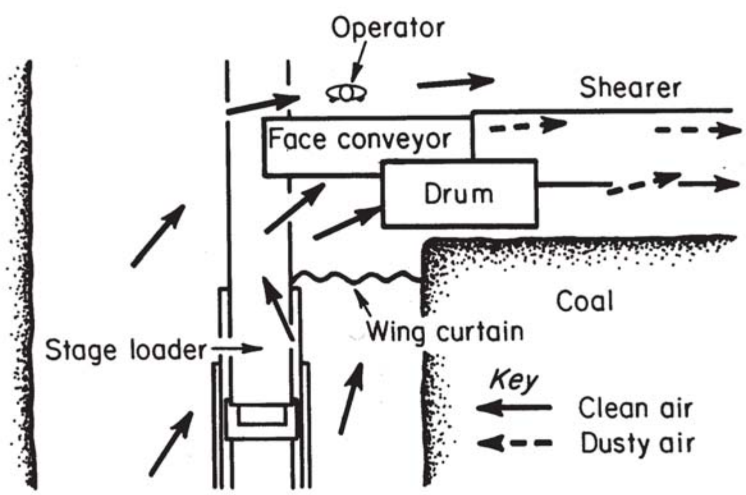

Figure 3-6.—Airflow at longwall headgate with a wing curtain.

During the tail-to-head cut, with shield advance following downwind, shields should be pulled as closely behind the shearer as possible. This keeps the shield movers ahead of the shearer dust cloud, which progressively spreads into the walkway as it moves downwind from the shearer. In this case, a shearer-clearer system may be of considerable help to the shield movers, since it holds the dust cloud over the panline for a greater distance downwind of the shearer, as shown in figure 3-3.

Water application on the immediate roof also may help to suppress some of the support dust generated during lowering, advancing, and resetting of the roof supports. The immediate roof can be wetted by spraying the roof with one or more narrow-angle water sprays mounted on top of the shearer body, directing water downwind at an upward 45° angle.

In addition, shield supports can be equipped with water sprays in the shield canopy that wet the broken roof debris on top of the shields. These achieve modest 25% reductions in shield-generated dust [Henke and Thiemann 1991], but are hard to maintain, especially since they soak the face workers. Mangolds et al. [1990] have reviewed the (mostly unsuccessful) attempts to control shield-generated dust.

Using a wing curtain to aid airflow. The purpose of a wing curtain is to shield the shearer operators from the very high concentrations of dust generated as the headgate drum cuts into the headgate entry. The high-velocity primary airstream passing over and through the drum entrains and carries large quantities of dust out into the walkway and over both operators. When a wing curtain is installed between the panel-side rib and the stageloader (figure 3-6), it shields the headgate drum from the airstream as the drum cuts out into the headgate entry.

The wing curtain is located 4 to 6 ft back from the corner of the face to provide maximum shielding without interfering with the drum. The curtain is only in place during the cutout operation and is generally advanced every other pass. A wing curtain can reduce operator dust exposure by 50% to 60% during the headgate cutout [Jankowski et al. 1993; Cecala et al. 1987].

FUTURE POSSIBILITIES FOR LONGWALL DUST CONTROL

Because of longwall production increases over the years, there is a continuing demand for better dust control. This section discusses dust control methods that might be used at future longwalls. Some are newer methods. Others are older methods that have been little used because of higher cost or operating difficulties. Examples of future possibilities are advances in production technology, water infusion, foam, a face partition, and high-pressure drum sprays.

Advances in production technology. Any advance in longwall production technology that allows workers to move upwind of dust sources will reduce their dust exposure. This has already taken place through the use of remote control of shearers and batch control of shields.

The implementation of more advanced technology has been delayed because of practical operating difficulties with these systems. For example, control packages are now available for complete automation of shield movement; however, they are not yet in wide use.

Another advanced technology that offers lower longwall dust levels is the memory-cut system in which a computer logs the precise height of the drums as the shearer moves across the face. With such a system, the operators make the initial cut, and the computer controls several subsequent cuts while the operators wait in a less dusty location. Several memory-cut systems have been sold to mine operators. Again, they are not yet in regular use because of practical operating difficulties.

Nothing works as well as measures that put workers upwind of dust sources. Because of this, any new technology that moves workers upwind can greatly reduce their dust exposure [Organiscak et al. 1996b].

High-Pressure Inward-Facing Drum Sprays. High-pressure water can have a significant impact on shearer-generated dust. The basic concept is to use high-pressure drum sprays to improve wetting of the coal and improve the airborne capture efficiency of the sprays. The nozzles are angled inward to avoid blowing the uncaptured dust cloud out into the walkway.

An underground evaluation of high-pressure, inward-facing drum sprays gave good results [Jankowski et al. 1989]. Of those tested, the most effective spray system was the 30°, 800-psi configuration. Not only was the dust reduction greater (39%), the concentration was lower at all sampling sites using this configuration. Also, wetting of the coal was improved since intake dust levels along the face were reduced by about 45%.

A drawback of high-pressure sprays is that the small-orifice nozzles tend to clog unless the water is very clean. Also, space has to be found on the shearer for a booster pump or the pump located outby with a high-pressure line running to the shearer. Neither alternative may be feasible.

Solid-stream (jet) sprays. Some preliminary longwall tests during the 1980s [Kost et al. 1985; Jankowski et al. 1987] showed that using solid-stream (jet) sprays on the shearer drum yielded 30% less dust at the shearer operator position than the conventional conical sprays. Whether this dust reduction was due to better wetting of the coal or less boil-out from the drum is not clear. Followup tests to confirm these results under a variety of conditions were never done.

Foam. Tests in two mines have shown that foam works well to lower dust when it is released from nozzles located on the shearer drums. In the first mine, the shearer operator dust exposure was cut by 56% compared to conventional water sprays on the drum. In the second mine, operator dust exposure was cut by 84%, and the dust level at the tailgate declined by 78% compared to water sprays [Laurito and Singh 1987; USBM 1989]. Also, during the test the foam system used less water than the conventional sprays.

A test in a third mine measured the impact of foam applied with nozzles located on the ends of the shearer body. The effectiveness of this external foam application was less than 20%, indicating that for foam to be effective, it must be applied through the shearer drums so as to be thoroughly mixed with the coal.

Long-term tests to assess feasibility and cost of foam at longwalls have not been done.

Face partition. The concept of a face partition is to maintain two parallel splits of air along the longwall face by a transparent mesh partition (figure 3-7). This partition acts to retard the spread of shearer-generated dust into the walkway, reducing the dust exposure of the shearer operators and roof support movers [Organiscak and Leon 1993; Organiscak 1999]. During testing, a 1/8th-inch mesh partition was hung from the roof supports to separate the walkway from the panline. When the partition stayed parallel to the face, walkway dust was cut in half. However, where supports were being advanced, there was always a short segment of mesh partition perpendicular to the airflow. This perpendicular segment caused a decline in partition effectiveness. Overall, the results were mixed.

Water Infusion. To infuse a coal seam, boreholes are drilled into the coal seam ahead of mining and large volumes of water are pumped in under high pressure to wet the coal [McClelland et al. 1987; Lama and Liu 1992; Stricklin 1987]. Water infusion has been used occasionally by mine operators for several decades. Although it is not widely used because of high cost, water infusion

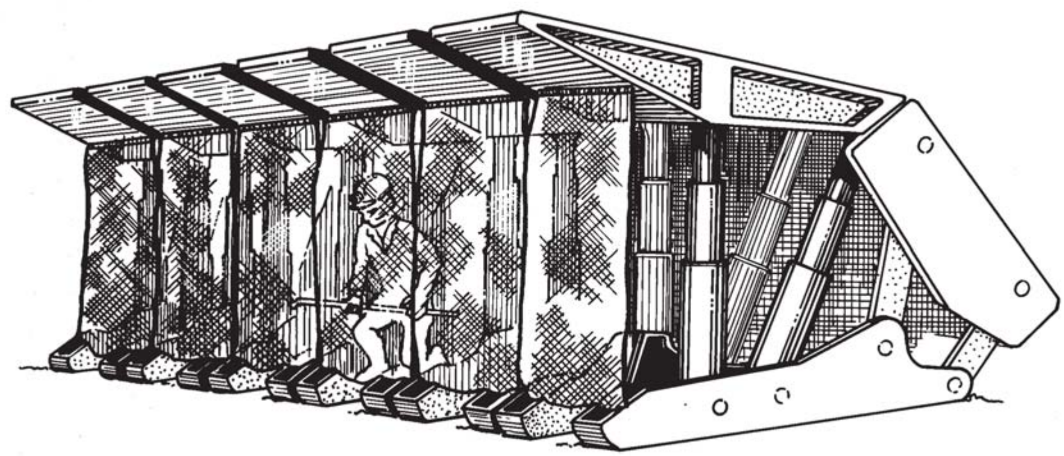

Figure 3-7.—Transparent mesh partition retards the spread of shearer dust into the walkway.

of coal seams will reduce dust by about 50% in those seams that can be infused.[45] Many coal seams cannot be infused. Water infusion is much more economical if the holes have already been drilled to remove methane gas.

Homotropal ventilation. With homotropal ventilation, intake air is routed up the tailgate entries and across the longwall face from tailgate to headgate, where it then passes into the gob. A separate split of air must be routed up the headgate entry to keep the headgate operator out of dusty return air [Stevenson 1985].

Because air routed up the tailgate entries is free from the headgate-side dust sources, the dust exposure of workers on the face is lower. The disadvantages of homotropal ventilation are that the tailgate-side entries must be kept in good condition and the gob at the headgate must remain open. Otherwise, the flow of air will be restricted. Keeping the tailgate entries and the headgate side of the gob open may require additional cribbing [Kelly and Jankowski 1984]. Homotropal ventilation may only be feasible in a small proportion of mines.

Water proportioning. While it is well-known that more water added to the shearer drums will reduce dust, the maximum amount of water that can be added is usually limited by operational problems (such as softer clay floors and slipping conveyor belts) that are created by excessive water. Since the upwind drum is usually the one that contributes the most to worker dust exposure, some success in reducing dust might be obtained by proportioning more water to the upwind drum. However, solid evidence for an overall benefit is lacking [Kok and Adam 1986].

[45]Many coal seams cannot be infused because of nonuniform seam permeability.

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CHAPTER 4.—DUST CONTROL IN STONE MINES

By Fred N. Kissell, Ph.D.,[46] and Gregory J. Chekan[47]

In This Chapter

- ✓ Drilling, blasting, and crushers
- ✓ Diesel particulate
- ✓ Enclosed cabs
- ✓ Ventilation with jet fans
- ✓ Stopping construction methods
- ✓ Propeller fans as main fans

This chapter explains how to control dust in large-entry stone mines, including both silica dust and diesel particulate. Most stone mines are limestone mines, but a substantial minority are marble, sandstone, and granite mines. These mines differ from most others in that entry widths are 30 ft or more and entry heights are 25 ft or more. Such mines, developed with room-and-pillar methods, have large open areas that can make ventilation and dust control more difficult.

Because of the difficulty of ventilating stone mines, improved ventilation is a major focal point of this chapter. However, the chapter also covers the control of dust from drills, blasting, and crushers. Another part of the chapter covers enclosed cabs, an effective dust control technique for some workers.

BACKGROUND

The major dust compliance problem in stone mines is caused by silica (quartz) in the rock. Mines in high-silica rock, 8% or more, are far more likely to have a dust problem than those where there is less silica. Geographically, the limestone in the Northeastern and South Central United States has higher silica than the rest of the country.

Chekan and Colinet [2002] have analyzed Mine Safety and Health Administration (MSHA) dust sampling results [MSHA 2001] from the stone industry. They have concluded that, on average across the United States, the workers exposed to the highest dust concentrations are rotary drill operators, front-end loader operators, truck drivers, and crusher operators. However, there are many regional differences. Also, occupations that work outside of cabs, such as blasters, roof bolters, and laborers, can be exposed to high dust levels.

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CONTROL OF DUST FROM DRILLS, BLASTING, AND CRUSHERS

Drills, blasting, and crushers produce the most dust in stone mines. Drill dust can usually be controlled by proper maintenance of the water supply system. Blasting dust is controlled by firing off-shift. Crusher dust, a more difficult problem, is usually managed (with varying success) by ventilation and water sprays.

Control of drill dust. Drill dust is suppressed by water injected through the drill steel, a common practice for many years [ILO 1965]. Usually, respirable dust is reduced by 95% or better [MSA Research Corp. 1974]. However, this does not prevent dust from entering the air during the initial collaring period as the drill hole is started. Various means have been tried to prevent the escape of dust during collaring. These range from simple handheld sprays to elaborate types of suction traps around the end of the drill steel. None of these are very efficient.

Drills powered by compressed air are much less common than in the past, eliminating the dust problems associated with their use. For example, if some of the compressed air operating the drill leaks into the front head of the drill and escapes down the drill steel, it will cause dry drilling and carry dust out of the hole. Compressed air escaping through the front head release ports will atomize some of the water in the front head. This atomized water evaporates rapidly and, if the water is dirty, many dust particles will remain in the air [Sandys and Quilliam 1982].

MSA Research Corp. [1974] has listed the factors that can lead to high dust levels on drills. Many result from lack of proper maintenance. These are failure to use water, inadequate quantities of water, plugged water holes in the drill bit, dull drill bits, and dry collaring.

Control of blasting dust. Control of blasting dust is described in more detail in chapter 6, the chapter on hard-rock mines. Water is used to spray the blast area beforehand. Ventilation is used to exhaust fumes and dust via an untraveled return and between shifts. In most cases, the faces are shot during an off-shift, so no workers are in the mine at the time of the blasts. Studies have shown [Chekan and Colinet 2002] that in stone mines the retention time of the dust is usually less than 2 hr. If ambient levels of silica dust are high after this period or if workers are exposed to an excessive amount of dust from blasting when they reenter the mine, it usually indicates that the ventilation needs to be improved.

Control of dust from crushers. Dust from crushers is controlled by water sprays and local exhaust ventilation from the crusher enclosure. The amount of water needed to do the job is hard to specify. It depends on the type of material crushed and the degree to which water will cause downstream handling problems. If the rock is dry, a starting point is to add a water quantity equivalent to 1% of the weight of the material being crushed [Quilliam 1974]. The nozzle pressure of sprays at the grizzly and crusher jaw should be below 60 psi to avoid stirring the dust cloud and reducing the capture efficiency of the ventilation system.[48]

The amount of air required for dust control depends on how much the crusher can be enclosed. Enough air should be exhausted from a plenum under the crusher to produce a strong indraft at the jaw, grizzly, and any other openings around the crusher. The required airflow is usually large. For example, Rodgers et al. [1978] have described how dust from a 5-ft cone crusher was reduced by using a 75,000-cfm[49] exhaust ventilation system and a control booth for the operators.[50] Yourt [1969] has given a comprehensive set of design principles for dust control at crushing and screening operations.

Crushers need lots of air and lots of water because they break lots of rock.

In stone mines, dust that escapes the crusher is hard to contain because of the large cross-sectional area of the entries. Figure 4-1 shows a conceptual approach to controlling crusher dust in a limestone mine. The crusher is located in a crosscut that has been benched to facilitate dumping from trucks. The crusher operator is located in an enclosed booth that is pressurized with filtered air. The crosscut is divided by a stopping (or leak-tight curtain) that essentially puts the crusher and dump point in a stub heading. Air is exhausted from a plenum under the crusher to create an indraft at the crusher jaws. It is then directed through the stopping. Dust in this air can be removed with a baghouse or directed into the return.

Directing air through the stopping creates an inward air movement in the travelway. Because of this inward air movement, dust that escapes the crusher is more likely to stay confined within the stub heading and not escape into the rest of the mine. If the air velocity in the travelway is not high enough to confine the dust, a "half-curtain" approach might be helpful. Installing a half-curtain in the travelway reduces the cross-sectional area and raises the air velocity. The higher air velocity provides better dust confinement.[51]

The arrangement shown in figure 4-1 has the air doing double duty. It first confines dust in the crusher, then in the travelway. Whether all of this is necessary will depend on the circumstances in each individual mine. An enclosed operator booth alone may be adequate. However, it is

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[48] Chapter 1, the dust control methods chapter, has a more comprehensive discussion on why high spray pressures should be avoided most of the time.

[49] Large air quantities may be required because falling rock induces its own airflow. Pring [1940] investigated the amount of air required to produce an indraft in surge bins at crusher installations. About 35,000 cfm was required at a large crusher installation.

[50] If large (80% or more) dust reductions are sought for workers near a crusher, the most practical way to achieve this is to provide an enclosed and pressurized control booth supplied with filtered air.

[51] The half-curtain is described more fully in chapter 2 on continuous miner dust control and chapter 1 on dust control methods.

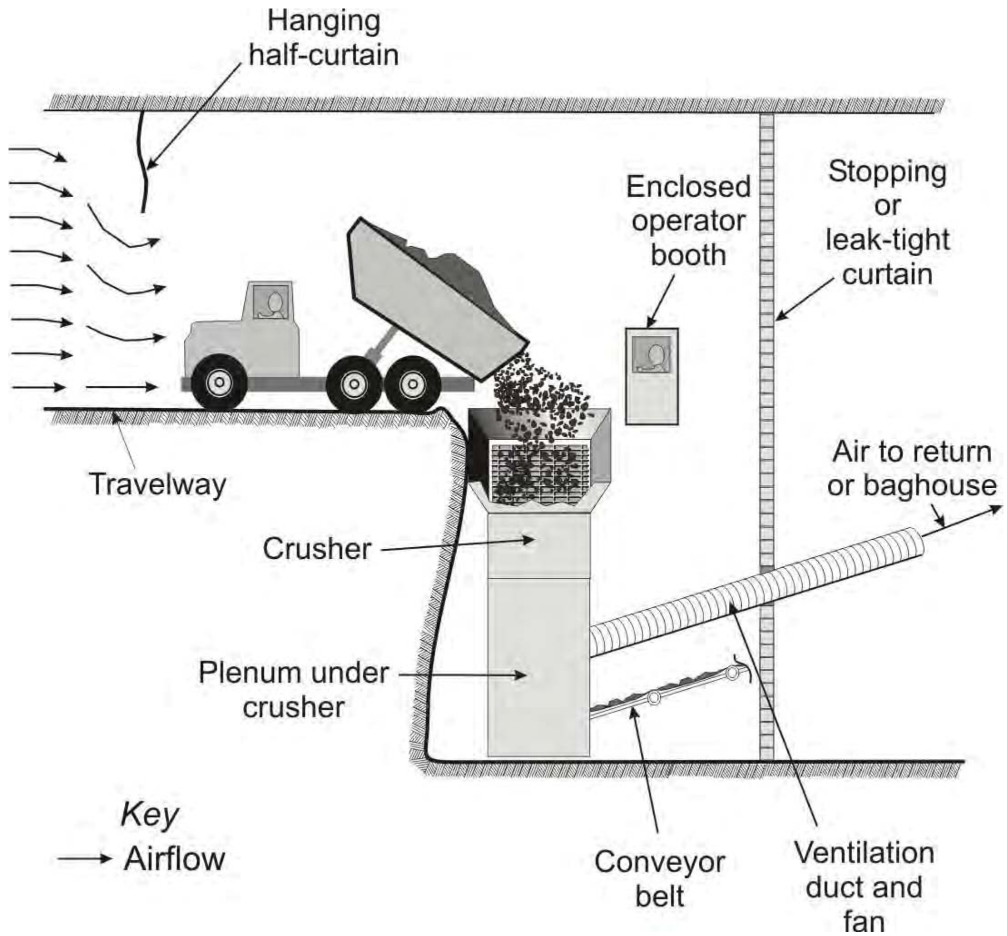

Figure 4-1.—Conceptual approach to controlling crusher dust in a stone mine.

hard to reliably get better than a 90% dust reduction in such booths under real mining conditions, so additional measures to reduce dust may be required.

CONTROL OF DIESEL PARTICULATE

Diesel particulate control is included in this chapter because new MSHA diesel rules may require upgrades to stone mine ventilation systems and diesel equipment. A detailed but readable review of diesel particulate controls has been written by Schakenberg and Bugarski [2002]. Essentially, the technology selected depends on how much the particulate must be reduced. Moderate particulate reductions may be obtained by better engine maintenance, engine derating, biodiesel fuel, fuel-water emulsions, and oxidation catalysts in conjunction with low-sulfur fuels. Large particulate reductions (80% or better) can be obtained with ceramic particulate filters on the engine tailpipe. Also, new low-emissions engines are available. These new engines can lower the particulate level as much as 75% if the existing engine has an old design.

Some reduction in diesel particulate levels can be achieved by running haulage trucks in return airways. However, since other equipment in the mine is also powered with diesel engines, the benefits of return haulage may be minimal. In many mines, the haulage truck horsepower is only a fraction of the installed diesel horsepower in the mine.

Reduction in diesel particulate can be obtained with improvements in the ventilation, as described in later sections on jet fans and stoppings. Head [2001a,b,c] recently wrote three helpful articles on better ventilation and reducing diesel emissions in stone mines.

USING ENCLOSED CABS TO CONTROL SILICA DUST AND DIESEL PARTICULATE

Cabs can reduce dust *if* their dust control systems are properly designed and maintained. Don't expect a dust reduction over 75%, though. There is more information on enclosed cabs in chapter 5, the surface mining chapter.

A high proportion of stone mine workers exposed to high dust levels can be protected with enclosed cabs or control booths. Haulage trucks in stone mines are often equipped with cabs. These cabs, if properly designed and maintained, can greatly lower the dust exposure of the truck drivers.

Impact of retrofitting. Chekan and Colinet [2002] recently measured the efficiency of an enclosed cab on a 27-year-old haulage truck in a limestone mine. In this study, the cab was originally equipped with a heating and air-conditioning unit that did not filter the intake air or pressurize the cab. Dust level measurements showed that its overall efficiency in reducing respirable silica dust was only 33%. The cab was then sealed and retrofitted with a new heating and air-conditioning unit that filtered the air and slightly[52] pressurized the cab. A new set of dust measurements gave an overall efficiency of 75% for respirable silica dust. This 75% overall efficiency figure was in line with dust efficiency results obtained with newer trucks.[53]

Cab filtration systems. Cab filtration systems can also trap diesel particulate if they are designed with this goal in mind. In underground stone mines, the level of diesel particulate is usually much higher than that found at surface mines, so the filtration of diesel particulate becomes an important consideration. Diesel particulate is much smaller in size than respirable mineral dusts, such as silica dust. So, if this diesel particulate is to be trapped by the cab filtration system, the filter must be much finer than that normally used to trap respirable dust. These

[52]To a pressure of 0.01 in w.g.

[53]These figures represent the overall cab efficiency, which is calculated from the inside and outside dust concentration values. Usually the filters have much higher efficiency values. However, leakage of dust into the cab and dust sources in the cab (such as dirty boots) cause the overall efficiency to be lower.

finer filters, usually designated as HEPA filters, have a higher pressure drop and require a more powerful fan.[54] They also require more frequent cleaning or replacement.

Efficiency to expect. When considering the use of cabs, it is important to recognize that the 75% efficiency figure cited above is a typical efficiency value for a relatively new cab with an average level of maintenance. Higher efficiency values can be obtained, but they are the exception rather than the rule. A sustained efficiency over 75% is hard to achieve under realistic underground mining conditions. The main reasons for this include poor or aging seals on the cab, the operator opening the cab door for work-related tasks, and the operator bringing dirt into the cab without performing a regular cleaning of the interior.

FACE AREA VENTILATION WITH JET FANS

Jet fans can aid stone mine ventilation if these guidelines for their use are closely followed.

A jet fan is a freestanding fan designed to induce additional air movement through a mine airway. Typically, no ductwork is attached to the fan, and the high-velocity[55] exhaust jet from the fan entrains additional air from around the fan and pushes it forward. Usually jet fans do not outperform those fans with attached ductwork. However, for ductwork to be effective it must be extended close to the working face where it is subject to blast damage. Jet fans are located farther away and can always be temporarily moved around a corner to avoid the direct path of a blast.

Jet fans have two applications. They are used to ventilate a straight single heading provided it is not too long, and they are used to ventilate a portion of the mine a few crosscuts away from the main pathway of fresh air. Jet fans cannot be used to ventilate an entire mine or even to move air more than a few crosscuts.

Jet fan ventilation of single headings. Figure 4-2 shows a jet fan placed to ventilate a straight single heading. It is placed at the entrance of the heading on the intake air side. It must be close to the rib, pointed straight ahead, and with the inlet extended slightly into the crosscut. Performance inevitably suffers when other locations are used. Keeping the fan within a foot or two of the rib ensures that the jet expands only on one side, increasing its penetration. Extending the inlet into the crosscut reduces recirculation.

Several studies have measured the performance of vane-axial fans at single headings like that shown in figure 4-2. Matta et al. [1978] used a 20,000-cfm fan to ventilate a heading 28 ft wide by 165 ft long. The height ranged from 17 ft at the crosscut to 9 ft at the face. Tracer gas tests

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[54]MSHA recommends that HEPA filters always be used.
[55]4,000 to 9,000 ft/min or more.

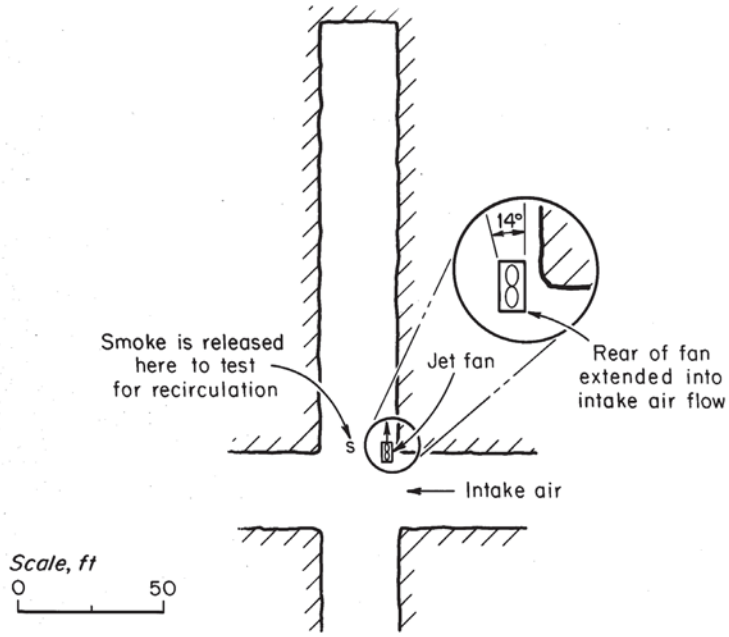

Figure 4-2.—Jet fan ventilating a single straight heading.

showed that 5,000 cfm of fresh air was reaching the face at 150 ft. A smaller 12,000-cfm fan with a 3-ft outlet nozzle pushed 6,000 cfm of fresh air to the face, and a 10,000-cfm compressed air-powered venturi air mover gave 3,500 cfm of fresh air to the face. The airflow in the crosscut was 57,000 cfm.

Matta et al. got better results when the fan had a nozzle attached. Lewtas [1980] obtained similar findings. Lewtas achieved the best air jet penetration when the nozzle was a truncated cone attached to a 1-ft-long straight section at the outlet. The sides of the cone were sloped at 18º from the axis; the ratio of the outlet diameter to the fan diameter was 0.68.

Brechtel et al. [1985] tested a jet fan in a larger heading, 55 ft wide by 30 ft high by 320 ft long. An 88,000-cfm jet fan was surprisingly effective, with 66,000 cfm of fresh air reaching the face, according to the tracer gas dilution tests. Airflow in the crosscut was 124,000 cfm.

Dunn et al. [1983a] tested jet fans in two different sizes of headings. Both were wide relative to their depth, probably the main factor leading to the high ventilation efficiencies. For example, in a heading of medium cross-section, 45 ft wide by 21 ft high by 115 ft long, a 7,000-cfm fan inclined up at 10º forced 6,700 cfm of fresh air to the face. There was 14,000 cfm in the cross-cut. In another heading with a large cross-section, 52 ft wide by 38 ft high by 150 ft long, a 14,000-cfm jet fan inclined upwards at 12º forced all of the 14,000 of fresh air to the face. The baseline ventilation with no fan was 4,500 cfm. A larger fan performed no better because only 15,000 cfm of fresh air was available in the crosscut.

Table 4-1 shows the results of all of the large-entry tests. The face ventilation effectiveness is the fresh air delivered to the face divided by the fan quantity, expressed as a percentage.

Table 4-1.—Results of jet fan studies

Researcher	Cross-sectional area, ft^2	Length, ft	Area-to-length ratio	Fan size, cfm	Face ventilation effective-ness, %
Matta et al. [1978]	476-252	165	~2:1	20,000	30
Matta et al. [1978]	476-252	165	~2:1	12,000 with nozzle	50
Matta et al. [1978]	476-252	165	~2:1	10,000, venturi	35
Brechtel et al. [1985]	1,650	320	5:1	88,000	75
Dunn et al. [1983a]	945	115	8:1	7,000, up 10º	96
Dunn et al. [1983a]	1,976	150	13:1	14,000, up 12º	100

Overall, these results show that jet fans can work reasonably well in a dead heading if the heading is large enough, the fan is properly located, and enough fresh air is provided to the fan inlet. The best results were obtained when the heading area to length ratio was high. A nozzle should be used to improve the jet penetration. Also, it may help to angle the fan upwards by 10º, per the findings by Dunn et al. [1983a].

Jet fans in headings should always be tested for recirculation by releasing smoke at location S in figure 4-2 and observing whether any travels back to the fan inlet. If recirculation to the fan inlet is present, it may help to attach a short length of ventilation duct to the inlet and then extend the other end of the duct upwind in the crosscut.

Jet fan ventilation of multiple headings a few crosscuts away from fresh air pathway. Jet fans have great potential for moving air short distances. However, ensuring an adequate quantity of fresh air can be difficult. Figure 4-3 shows a jet fan placed in the center of an airway and indicates how the air jet spreads as it moves away from the fan. This jet spreading results from the entrainment of the air next to the jet, and the amount of air entrained can be surprisingly high—

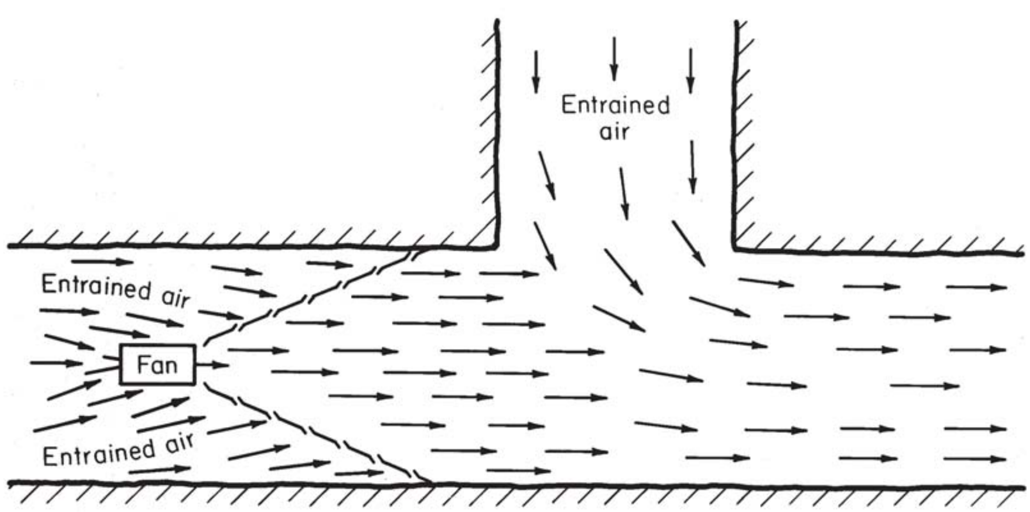

Figure 4-3.—Jet fan entrainment of mine air.

9 to 15 times the air quantity passing through the fan [Dunn et al. 1983b]. Air can also be entrained from crosscuts ahead of the fan, as shown in figure 4-3. Unfortunately, much of the entrained air is contaminated air that is recirculated back from the face, not fresh air.

Fresh air and recirculation. The challenge when using jet fan ventilation is how to place the fan to maximize the amount of fresh air. Having some recirculated air is not necessarily a problem. Studies have shown that recirculated air becomes a problem only when it is substituted for fresh air rather than added to a fixed quantity of fresh air [Kissell and Bielicki 1975].

As an example of how recirculated air can substitute for fresh air, figure 4-4 shows a portion of a mine a few crosscuts away from a fresh air pathway. Without a jet fan in operation, the mine air circulation in this part of the mine was directly from location 1 to location 2. A 14,000-cfm jet fan was placed close to a pillar at location A and directed toward the face area [Dunn et al. 1983a]. In this location, the fan worked well since the air movement it generated brought an average of 10,000 cfm of fresh air to faces FA through FD. Location B, close to the opposite side of the pillar, was almost as effective in relation to fan placement.

Experimenting with other locations, when the fan was placed at either of the two locations close to the adjacent pillar, marked X and Y, fresh air delivery was cut by 40% and 80%, respectively. Even though the distance from A and B is less than 100 ft, X and Y are too far from the intake air source, permitting recirculated air to return on both sides of the fan and diminish the fresh air. However, for fan locations A and B, the recirculated air returns only on one side, the left side, since the rib on the right side serves as a natural barrier. Figure 4-5 shows the airflows obtained with the jet fan in operation at location A. The airflow directions show that all of the fresh air was being directed toward the working faces, even though there was also a large amount of recirculated air.

Important conclusions from this work done by Dunn et al. were that fans must be placed in the incoming fresh airflow. In the larger airways, it helped to angle the fan upwards by 10º. Also, under this work it was concluded that larger-capacity fans ventilate more effectively if enough intake fresh air is available.

If you want to move air for distances greater than those shown in figure 4-5, forget about jet fans. Use ventilation ductwork or build stoppings.

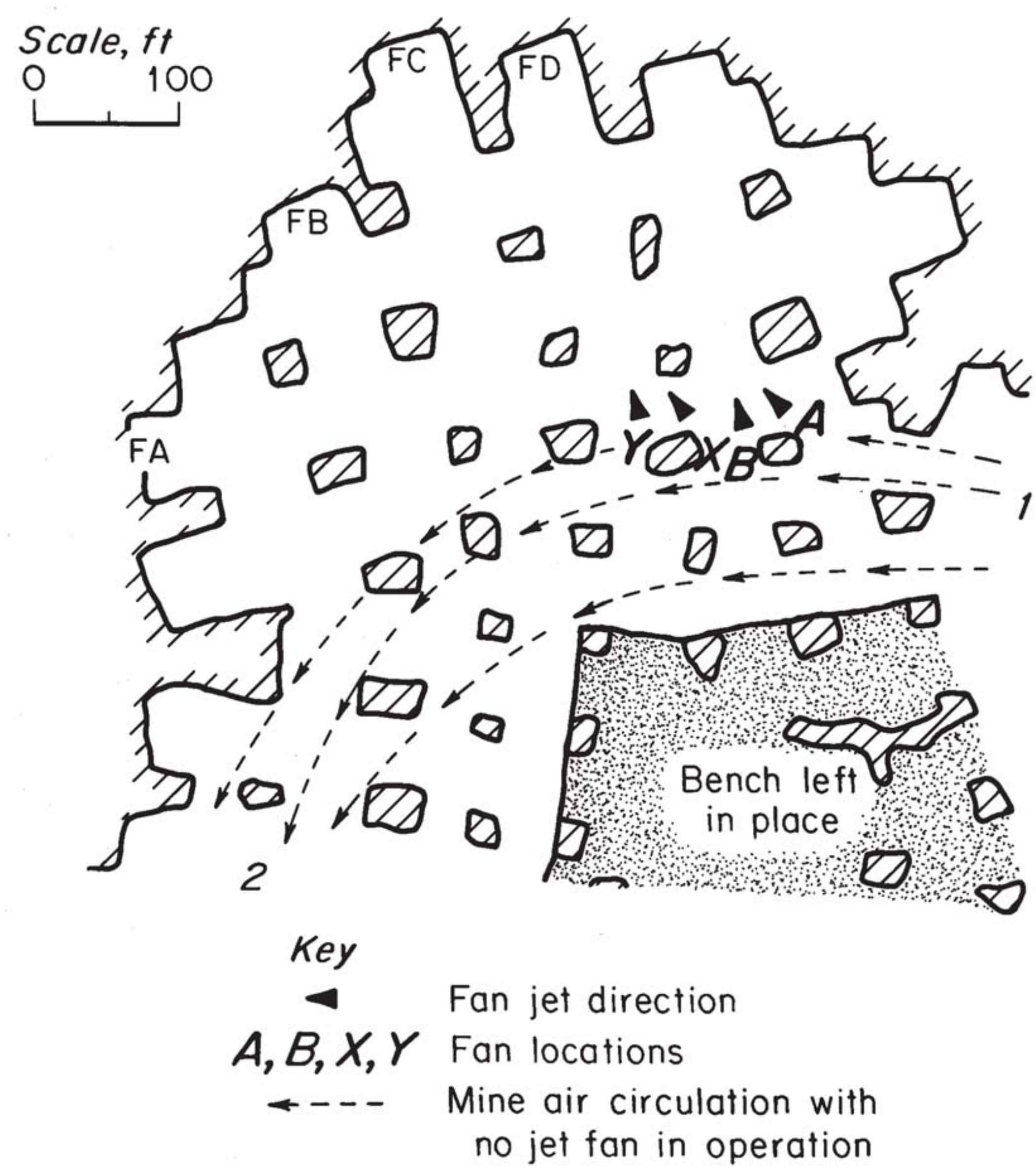

Figure 4-4.—Multiple headings a few crosscuts away from a fresh air pathway.

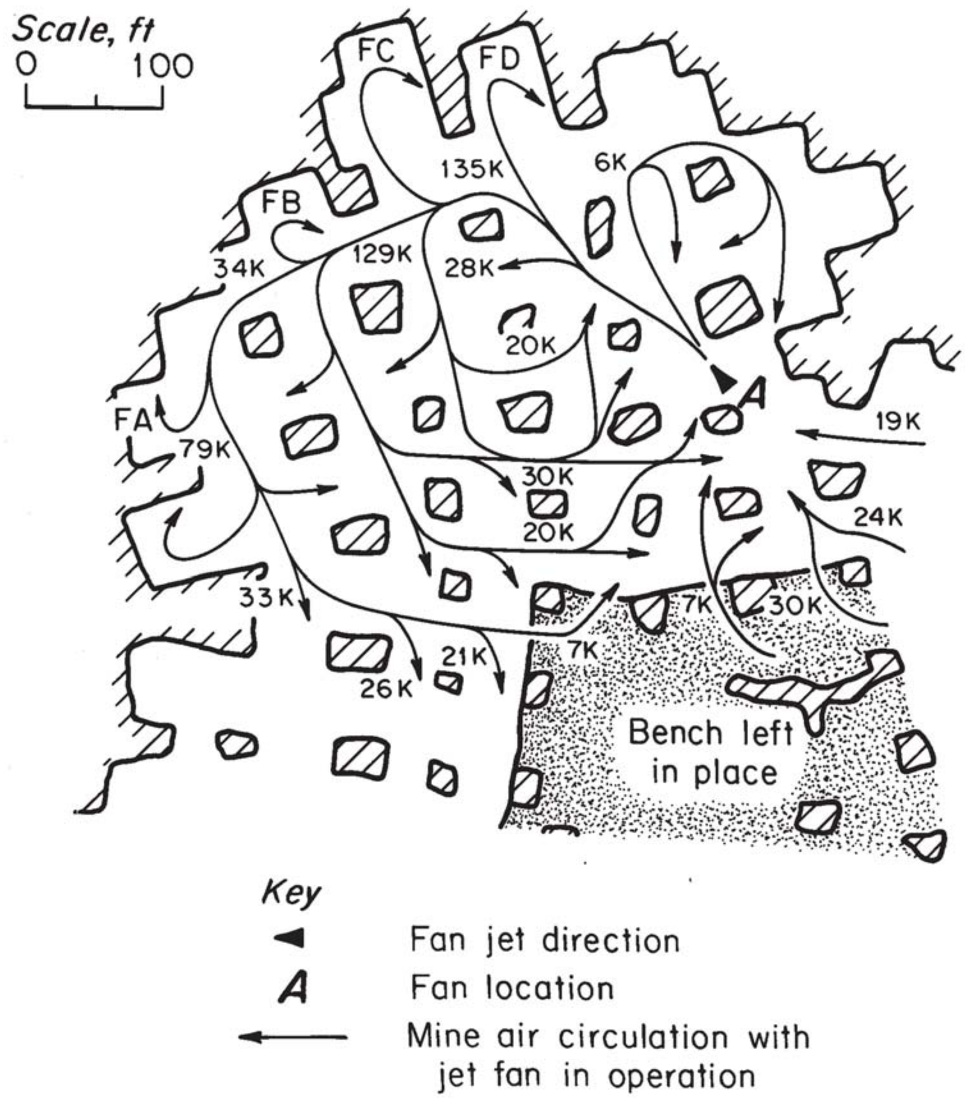

Figure 4-5.—Airflows obtained with jet fan in operation.

METHODS OF STOPPING CONSTRUCTION

In mines with large entries, stopping construction is a major task. Fortunately, some innovative stopping designs are available.

Well-built low-leakage stoppings are essential for good mine ventilation. Adam et al. [1986] have experimented with alternative stopping designs for large mine openings. The work was undertaken to develop construction techniques and cost data and to measure leakage rates on full-scale structures in an oil shale mine where the entries were 30 ft high by 55 ft wide. Six full-size stoppings and one overcast were built. Leakage was measured before and after a full-scale face blast. The lessons learned are applicable to today's stone mines.

Muckpile stoppings. Muckpile stoppings elicited the most interest from mine operators. These were simply piles of waste material stacked in crosscuts. However, the air leakage from this type of stopping was far too high, possibly because there were not many fines in the waste. Adam et al.'s recommendation for achieving less leakage was to use a "pipe and sheeting" stopping in main entries and a "brattice and wire-mesh" stopping in individual panels.

Pipe and sheeting stoppings. The pipe and sheeting stopping is formed on 5- and 6-inch telescoping, 1/4-inch wall, square-section steel tubes. These tubes were set into shallow holes that had been drilled into the floor on 7.5-ft centers. At the roof, directly above each floor hole, an 8-in-long, 3-in by 3-in by 3/8-in piece of angle iron was attached using a 2-ft resin roof bolt. The top of each telescoping member was welded to a roof angle. The connection between the two tubes was also welded. Corrugated metal sheets were then fastened to the vertical support members on the high-pressure side using self-drilling screws. All sheeting seams and the stopping perimeter were then sealed with a polyurethane foam.

Brattice and wire mesh stopping. To build a brattice and wire-mesh stopping, short pieces of threaded rod, 1/2-inch in diameter by 4 inches long, were first welded every 2 ft to a section of angle iron 4 inches by 4 inches by 1/4 inch by 10 ft long. This angle iron was then bolted to the roof and floor using 2-ft resin bolts on 3-ft centers. Next, a wire fencing layer was placed across the opening, and each panel of fence was attached to the angle base on the roof and floor. Then, brattice with velcro strips sewn down the vertical edges were attached to the angle bars on the high-pressure side. The velcro seams were then fastened to create a sealed wall of brattice. Following the brattice installation, a second layer of wire fence was attached across the drift in a fashion similar to the first. The two layers of fence sandwiching the brattice were then securely fastened to the threaded rod with roof bolt plates, washers, and nuts. Finally, all velcro seams and the stopping perimeter were sealed with polyethylene foam.

Blast relief with damage-resistant brattice. Close to the face, some blast relief is needed. A stopping of "damage-resistant brattice" (figure 4-6) can be used [Thimons et al. 1978]. Damage-resistant brattice consists of vertical brattice panels joined by velcro seals. To form a stopping of damage-resistant brattice, a strip of velcro is sewn to each edge of a roll of brattice cloth on the same side of the fabric. The end of the roll is wrapped around a wooden 2 by 4 that is slightly shorter than the width of the roll. The 2 by 4 is then bolted to the roof, with the brattice hung down to the floor. The operation is repeated to extend a curtain all the way across the entry. Adjacent cloth panels are sealed to each other with the velcro. The velcro strips are sewn to the same side of adjacent panels so that they separate by peeling rather than shearing. Next, other wood 2 by 4s are bolted to the ribs. Velcro is then stapled on and the adjacent brattice curtain attached. Blast forces can split the seams between the panels and at the ribs, but they can easily be reattached. When blast forces are no longer a concern at that location, adjacent panels can be stapled together. Also, wire mesh can be placed on either side to make a more pressure-resistant brattice and wire-mesh stopping.

Table 4-2 shows the leakage and cost of the three types of stoppings, along with two types of muckpile stoppings. With the exception of the muckpile stoppings, the leakage values were reasonable. However, the costs were high because there were such large entries to be sealed.

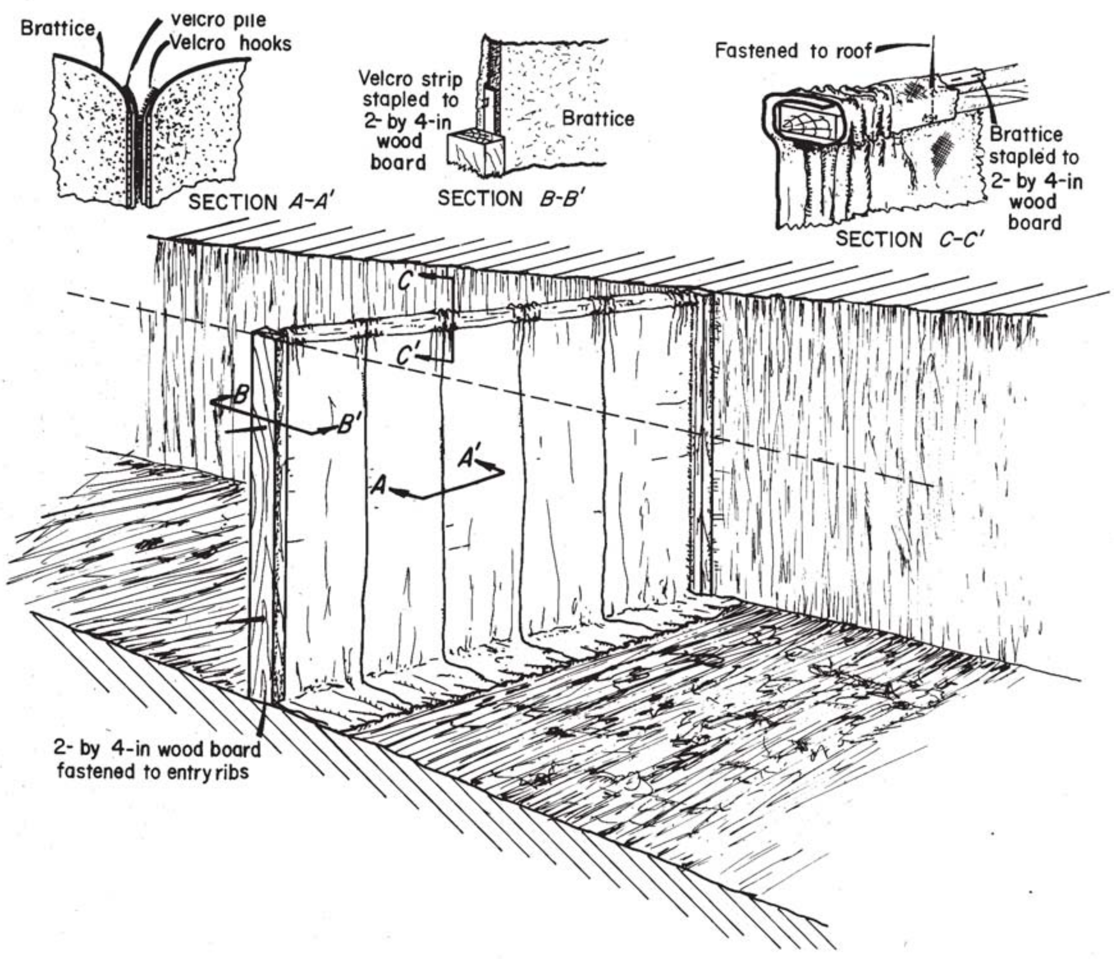

Figure 4-6.—Stopping built from damage-resistant brattice.

Table 4-2.—Cost and leakage of five types of stone mine stoppings

Type of stopping	Cost (2001 prices)	Leakage in cfm/1,000 ft^2 at 0.10 in w.g.
Pipe and sheeting	$15,000	80
Brattice and wire-mesh	$7,000	160
Damage-resistant brattice	$2,400	200 (before blast)
Muckpile stopping	$5,800	5,100
Muckpile and brattice stopping	$2,400	2,200

Because of the high stopping costs, Adam et al. [1986] also considered a wide variety of alternatives in the room-and-pillar layout to reduce the number and size of stoppings required. Typical alternatives were longer pillars along a stopping line, development of bleeder entries, ventilation from adjacent panels, and reduced-width "hourglass" crosscuts that were widened on the retreat benching operation. These alternatives were then weighed in a cost-efficiency model that considered the volume mined per unit stopping area, haulage distance, and equipment tram distance. Adam et al. concluded that stopping size and cost could be reduced by any of several cost-effective alternatives.

PROPELLER FANS AS MAIN FANS

Save money by using propeller fans.

Improved dust control in many stone mines will require installing new main fans. Many stone mines have access exclusively through parallel drift entries, that is, they have no shafts or slopes. Because the pressure drop associated with moving air through large entries is low, these mines may be able use low-pressure, high-volume propeller fans as main fans. Grau et al. [2002] have measured air quantities and pressure drops in two stone mines having only parallel drift entries and no shafts or slopes. Results are shown in table 4-3.

Table 4-3.—Pressure drop in stone mine airways

Mine	Airway length, ft	Air quantity, cfm	Fan pressure, in w.g.
A	2,400	350,000	0.12
B	7,000	280,000	0.06

These air quantities and fan pressures are well within the reach of large-diameter (10- to 12-ft) propeller fans. Such fans will be much less expensive to purchase and operate as main fans than vane-axial fans delivering the same airflow and pressure.

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CHAPTER 5.—SURFACE MINE DUST CONTROL

By John A. Organiscak,[56] Steven J. Page,[57] Andrew B. Cecala,[1] and Fred N. Kissell, Ph.D.[2]

In This Chapter

- ✓ *Drill dust control: wet and dry*
- ✓ *Enclosed cabs on drills and mobile equipment*
- ✓ *Haul road dust control*

Overburden drilling generates most of the respirable dust that affects workers at surface mines. Both wet and dry methods are available to reduce this drill dust. Overburden removal by mobile excavation equipment such as bulldozers, front-end loaders, and haulage trucks can be dusty, particularly under dry and windy conditions. Tightly enclosed cabs with dust filtration systems can substantially lower the dust exposure of both drill and mobile equipment operators. Haul road dust control can be achieved by water application or chemical application.

DRILL DUST CONTROL

Drill dust is controlled with wet or dry systems. Wet systems can be more efficient, but may freeze in the winter. Dry systems require careful maintenance of the drill deck shroud. An improved deck shroud is shown.

Wet Suppression. Wet drilling systems pump water into the bailing air from a water tank mounted on the drill. The water droplets in the bailing air trap dust particles as they travel up the annular space of the drilled hole, thus controlling dust as the air bails the cuttings from the hole [Page 1991].

In wet drilling systems, typical water flow rates are 0.1 to 2.0 gpm depending on the size and type of drill and the moisture level of the overburden. The drill operator controls the flow using a control valve located in the cab. Some drills are equipped with a flow meter to give the operator a visual sign of the flow rate. Raising the water flow will improve dust capture, but too much water causes operational problems. Because of this, the drill operator must exercise care in finding the best water flow rate.

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To operate the drill at the best water flow rate, the operator slowly increases the amount of water just to the point where visible dust emissions abate. The visible dust abatement point is easy to identify. Increasing water flow beyond the dust abatement point does not yield much improvement in dust control, but will most likely cause increased tricone bit degradation and possible seizing of the drill stem. If the cuttings look moist, it usually indicates that too much water is being used. This approach to adjusting the water flow can be effective; however, the time delay between adjusting the valve and expulsion of the cuttings from the hole can be several seconds. Finding the proper water flow is not as crucial with drills using drag bits, but the cuttings still should not look moist. Particular care in finding the proper flow setting must be exercised when drilling through alternating dry and wet strata.

Tests show that wet suppression systems can effectively control respirable dust. In testing, control efficiencies for 8-in holes varied widely, from a low of 9.1% at a flow of 0.2 gpm to a high of 96.3% at a flow of 1.2 gpm. The most significant increase in efficiency is usually between 0.2 and 0.6 gpm. Above this, the efficiency levels off. For those drills tested, a flow rate approaching 1.0 gpm began to cause operational problems [Zimmer et al. 1987].

The most obvious drawback to wet system drilling occurs when the outside temperatures drop below freezing. The entire system must then be heated while the drill is in operation; during downtime the system must be drained.

Dry Collection. Dry collection systems require an enclosure around the area where the drill stem enters the ground. This enclosure is constructed by hanging a rubber or cloth shroud from the underside of the drill deck. The enclosure is then ducted to a dust collector, the clean side of which has a fan. The fan creates a negative pressure inside the enclosure, capturing dust as it exits the hole during drilling. The dust is removed in the collector, and clean air is exhausted through the fan.

The dust that escapes dry collection systems has several possible sources: the shroud around the drill deck, the drill stem access hole in the drill deck, the dust collector dump, and the dust collector exhaust. Determining which is the problem is not difficult. The presence of a visible dust cloud is a good sign that respirable dust is present, even though such clouds are mostly larger-sized particles.

The integrity of the drill deck shroud, including how well it seals to the ground, is probably the single most important factor contributing to the effectiveness of a dry collection system. The shrouded volume under the drill deck should be at least 1.8 times the volume of the hole and should be at a negative pressure of at least 0.2 in w.g. The minimum ratio of dust collector air to bailing air flow recommended for most drills with a rectangular shroud is 3:1, with higher ratios desirable. Openings in the shroud lower its capture efficiency. The most common open area is the gap between the bottom of the shroud and the ground. With a ground gap of 6 to 9 inches or less, dust capture will usually be satisfactory for a 3:1 airflow ratio. However, as the ground gap increases, dust capture efficiency decreases, and a considerable amount of dust may escape [Page 1991].

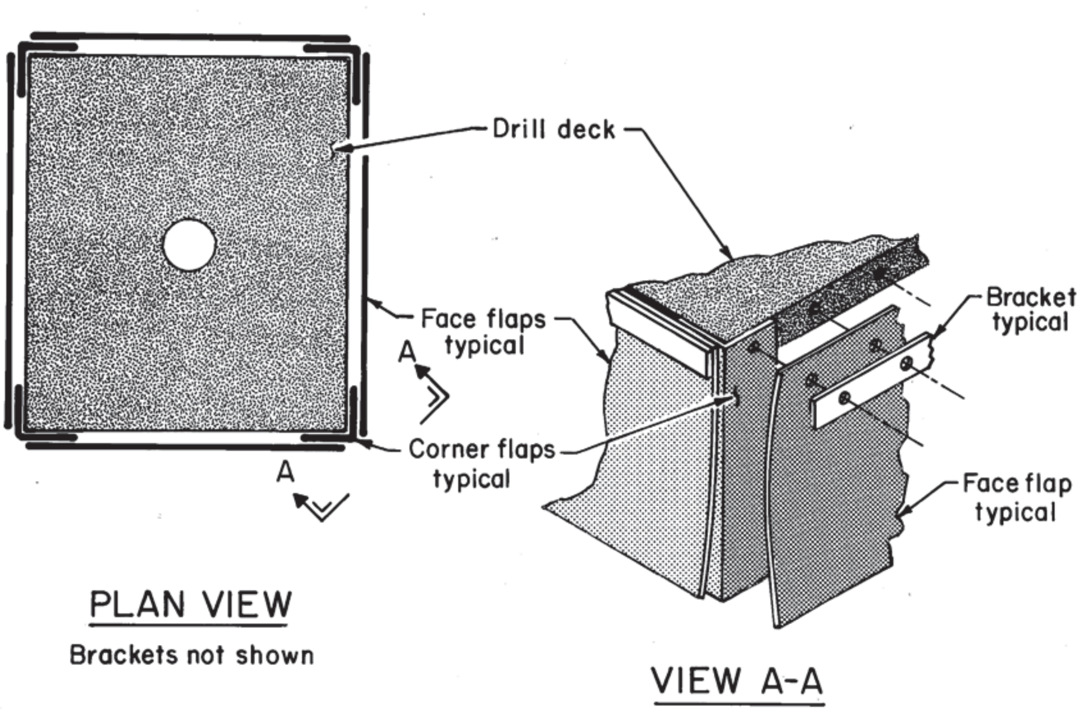

Figure 5-1.—Corner flaps added to a deck shroud to reduce leakage.

During drilling, it is sometimes necessary to raise the drill for two reasons: (1) the driller/helper needs to shovel the cuttings to prevent them from falling back into the hole, and (2) the operator must be able to observe when the coal seam has been reached and stop drilling. As a result, there are times when a ground gap cannot be avoided. However, it is important for good dust control to keep the gap to a minimum.

The effectiveness of the dust collection system also decreases if significant leaks are present from holes in the shroud. Most deck shrouds are rectangular and constructed from four separate pieces of rubber belting attached to the deck. Thus, leakage occurs at the corner seams as the individual pieces of belting separate from one another. Adding corner flaps to the shroud (figure 5-1) [Page and Organiscak 1995] can help to reduce this corner leakage.

Improved shroud design for dry collection systems. A new type of circular rubber shroud is much superior to the traditional rectangular design because it has no corner seams and it can be easily raised and lowered to make a better seal at the ground [NIOSH 1998] (figure 5-2). The circular shroud is attached to the drill deck with steel banding. A second much thicker steel band is attached to the bottom of the shroud to maintain shape and provide weight. The shroud is raised and lowered through activation of a hydraulic cylinder and lift wires attached to the bottom steel band. The bottom can be raised almost to the drill deck and lowered to make contact with the ground after raising and leveling the drill. Raising and lowering of the shroud is helped by using thin sheet rubber and cutting the rubber so the shroud has a slight conical shape. The shroud also has a small trap door that can be manually opened to shovel the cuttings out of

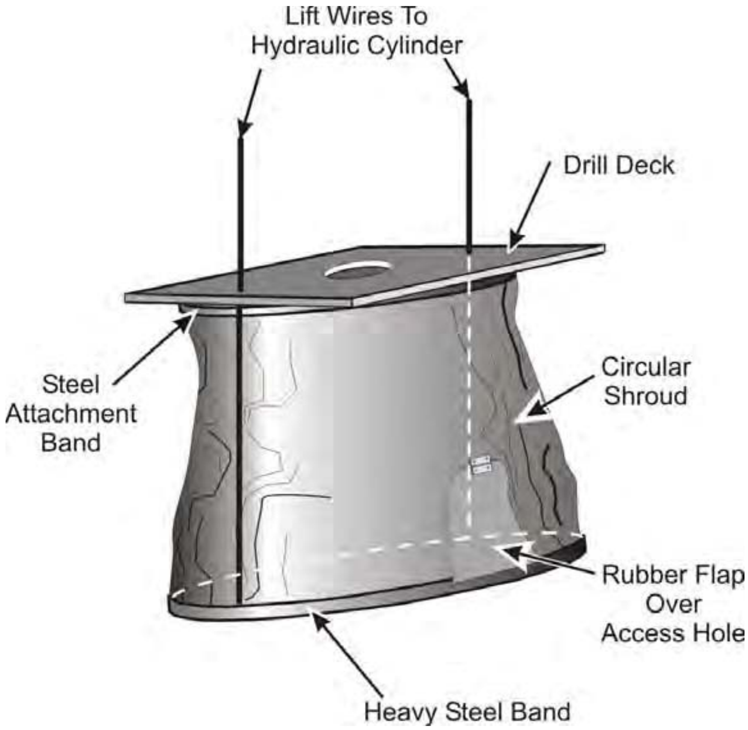

Figure 5-2.—A circular shroud that can be raised and lowered improves dust collection efficiency.

an access hole without having to raise the shroud above the ground and lose dust capture efficiency.

During testing, the circular shroud had a dust reduction efficiency of 99% or better. Comparable tests on the common square shrouds typically achieve 95%, so the amount of dust escaping from the circular shroud is lower by a factor of five.

Maintenance of dry collection systems. A recent field survey of six highwall drills [Organiscak and Page 1999] has shown that proper maintenance is crucial to the performance of dry collection systems. During the survey, the dry dust collection systems on four of the six drills were malfunctioning, and dust levels were very high. The collector fan on one drill was not operating because the drive belts were broken. Another drill had one-quarter of the shroud material missing. The two remaining drills had dust escaping from underneath the shroud due to sloped and uneven ground conditions. When these problems were corrected, dust was reduced by 51% to 88%.

Other maintenance-related dust sources were also identified during this survey. Dust was escaping from torn drill stem seals at the top of the drilling tables. Dust was discharged from a collector's exhaust because the collector filter was torn, and dust was entrained by the wind when the gathered fines in the collector were dumped 4 ft onto the ground. The problems with the drill stem seal and collector discharge were easily fixed by replacing the worn items. Wind entrainment of dust from dumping of the collector was reduced by attaching a cloth shroud to the dust discharge port [Page and Organiscak 1995] and extending it down to within a few inches of ground level.

ENCLOSED CABS ON DRILLS AND MOBILE EQUIPMENT

Enclosed cabs can work well to reduce dust, but high efficiencies require a lot of maintenance. Cab sealing is important.

Dust surveys on drills and bulldozers have shown that enclosed cabs can effectively control the operator's dust exposure. In practice, many enclosed cabs do not provide adequate dust protection [Organiscak and Page 1999]. The cab protection factors (outside versus inside dust level) measured on rotary drills ranged from 2.5 to 84; those measured on bulldozers ranged from 1 to 45. Newer cabs were usually better sealed and cleaner; older cabs tended to be more poorly sealed and dirtier.

Older cabs can be improved by being retrofitted with systems that heat, cool, and filter the air and by being tightly sealed. Both steps are necessary to ensure good dust control. First, the cab needs to have a high quality of recirculated and incoming filtered airflow. Second, the cab structure must be adequately sealed so that clean make-up air pressurizes the cab, keeping out dust that would otherwise be blown in by the wind.

A recent cab retrofit study by Cecala et al. [2002a,b] showed the importance of cab sealing and pressurization. A poorly sealed cab with no pressurization showed no improvement in dust levels even when retrofitted with a new filtration/air-conditioning system. However, a cab retrofitted with a new filtration/air-conditioning system and pressurized to 0.2-0.4 in w.g. gave a protection factor of 52. Another cab pressurized to 0.01-0.15 in w.g. gave a protection factor of 10. An earlier study by Organiscak et al. [2000] also concluded that cabs must be pressurized to offer adequate protection. Very small one-person cabs need at least 25 cfm of make-up air for adequate pressurization, and larger cabs proportionally more. Also, it was found that pressurization must be continuous and the operator must always keep the doors and windows closed. During the study, the operator of one drill opened the cab door to collar the next hole, letting notable amounts of dust enter the cab. Although the operator then shut the cab door during the drilling operation, the air filtration system took about 7 min to remove the dust cloud.

Since positive pressurization cannot be achieved unless cabs are leak-tight, cabs should be checked regularly for leaks. Doors should be on a single hinge, with intact tight gaskets. Bifold and slider doors leak too much. Flexible boots must be on all control linkages entering the cab and the boot seams sealed with silicone caulking. All other seams and gaps should also be sealed with silicone. A flashlight can be used to check for gaps, and a smoke bomb released inside the cab will reveal even the smallest leaks. Older cabs are often hard to seal properly.

Cecala et al. [2002a,b] also make recommendations on the design and installation of filtration/air-conditioning systems. For effective filtration, the system should have two fans, one to recirculate inside air through a filter and a second to pressurize the cab with outside make-up air passed through a second filter. The filters must be designed to trap small-sized respirable dust. About 75% of the air passing through the cab should be recirculated, thus keeping the air-conditioning unit to a reasonable size. The inlet for the make-up air should be located high on the cab and away from outside dust sources [NIOSH 2001a] to extend filter life and reduce air-conditioner maintenance.

Inside the cab, several actions can be taken to reduce dust. Air outlets should be at the top and inlets at the bottom. This top-to-bottom airflow keeps down the dust originating from dirty work clothes, boots, and a dirty floor. Potential dust sources on the cab floor also need to be relocated or removed. The fans on floor heaters will stir up dust, so these heaters should be moved higher up in the cab [NIOSH 2001b; Cecala et al. 2001]. Cab interiors should also be vacuumed and cleaned regularly to remove the dust that drifts in through open windows or is carried in on the operator's shoes and clothing. In many instances, a thick layer of sweeping compound on the cab floor will reduce dust [NIOSH 2001c].

HAUL ROAD DUST CONTROL

The best dust control method depends on the type of road aggregate. Spillage is a consideration in selecting the dust control.

Many methods are available for haul road dust control. Water application to the road surface is the most obvious, but there are many others. These include:

- *Salts*—hygroscopic compounds such as calcium chloride, magnesium chloride, hydrated lime, sodium silicates, etc. Salts increase roadway surface moisture by extracting moisture from the atmosphere.

- *Surfactants*—such as soaps and detergents. Surfactants decrease the surface tension of water, which allows the available moisture to wet more particles per unit volume.

- *Soil cements*—compounds that are mixed with the native soils to form a new surface. Examples are calcium or ammonium lignon sulphonate, portland cement, etc.

- *Bitumens*—compounds derived from coal or petroleum such as coherex peneprime, asphalt, oils, etc.

- *Films*—polymers that form discrete tissues, layers, or membranes such as latexes, acrylics, vinyls, fabrics, etc.

- *Soil cements, bitumens, and films*—These form coherent surface layers that seal the road surface, thereby reducing the quantity of dust generated.

Chlorides. Chlorides are the most commonly used products for haul road dust control. A study by Rosbury and Zimmer [1983a,b] showed that the highest control efficiency measured for a chemical dust suppressant, 82%, was for calcium chloride 2 weeks after application. Average efficiencies hovered in the 40% to 60% range over the first 2 weeks after application, then decreased with time. After the fifth week beyond application, the limited data show a control efficiency of less than 20%. The effectiveness of chlorides is enhanced by good roadway preparation, that is, a good crown and good drainage at the shoulder. Also, it is helpful to loosen at least 1-2 inches of the existing roadway surface. This allows the chloride to penetrate evenly into the gravel. To enhance dust control efficiency, the roadway surface should not be compacted before applying chlorides.

It is important that the gravel be kept close to the optimum moisture just before applying chlorides. The product will thus be absorbed much more quickly and evenly into the gravel. Chloride should never be applied to dry gravel in that it will not be evenly absorbed and may show failure in spots. Also, rain on a freshly treated surface will leach out and dilute the chloride, causing it to run off the road. Therefore, application should be postponed if rain is forecast for that day.

Water and chemical suppressants. Untreated plain water is commonly used for roadway dust control. The study by Rosbury and Zimmer [1983a,b] showed that watering once per hour resulted in a control efficiency of about 40%. Doubling the application rate increased the control effectiveness by about 15% to 55%. Chemical dust suppressants (primarily salts and lignons) can be more cost-effective than watering under some conditions. However, all chemical dust suppressants (with infrequent watering) share one common failing compared to frequent watering. Material spillage on roadways is very common, and the material spilled is subject to reentrainment. With frequent watering, newly spilled material is moistened at close intervals. When chemicals are applied with infrequent watering, newly spilled material could go for long periods before being moistened. Therefore, in mines where spillage cannot be controlled, watering alone is better for dust control.

In many instances, chemical suppressants have an advantage over plain water. In locations where trackout from an unpaved road to a paved road creates a dust problem, chemical suppressants are a good choice. Watering actually aggravates the trackout problem with moisture and mud; chemical suppressants, particularly bitumens and adhesives, leave the road dry. Finally, some mines have a dust problem in winter when temperatures are subfreezing but little moisture is present. The case for chemical suppressants over water in such instances is clear.

Road aggregate and dust control. Different types of road aggregate dictate different approaches to dust control. Recommendations based on specific road aggregate are:

1. *Gravel with few fines.* In gravel road surfaces with not enough fines, only watering will be effective. Chemical dust suppressants can neither compact the surface (because of the poor size gradation) nor form a new surface, and water-soluble suppressants will thus leach.

2. *Sand.* In compact sandy soils, bitumens, which are not water-soluble, are the most effective dust suppressant. Water-soluble suppressants such as salts, lignons, and acrylics will leach

from the upper road surface. However, in loose, medium, and fine sands, bearing capacity will not be adequate for the bitumen to maintain a new surface.

3. *Good gradation.* In road surfaces with a good surface gradation, all chemical suppressant types offer potential for equally effective control.

4. *Silt.* In road surfaces with too much silt (greater than about 20% to 25% as determined from a scoop sample, not a vacuum or swept sample), no dust suppression program is effective, and the road should be rebuilt. In high-silt locations, the chemical suppressants can make the road slippery and are not able to compact the surface or maintain a new road surface because of poor bearing capacity. Further, rutting under wet conditions requires that the road be graded, which destroys chemical dust suppressant effectiveness. If the road cannot be rebuilt, watering is the best program.

If there is uncertainty about the gradation of the gravel or if there is doubt about the equipment and products to be applied, the process can be tried on a 500- to 1,000-ft test section of the road. If the process fails at the test section level, then only a small investment and time are lost.

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CHAPTER 6.—UNDERGROUND HARD-ROCK DUST CONTROL

By Fred N. Kissell, Ph.D.,[58] and Jozef S. Stachulak, Ph.D., P.Eng.[59]

In This Chapter

- ✓ Ore pass dust control
- ✓ Drill dust control
- ✓ Blasting dust control
- ✓ Conveyor belt dust control
- ✓ Transfer point and crusher dust control
- ✓ Roadheader dust control

and

- ✓ How much ventilation air to use

This chapter discusses respirable dust control in underground hard-rock mines. These mines use a wide variety of extraction methods, but they have many common dust sources and dust control needs. Ore passes, drills, blasting, conveyor belts, transfer points, crushers, and load-haul-dump operations can be major sources of dust. Roadheaders, which are sometimes used in hard-rock mines, produce dust in large quantities. For the most part, dust in hard-rock mines is controlled with ventilation air, water sprays, and dust collectors. It is also important to prevent dust from getting into the air in the first place. Good dust control practices will reduce overall mine ventilation requirements.

Lack of maintenance is the main source of dust problems in hard-rock mines according to Rodgers [1974], who conducted a dust survey of hard-rock mines several decades ago. Rodgers found that spray systems had clogged sprays, dust enclosures had improperly fitted skirts, and ductwork was plugged and had leaks. Today's mines have better maintenance programs (we think), but when dust levels are high, maintenance is still the first topic to address.

The Mining Association of Canada [MAC 1980] and Knight [1980] provide good general information about hard-rock dust control. For conveyor belt dust control, Goldbeck and Marti [1996] and Swinderman et al. [1997] are valuable sources of information.

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ORE PASS DUST CONTROL

Falling rock moves air. That's the ore pass dust problem in a nutshell.

Ore and waste passes (figure 6-1) produce large quantities of airborne respirable dust. The broken rock delivered to the passes contains a considerable amount of attached dust from preceding operations such as blasting and loading. The grinding action on the rock as it falls down the pass produces even more dust. However, the main problem is that the falling rock entrains air, producing a powerful "piston effect" that generates pressure surges of dusty air.

Good ore and waste pass design can help to relieve these pressure surges. For example, if the ore and waste passes are located near each other, connecting them on several levels will relieve the pressure. Also, dusty air in the passes can be discharged into a return airway [Marshall 1964; Pullen 1974]. The Mining Association of Canada [MAC 1980] recommends exhausting sufficient air from the ore and waste pass system to indraft 200 ft/min air velocity at all leakages, assuming that one tipping location is open continuously. Discharging this air into a return airway eliminates the need to install a dust collector.[60]

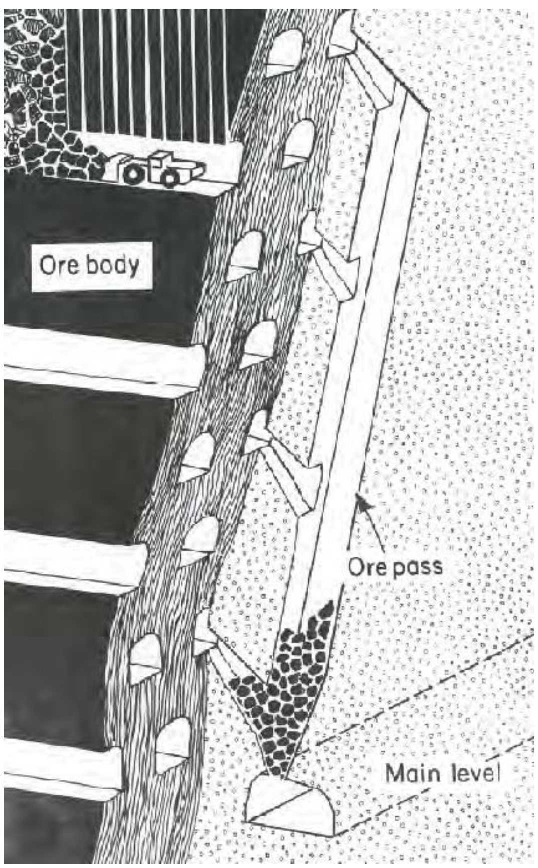

Figure 6-1.—Ore pass adjacent to steeply dipping ore body. ***(Courtesy of the Society for Mining, Metallurgy, and Exploration (SME) (www.smenet.org).)***

No matter what the ore and waste pass design, a critical step in dust control is to prevent its escape and dispersal into working areas by confining dust within the passes. This confinement can be accomplished by a system of stoppings and airtight doors over the ore and rock pass tipping locations. However, since some leakage from these doors is inevitable, another approach to dust control at tipping locations is to isolate them from travelways. This isolation is accomplished by locating the tipping locations in short, dead-end (stub) headings that have local exhaust dust collection systems.

Dust from ore and waste passes will be reduced if the rock is thoroughly wetted before delivery to the tipping site. More water can be added at the tipping site by spraying the rock as it falls into the pass. However, too much water at ore passes can be

[60]Dust collectors located underground must be able to handle high-humidity air and possibly some condensation.

objectionable for many reasons. These include (1) an adverse impact on crushing and milling; (2) accumulation of a large quantity of water on top of the material in the chute, which creates a hazard for workers on the lower levels; and (3) plugging of chutes caused by water-softened clay minerals.

Ore pass dust control is addressed by ILO [1965], Geldenhuys [1959], Kneen [1959], Gray et al. [1961], and Foster [1965]. Ore pass design has been discussed by Hambley [1987]. An extreme case of ore pass pressurization caused by falling material has been discussed by McPherson and Pearson [1997].

DRILL DUST CONTROL

Good drill dust control requires good maintenance.

Drill dust is suppressed by water injected through the drill steel, which has been a common practice for many years [ILO 1965]. Usually, respirable dust is reduced by 95% or better [MSA Research Corp. 1974]. This does not, however, prevent dust from entering the air during the initial collaring period as the drill hole is started. Various means have been tried to prevent the escape of dust during collaring. These range from simple handheld sprays to elaborate types of suction traps around the end of the drill steel. None of these are very efficient.

Drills powered by compressed air are much less common than in the past, eliminating the dust problems associated with their use. For example, if some of the compressed air operating the drill leaks into the front head of the drill and escapes down the drill steel, it will cause dry drilling and carry dust out of the hole. Compressed air escaping through the front-head release ports will atomize some of the water in the front head. This atomized water evaporates quickly and, if the water is dirty, many dust particles will remain in the air [Sandys and Quilliam 1982].

MSA Research Corp. [1974] has listed the factors that can lead to high dust levels on drills. Many result from lack of proper maintenance. These are failure to use water, inadequate quantities of water, plugged water holes in the drill bit, dull drill bits, and dry collaring.

BLASTING DUST CONTROL

Water and ventilation are necessary, but the key to reducing dust exposure is blasting off-shift.

Water is important in controlling dust generated by blasting. The area surrounding the blast (walls, floor, and back) should be thoroughly sprayed beforehand. This precaution will prevent dust settled out during previous operations from becoming airborne. A uniform rock moisture content[61] of only 1% greatly reduces dust compared to dry rock [Quilliam 1974]. However, since it is difficult to wet rock uniformly under realistic mining conditions, the optimum moisture content can be much higher.[62] The water used for dust suppression, particularly in drilling and in blasting, should be as clean as possible, because the evaporation of dirty water can also release dust.

Sufficient ventilation is critical for the control of blasting dust since water alone is usually inadequate. Blasting dust and fumes should be diluted quickly and exhausted to the surface[63] via an untraveled return route. If this is not possible, the common practice is to arrange the blasting schedule so that the contaminated air will pass through working places when the miners are absent.

CONVEYOR BELT DUST CONTROL

A conveyor belt can generate large amounts of respirable dust from several sources. If the belt is not clean, dust is knocked from the belt as it passes over the idlers. Belt scraping and washing will reduce this dust source, and if the belt is dry, just wetting it can help. Also, much respirable dust originates at belt transfer points.

Belt cleaning by scraping and washing. Conveyor belts are usually equipped with belt scrapers; some have belt washers as well. Several manufacturers sell scrapers and washers; these play an important role in reducing the amount of dust generated by conveyor belt carryback. Carryback is that portion of the carried material that sticks to the belt instead of falling off at the head pulley. It becomes airborne dust as the belt dries and passes over the return idlers. When dust levels are high, the usual approach is to add a second or even third scraper rather than trying to get a single scraper to work better.

While multiple scrapers will reduce dust, they may be more efficient at spillage control than respirable dust control. Roberts et al. [1987] have shown that with each successive scraping, both the percentage of fines and the moisture level of the carryback substantially increase. This

[61]Weight of water in the rock divided by the weight of rock.
[62]Quilliam [1974] recommends 5%, but this seems high to us.
[63]Much of the dust will be deposited in the return airways. For example, Ford [1976] found that 45% of a 4-µm particle size dust cloud was deposited within a distance of 600 ft. Bhaskar et al. [1988] measured 38% deposition of respirable dust at air velocities over 300 ft/min and 67% deposition at an air velocity of 165 ft/min. Stachulak et al. [1991] measured a 66% decrease in respirable dust in a 500-ft vertical return air raise.

shows that the larger material is preferentially removed by scraping and the smallest fines (which generate respirable dust) tend to stay stuck to the belt.

If multiple scrapers do not remove enough carryback to cut the respirable dust sufficiently, a water wash system may be necessary. These systems spray the belt with water in addition to scraping it. Stahura [1987] has written a comprehensive discussion of conveyor belt washing. Planner [1990] has reported on the average belt-cleaning efficiency of water sprays when used with primary and secondary scrapers. In the Planner study, water sprays placed between the primary and secondary scrapers reduced carryback from 11.1% to 3.4%. In another test, water sprays added to a secondary scraper reduced carryback from 13.9% to 1.1%.

Belt sprays also reduce airborne dust. Rodgers et al. [1978] added a 150-gpm water spray system to dry scrapers on a 54-in belt at a taconite processing plant. The sprays reduced respirable dust by 48% and total dust by 78% compared to dry scrapers alone. More recently, Baig et al. [1994] reported that airborne (respirable and float) coal dust levels were reduced 80%-90% when their belt scrapers were augmented with spray wash boxes.

Wetting of dry belts. Several studies have shown that wetting the bottom (return) belt can reduce dust from a dry belt. For example, Courtney [1983] measured the respirable dust reduction from a single 0.33-gpm spray onto the top surface (the noncarrying surface) of the bottom belt. The goal was to prevent dust from being knocked loose by the tail pulley and upper idlers. The spray was followed by a piece of ordinary floor carpet that wiped the belt to prevent channeling of the water. The spray and carpet were mounted close to the tail pulley so that the belt was wet as it passed around the tail pulley and moved outby over the upper idlers (figure 6-2).

Respirable dust reduction from installation of the spray and carpet averaged 75%. A 2-gpm spray without the carpet worked about as well. Slippage from excessive wetting was not a problem, as water usage was low (only 2 gpm) and the belt then traveled for 5,000 ft before passing over the drive at the head end.

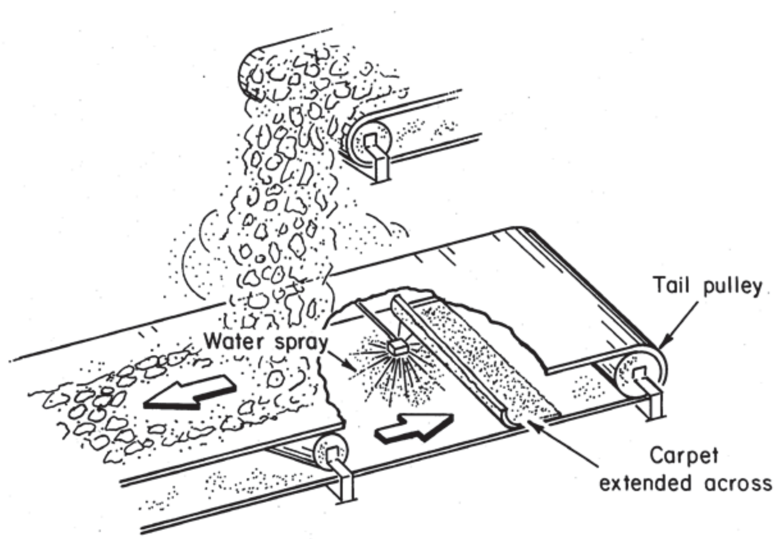

Figure 6-2.—Wetting the top surface of the bottom belt.

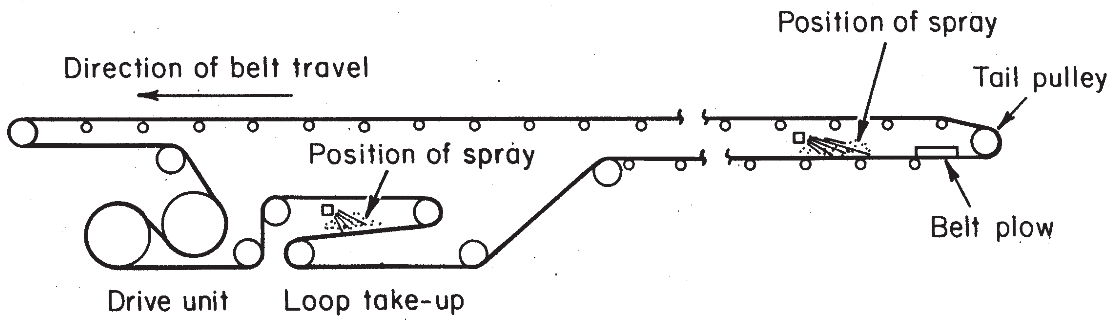

Figure 6-3.—Wetting both surfaces of the bottom belt.

A decade earlier than Courtney, Ford [1973] tested a system that wetted both surfaces of the bottom belt (figure 6-3). A spray in the loop take-up near the belt head wetted the carrying surface so that dust was not knocked loose by the ingoing trip over the lower idlers. Then, near the tail pulley, the noncarrying surface of the bottom belt was wetted by a second spray for the trip around the tail pulley and across the upper idlers, similar to the system described by Courtney. Sprays were mounted so as to wet the entire width of the belt, and they were controlled automatically to operate only when the belt ran. A belt plow was used in place of the carpet. Respirable dust was reduced by 67% with a total (all sprays) water flow of 0.53 gpm.[64]

TRANSFER POINT AND CRUSHER DUST CONTROL

Transfer points. The traditional approach to transfer point dust control is to tightly enclose the transfer point, exhaust the dust-laden air from the enclosure through a duct, and either remove the dust from the air with a dust collector or discharge the dust to a return airway (figure 6-4).

Transfer point dust control can be difficult because the falling rock has a "piston effect" due to air entrainment. This air entrainment draws mine air in at the top of the transfer point enclosure, and it can push dusty air out of the bottom of the enclosure. The piston effect of the falling rock can be reduced by lowering the drop distance, by using "rock ladders" to break the fall of the rock, and by increasing the enclosure size so that entrained air can circulate back to the top of the enclosure. Tight enclosure of the transfer point requires adjustable skirtboard sealing systems, a means to prevent belt sag in the loading zone, and careful sealing of belt entry and exit locations, among others. The usual airflow guideline is to plan for 200 (or more[65]) ft/min air velocity through all unavoidable openings.

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[64]Low-flow spray nozzles are prone to clogging because of their small orifice size. To avoid nozzle clogging while reducing water use, control timers have been developed to cycle belt sprays on and off (BWI Eagle, Inc.). Timers also allow better control over the degree of belt wetting.

[65]MAC [1980] recommends adding 25% to the 200 ft/min as a safety factor. Yourt [1969] recommends that if a loaded belt is leaving the enclosure the air velocity be set at 200 ft/min plus the belt speed to counteract the drag effect. For instance, if the belt speed is 300 ft/min, then the air velocity into all unavoidable openings should be 500 ft/min. Rodgers [1974] gives a rule of thumb of 700-800 cfm of exhaust ventilation per foot of belt width.

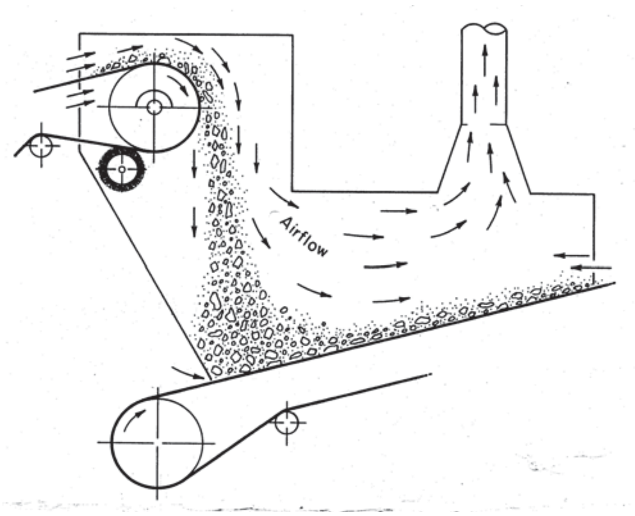

Figure 6-4.—Dust-laden air exhausted from transfer point enclosure.

Duct takeoffs from transfer point (and crusher) enclosures must be designed to avoid picking up large particulate. The Mining Association of Canada [MAC 1980] recommends that the takeoff air duct be at least 6 ft from the falling rock to avoid picking up particles. Yourt [1969] suggests that the base of the takeoff cone be large enough so that the velocity of air exhausted is 500 ft/min or less.

In addition to proper design of takeoffs, the ductwork leading to the dust collector or return airway must be designed to prevent dust settling. Yourt [1969] suggests that risers be installed at a steep angle, not less than 58º, and that horizontal runs be sized for a velocity of at least 3,000-3,500 ft/min. ACGIH [2001] suggests a velocity of 3,500-4,000 ft/min. Cleanout ports should always be provided in horizontal ductwork.

Another way to reduce dust at transfer points is to provide an enclosed sliding chute to transfer the material. Sliding chutes and spouts are widely used in materials handling; much information on them is available [Page 1991; Mody and Jakhete 1987].

There is a wealth of information on how to reduce transfer point dust [MAC 1980; Goldbeck and Marti 1996; Swinderman et al. 1997; Mody and Jakhete 1987; Yourt 1969; ACGIH 2001; Organiscak et al. 1986].

Crushers. Crushers in mines range from small roll types used in coal mines to large cone types used in hard-rock mines and mills. Whatever the size and method of crushing, dust is controlled by water sprays and local exhaust ventilation from the crusher enclosure. The amount of water needed is hard to specify. It depends on the type of material crushed and the degree to which water will cause downstream handling problems. If the rock is dry, a starting point is to add a water quantity equivalent to 1% of the weight of the material being crushed [Quilliam 1974].

Crushers need lots of air and lots of water because they break lots of rock.

The amount of air required depends on how much the crusher can be enclosed. Enough air should be exhausted from a plenum under the crusher to produce a strong indraft at the jaw, grizzly, and any other openings around the crusher. The design guidelines for determining the required airflow are the same as those for transfer points. The unavoidable open area is calculated and multiplied by a 200 ft/min indraft velocity.[66] The required airflow is usually large. For example, Rodgers et al. [1978] have described how dust from a 5-ft cone crusher was reduced by using a 75,000-cfm[67] exhaust ventilation system and a control booth for the operators.[68] Yourt [1969] has given a comprehensive set of design principles for dust control at crushing and screening operations. If there is an ore pass above the crusher, precautions should be taken to ensure that it is not pulled empty.

If the crusher can be located in a short, dead-end (stub) heading, then air can be drawn into the crusher in the usual way and then discharged from the heading through ductwork. This design approach creates an air movement into the stub heading that confines any dust that escapes the crusher.[69]

MAC [1980], Walker [1961], Phimister [1963], and Ahuja [1979] have described dust control methods used for large crushers at underground locations. Foam is also used to control dust at crushers, particularly where water use must be limited. Use of foam is described in chapter 1 on dust control methods.

VENTILATION OF PRODUCTION AREAS

Production areas are ventilated by directing an air split from the main ventilating stream through the workings. Sandys and Quilliam [1982] have recommended that a minimum air velocity of 100 ft/min is needed to remove mineral dust in headings where track- and tire-mounted loaders are used for mucking ore. Dust generated by moving equipment can be reduced by applying water or chemicals (most commonly hygroscopic salts) to the roadways.[70]

However, if enough air is supplied to meet the requirements of the diesel equipment in the heading, then the mineral dust is well controlled. The usual diesel airflow criterion has been to supply 100-125 cfm per horsepower of diesel equipment, all equipment being cumulative in any one split.

New MSHA regulations on diesel particulate, enacted in 2001, will require even more air in U.S. mines unless the particulate level can be reduced by other means.

[66] Plus a 25% safety factor [MAC 1980]. See also footnote 8.
[67] Large air quantities may be required because falling rock induces its own airflow. Pring [1940] investigated the amount of air required to produce an indraft in surge bins at crusher installations. About 35,000 cfm was required at a large crusher installation.
[68] If large (80% or more) dust reductions are sought for workers near a crusher, the most practical way to achieve this is to provide an enclosed and pressurized control booth supplied with filtered air.
[69] The benefits of locating a crusher in a stub heading are explained in more detail in chapter 4 on stone mines.
[70] Reduction of roadway dust is discussed at greater length in chapter 5 on surface mines.

Stachulak [1989] has pointed out that, not long ago, 10,000 cfm[71] was adequate for most development headings. However, some mines are now driving single drifts requiring 80,000 cfm to meet legal requirements for the diesel equipment.

In development headings, a blowing system kept to within 100 ft of the face will usually provide a satisfactory dust level. Exhaust systems can do a good job of removing dust when the end of the duct is held within 10 ft of the dust source. However, keeping a 10-ft distance can be difficult in development headings because of potential blast damage to the duct.

ROADHEADER DUST CONTROL

Roadheaders are occasionally used in hard-rock mines, but they are also used in many other underground excavations, from tunnels to wine storage caves. They have a reputation for generating dust for several reasons. Headings excavated by roadheaders are often larger in cross-section, and it can be hard to supply enough ventilation air to confine the dust cloud at the face. Some aspects of roadheader design also contribute to dust buildup. The cutting boom is narrow, so there is little of the dust cloud confinement provided by a wide boom. Also, the operator compartment is sometimes located far forward where the dust is inevitably higher. Finally, remote control of the machine, the best way to deal with dust, may not be available.

Dust control methods for machines like roadheaders usually depend on some degree of dust cloud confinement. In mines where methane is released along with the dust, confining the dust cloud will raise the methane concentration.

Below are the various methods used to control roadheader dust, assuming that the material being excavated generates no methane gas.[72]

Ventilation-based controls. For a ventilation-based dust control, provide an adequate air volume using an exhaust duct with the duct inlet located close to the face. The volume should be sufficient to provide a forward air velocity in the heading of at least 60 ft/min based on the cross-sectional area of the empty heading. The duct inlet should be at least 10 ft forward of the operator and within 5 ft of the face.[73] Decreases in the air volume and increases in the duct inlet

[71] The usual guideline was 50 cfm per square foot of face area, equal to a velocity of 50 ft/min.

[72] Lowering spray pressures will reduce the air turbulence. When air turbulence is reduced, methane concentration levels may rise. When a half-curtain is used at a gassy face, methane can build up behind the curtain. A good discussion of roadheader dust control, both with and without methane, is in Hole and Belle [1999].

[73] These recommended air velocities and duct distances are target values based on average conditions, assuming that remote control is not used. If a mine is under more stringent standards because of silica in the dust, more air may be needed.

distance can have a big effect on dust levels (figure 6-5) [Ford and Hole 1984].

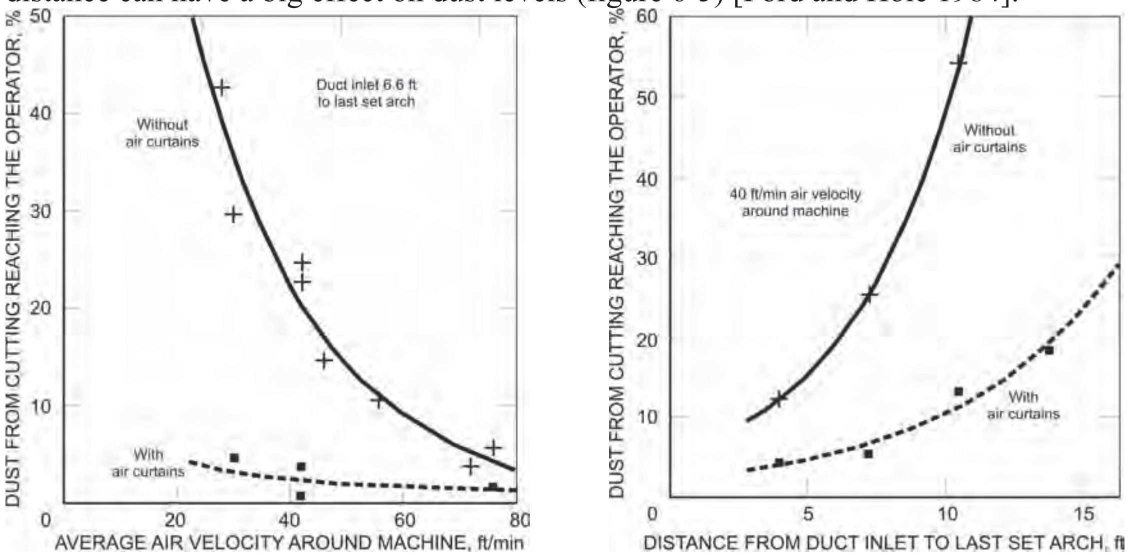

Figure 6-5.—Effect of duct inlet position, air velocity, and air curtain use on dust levels (from Ford and Hole [1984]).

The second step in ventilation-based dust control is to locate and use water sprays so as to minimize air turbulence at the face. High-pressure sprays or nozzles located to spray out into the open air will produce air turbulence. This turbulence will cause the dust cloud to expand and back up (rollback) against the ventilation air, covering the machine operator [Hole and Belle 1999]. To minimize turbulence, the water sprays on the boom should be located close to the cutting head to wet only the cutting head and the broken rock falling down from it. The water pressure (as measured at the spray nozzles) should be limited to 100 psi or less. If more water must be applied, larger orifice nozzles should be used. If the rock on the gathering pan must be wetted, only high-volume, low-pressure nozzles should be used. Finally, in headings where the cross-sectional area (not counting the machinery) is over 100 ft^2, a half-curtain should be considered in order to raise the air velocity for better dust confinement. Dust rollback and use of a half-curtain are explained more fully in chapter 1 on dust control methods.

Machine-based controls. Three machine-based controls are available to lower roadheader dust. First and most important is remote control. In conjunction with exhaust ventilation, remote control of the roadheader allows the machine operator to step back away from the dust cloud at the cutting face. In most cases, it is the most effective way to lower the operator's dust level.

The second control is to use a wet-head machine with low-pressure sprays. Several research studies have shown that wet heads will yield moderate dust reductions. The downside of wet heads is that the sprays can produce turbulence that causes the dust cloud to expand and roll back against the ventilation air, covering the machine operator with dusty air. For this reason, the nozzle pressure should be held below 50 psi. Hole and Belle [1999] report that a roadheader wet head operating at 20 psi and 6 gpm gave a 40% dust reduction compared to external sprays.

The third machine-based dust control is to use a Coanda air curtain to hold the dust cloud against the cutting face and away from the operator. Air curtains for dust control were devised in Germany and the United Kingdom. They are available as an option on some new machines. The greatest benefit is obtained when the ventilation quantity is low and the exhaust duct inlet cannot be held close enough to the cutting face. In underground testing, dust rolling back from the face was reduced by 80% when air curtains were used[74] (figure 6-5) [MRDE 1983; Hole and Belle 1999].

The best way to approach roadheader dust control will depend on individual circumstances. Providing sufficient airflow, keeping the exhaust duct inlet close to the cutting face, and using remote control will normally be sufficient to control dust. However, sufficient airflow and remote control are not always available. Keeping the duct inlet close to the face subjects it to damage by the cutter head. Therefore, if these conventional ventilation and remote-control remedies cannot be used, a half-curtain should be tried. Also, it might be possible to cut the face in two steps, first on the duct side, after which the duct is moved forward, and then the other side. Diligent replacement of worn picks can always help as well.

If all else fails, the operator of the roadheader should have a respirator or a fully enclosed cab that is equipped with an air filtration system. Cabs with filtration systems are discussed in chapter 5 on surface mines. Dust respirators are discussed in chapter 9.

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CHAPTER 7.—CONTROL OF DUST IN HARD-ROCK TUNNELS

By Fred N. Kissell, Ph.D.[75]

In This Chapter

- ✓ Finding the dust source
- ✓ Ventilation and dust collector malfunctions
- ✓ Upgrading the dust controls
- ✓ Design stage ventilation planning

This chapter explains how to reduce respirable dust[76] in hard-rock tunnels during excavation by using tunnel boring machines (TBMs). The first steps in combating a dust problem are to take dust samples to pinpoint the source, check the ventilation system, and check the dust collector. If the ventilation system and dust collector are operating properly, then other dust controls such as water sprays and conveyor belt scrapers must be upgraded. For tunnels in the design stage, recommended air quantities are provided.

FINDING THE DUST SOURCE AND LOOKING FOR VENTILATION MALFUNCTIONS

> **The first steps in fighting a dust problem are to take dust samples to pinpoint the source, check the ventilation system, and check the dust collector. Without knowing the exact source, efforts to reduce dust are hit-and-miss (mostly miss).**

Taking samples to pinpoint the dust source. In tunnels with high levels of airborne dust, the first task is to pinpoint where the dust enters the airstream. Most dust originates from rock breakage at the tunnel face, but the location where this dust enters the airstream can vary. Dust can leak from behind the TBM face shield, from gaps in the ventilation duct, or from a malfunctioning dust collector. It can be entrained into the air from the muck on a moving conveyor belt. It can even be shaken loose from the underside of the belt as it passes over the idlers. As a start, to locate the dust source, dust samples and air quantity measurements should be taken at the following locations:

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[75]Research physical scientist, Pittsburgh Research Laboratory, National Institute for Occupational Safety and Health, Pittsburgh, PA.
[76]An information source for controlling methane and diesel fumes in tunnels is Kissell [1996].

(1) At the portal or at the base of the entrance shaft
(2) At a location one-third of the way from the portal to the TBM
(3) At a location two-thirds of the way from the portal to the TBM
(4) At the rear of the TBM trailing gear, about 50 ft toward the portal
(5) At the middle of the TBM trailing gear
(6) At the front of the TBM trailing gear
(7) At the front of the TBM where ground support is installed
(8) At the outlet of any ventilation duct if the outlet is inside the tunnel

The dust samples can be 8-hr gravimetric filter samples, or they can be measurements taken with a light-scattering dust monitor. If the latter is used, repetitive readings must be made to ensure that observed changes in the dust level are not the result of changes in the TBM cutting rate.

Figure 7-1 gives the results from a dust concentration survey in a tunnel with an exhaust ventilation system. Both gravimetric filter and light-scattering measurements were made at regular intervals between the portal and the front of the TBM. The figure shows that, for this tunnel, most of the dust breathed by workers entered the airstream between the TBM and the portal, either from the conveyor belt or a leaking ventilation duct.

After the initial sampling, additional sampling in and around the TBM and trailing gear with a light-scattering dust monitor can provide useful information. Possible dust sources at the TBM include leakage from the head or from ventilation duct, emissions from rock drilling and

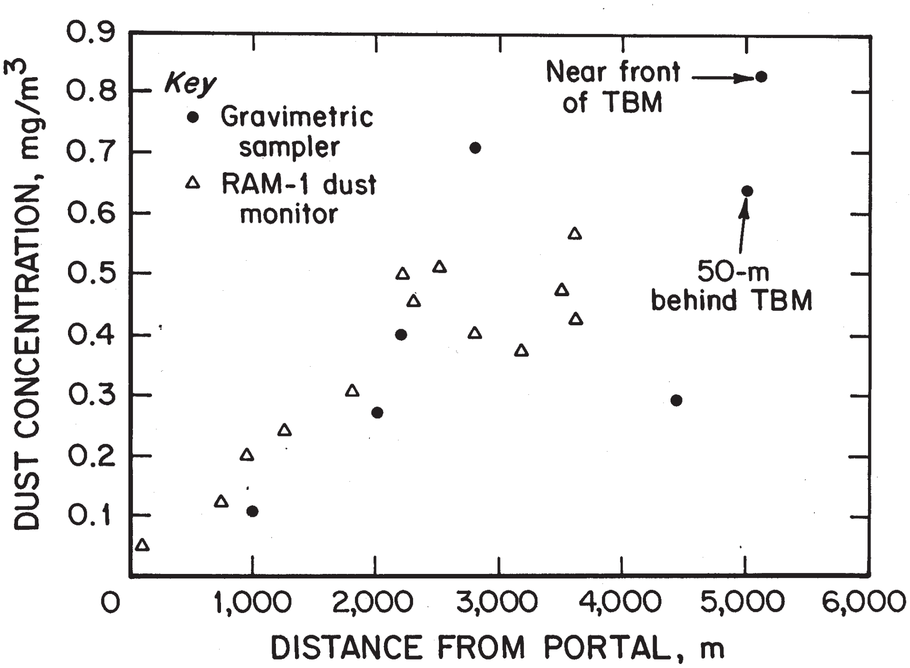

Figure 7-1.—Results from a dust concentration survey.

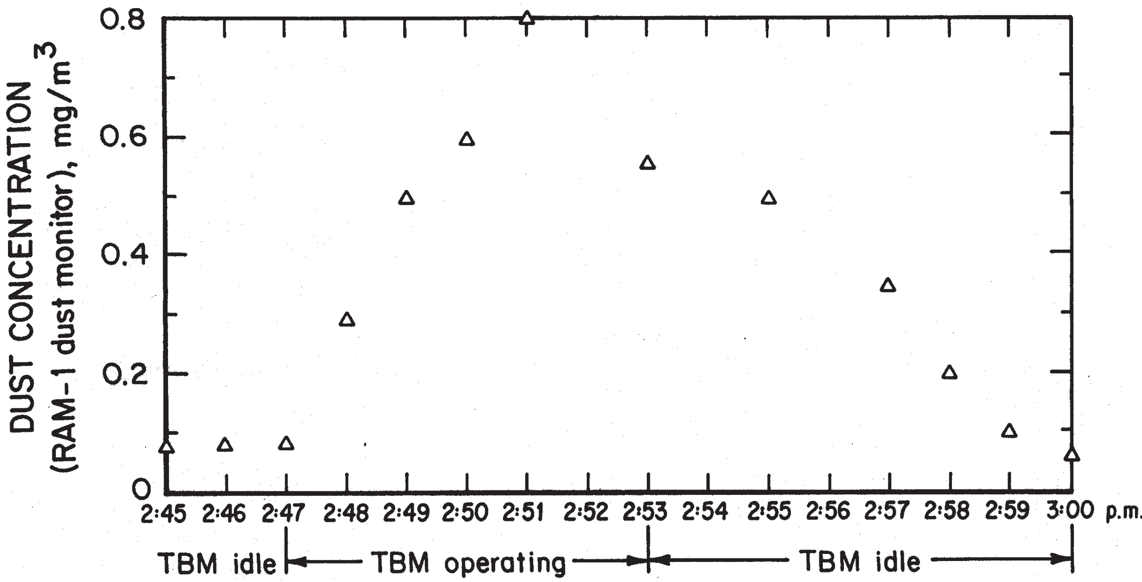

Figure 7-2.—Dust concentration measured near cutter head with TBM idle and operating.

conveyor transfer points, or the stirring of settled dust by work activities and cooling fans. To assess which of these are relevant, a light-scattering dust monitor can be used to measure the dust level close to each suspected source.

Figure 7-2 demonstrates the value of additional sampling around the TBM. In this tunnel, the only dust level of any consequence was measured at the front of the TBM near the cutter head as the cutter head operated. As the figure shows, the dust concentration rose (with little delay) after the cutter head began to rotate, then immediately dropped when the cutter head stopped. Rising and falling concentration profiles of this sort were only measured close to the cutter head, which indicates that the dust was leaking out somewhere close to the cutter head.

Checking the ventilation system. Air quantity measurements, taken at the same locations as the dust samples, are to ensure that the ventilation system is operating properly. Hidden leaks in ventilation ductwork are common and may cause abnormally low air velocities in a portion of the tunnel. Thus, high dust levels may result from the simple failure to deliver enough air. Ventilation systems with multiple fans will inevitably leak and recirculate some air. The recirculated air will usually contain dust, and the amount of recirculation may be enough to create a dust problem.

If recirculation is a concern, small holes should be drilled in the ventilation duct and the air pressure checked with the static pressure port of a Pitot tube. Exhaust systems should be under negative pressure, and blowing systems under positive pressure. Short regions of ductwork next to the fans may have the pressure reversed because of system imbalances, but reversed pressure regions should make up a very minor part of the ductwork.

If the dust concentration at the front of the TBM is much higher than that measured elsewhere, check to ensure that the ventilation duct is extended far enough forward. Exhaust duct must extend as far as the forwardmost worker, and ideally an additional 10 ft or more. Blowing duct must extend to within 20 ft of the forwardmost worker, assuming the jet of air emerging from the duct is unobstructed.

Unusually warm air from the TBM electrical equipment may indicate a malfunctioning ventilation system.

Occasionally, the ventilation system design includes some faults. Faulty designs inevitably result in higher dust levels. A common ventilation fault is the failure to provide overlap in auxiliary, or scavenger, systems. Figure 7-3 shows a properly operating scavenger system. The main fan acts to bring in clean air; the scavenger fan inlet is located in the clean air stream.

Figure 7-4 shows what happens when the proper overlap between the main duct inlet and the scavenger inlet is not maintained. The scavenger fan picks up some contaminated air returning from the face, so the amount of clean air delivered to the face is reduced.

Clean air delivery also suffers in mismatched scavenger systems. Figure 7-5 shows a blowing main ventilation duct mismatched to a blowing scavenger system. The scavenger fan intake is a mixture of clean air from the main duct and contaminated air returning from the face.

Another common problem found in tunnel ventilation systems is the low velocity zone created by moving similar quantities of air through ductwork in opposite directions. For example, figure 7-6 shows a tunnel with 5,000 cfm in a scavenger fan fresh air duct and 5,000 cfm in a dust

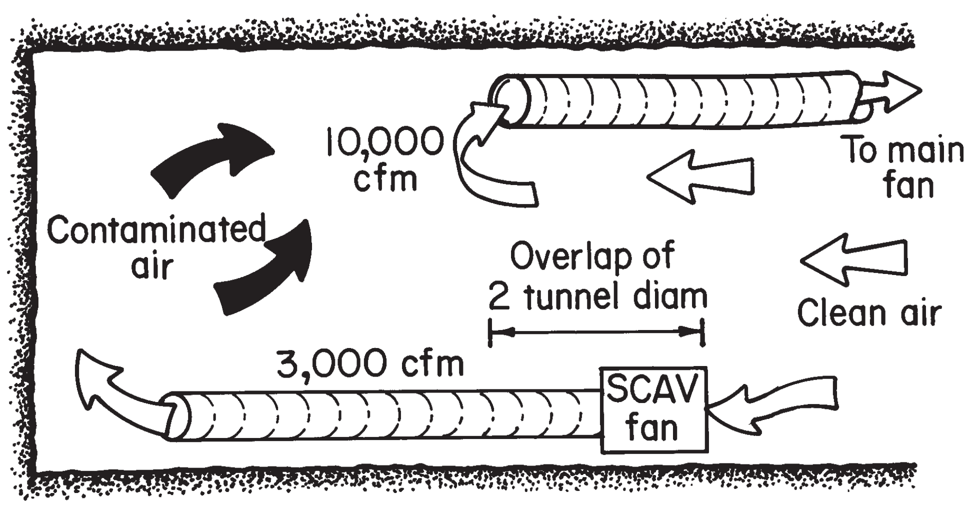

Figure 7-3.—Auxiliary, or scavenger, system with adequate overlap.

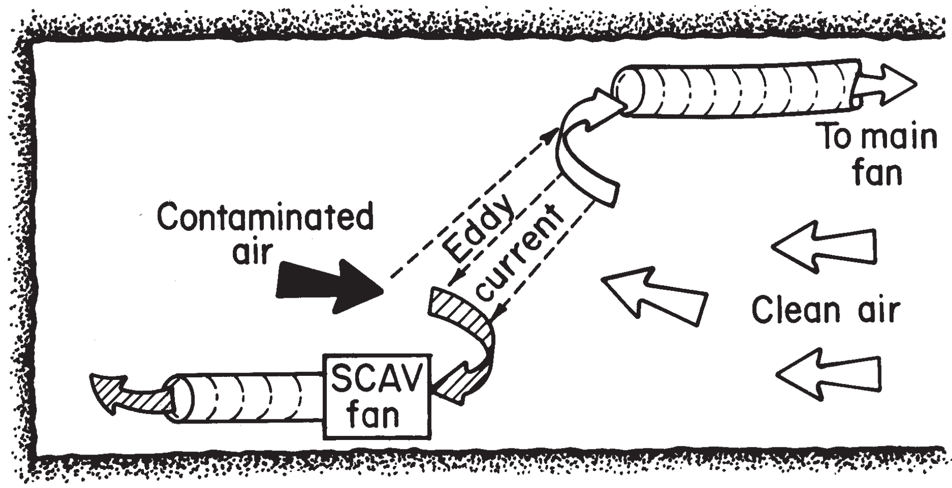

Figure 7-4.—Auxiliary, or scavenger, system with no overlap.

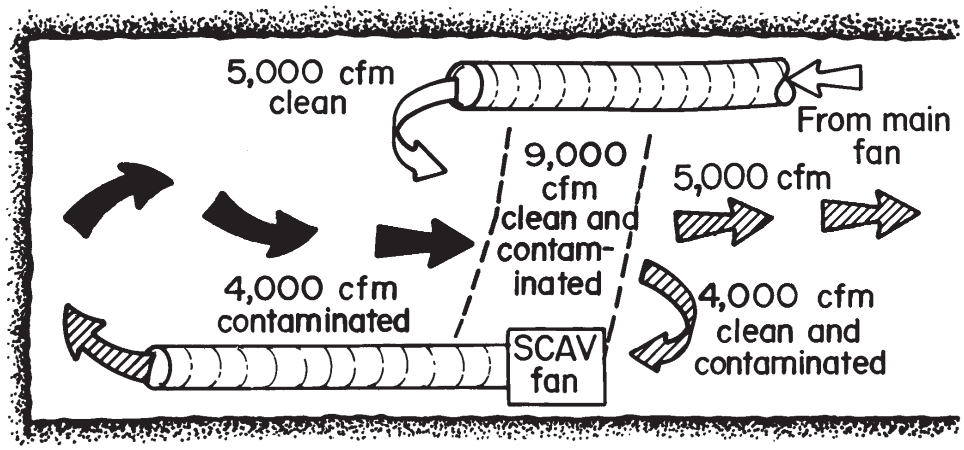

Figure 7-5.—Loss of ventilation efficiency from mismatched airflow directions.

collector duct. Because these two ducts have similar air quantities moving in opposite directions, there is a zone of low air movement between them. Therefore, dust sources in this zone can produce high dust concentrations.

It should be noted that if the scavenger fan duct shown in figure 7-6 moved air in the opposite direction, the air quantity delivered to the immediate face area would be increased from 5,000 to 10,000 cfm, and the amount of air moving through the zone between the ducts would be 10,000 cfm.

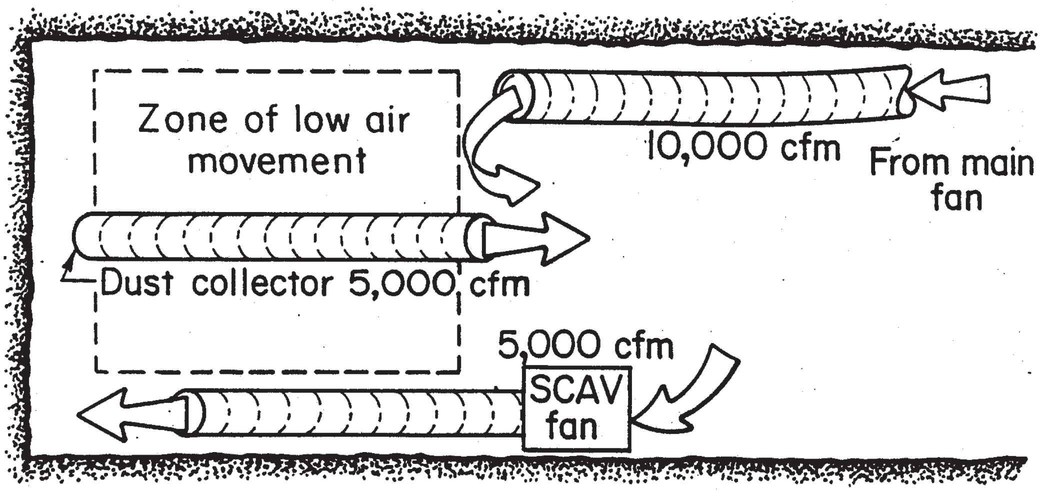

Figure 7-6.—Zone of low air movement is created because ducts have similar air quantities moving in opposite directions.

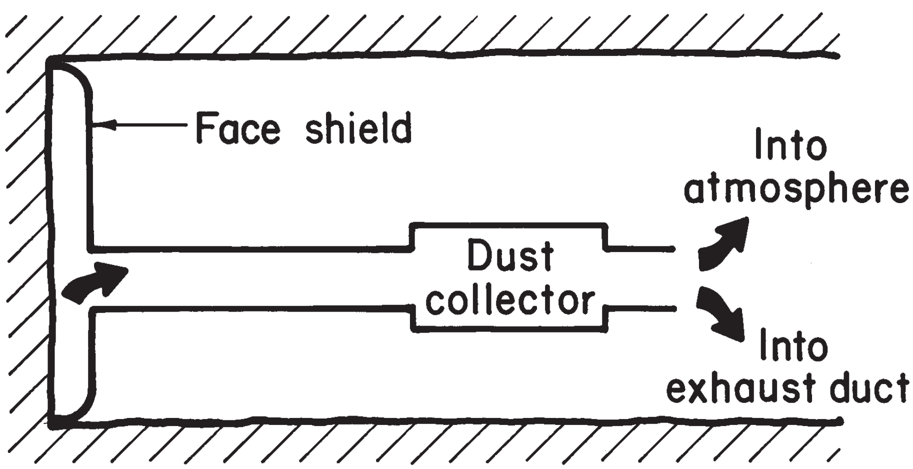

Figure 7-7.—TBM dust collection system.

Checking the dust collector. Most dust is removed via the dust collector system (figure 7-7), so it is important that the system works properly. Dust collectors in mines and tunnels can be high-maintenance equipment. Screens and filters often clog. Gaskets disappear, and access doors leak. Ductwork leading to the collector fills with coarse particulate that cuts off the airflow. Fans located on the inlet side of the collector suffer rapid erosion of their blades. Filters can be improperly seated, with air leaking around them. Filters also develop holes from abrasion by larger sized particulate. A dust sample and an air quantity measurement taken in the collector outlet will reveal if the filters are working properly and whether the air quantity is adequate.

UPGRADING THE DUST CONTROLS

Upgrade the other dust controls when checks of the ventilation and dust collector show no correctable problems. The water spray system should adequately wet the broken rock. The dust controls on the drills and conveyor should also be upgraded if they are sources of dust. Consider using foam to control dust.

Water sprays. Water sprays have two roles: (1) airborne capture and (2) surface wetting of the broken rock. Of the two, airborne capture is less effective. The typical water spray gives no more than 30% capture of respirable dust [Courtney and Cheng 1977]. Because of this, adequate surface wetting of the broken rock is most important. The vast majority of dust particles created during breakage are not released into the air, but stay attached to the surface of the rock [Cheng and Zukovich 1973]. Wetting the broken rock ensures that the dust particles stay attached. A key factor is the uniformity with which the rock is wetted [Hamilton and Knight 1957]. For example, in coal mining, releasing water near the cutting picks of rotating shearer drums is far more effective at suppressing longwall dust than external sprays on the shearer body, because the rotating drums act to mix the coal and the water. Increasing the number of sprays can also promote uniformity of wetting. For example, Bazzanella et al. [1986] showed that dust suppression is improved by increasing the number of sprays on a shearer drum, even when the total water flow and nozzle pressure were held constant by using smaller orifice nozzles. Increasing the number of nozzles on the drum from 17 to 46 lowered respirable dust by 60%. This is better than the dust reduction afforded by most other techniques.

The lessons from this knowledge are twofold. First, it is best to fully wet the material during the breakage process. This is when most mechanical mixing is likely to take place, and it ensures that the benefits will carry over to any downstream secondary handling operation. Because of this improved mixing, it is better to have an additional 30 gpm at the cutter head than to have 10 gpm at each of three conveyor transfer points downstream. Also, it gives more time for the water to soak in and the excess to drain away. Second, best uniformity of wetting is achieved by using more nozzles at lower flow rates and ensuring that the nozzles are aimed at the broken material rather than just wetting an adjacent metal or rock surface.

As little as 1% of moisture on dry rock significantly reduces dust. However, since it is hard to achieve a uniform application of such a low moisture level underground, the best moisture content might be as high as 5%. Whether this much water is always practical is another matter, so one should ensure that the water is being uniformly applied before automatically raising the flow rate. For instance, on a TBM, sprays located on the rotating head will be more effective than fixed sprays at the crown, and sprays aimed to intercept the falling muck will be more effective than those aimed at the uncut face. One way to improve the airborne capture of water sprays is to raise the pressure to 500 psi or more. However, a marked disadvantage of high-pressure sprays is that they entrain large volumes of air. This can lead to more dispersal of dust than is captured. Because of this, their application is limited to enclosed or semienclosed spaces, such as the cutting head area of a TBM.

Aside from efforts to improve spray effectiveness, one of the most helpful actions a contractor can take is to provide some automatic feature that turns sprays on and off as needed. This allows sufficient wetting while helping to avoid the problems associated with overuse of water. If the dust standard is below 1 mg/m^3 because of silica, then spray water should be clean because the evaporation of dirty water can release dust from dissolved minerals. Frequent clogging of spray nozzles from particulates in the water line can also be a problem. In such cases, water line filtration can reduce clogging.

Control of drill dust. It is better to control drill dust at the source than to depend on ventilation to carry the dust cloud away. Drill dust controls can be particularly effective. The best method is to introduce water through a hollow drill stem [ILO 1965; Page 1982]. Less effective are water sprays at the collar of the hole and dry dust collectors that capture the dust cloud near the collar and filter it out [Page and Folk 1984]. Most failures of drill dust controls are readily found and corrected. Rather than mechanical breakdown of the controls, malfunctions generally result from oversights such as a failure to turn on water or to service clogged filters.

Control of conveyor dust. Conveyor belts can generate large amounts of dust. Methods to deal with belt dust are well known [Goldbeck and Marti 1996; Swinderman et al. 1997]. The following questions must be addressed if belt dust is high.

1. Are transfer points enclosed? A simple enclosure with a spray or two inside of it may be adequate. If this is not enough, the air inside must be exhausted to a dust collector or ventilation duct, with all of the leakage points on the enclosure sealed properly [Swinderman et al. 1997].

2. Is the material being conveyed adequately wet, but not so much that it leaves a sticky mud residue on the belt? When this residue dries, dust is released. Thus, an end result of excessive wetting can be an increase in belt dust.

3. Are the undersides of both the top and the bottom belts being wetted [Ford 1973] so that dust sticking to the belt is not shaken loose by the idlers? Does the belt stay wet or is it drying out and releasing dust?

4. Are the belt scrapers working properly? Is a second set of scrapers being used? Has a belt washing system been installed [Bennett and Roberts 1988; Stahura 1987]?

5. Is the belt running true and not spilling its contents [Swinderman et al. 1997]?

More information on conveyor belt dust control can be found in chapter 6 on hard-rock mines. See page 86.

Foam. The use of foams for dust control has been studied extensively in coal mines. Here, foam works better than water, providing dust reductions in the 20%-60% range compared to water. Foam also can produce similar results at lower water use. Seibel [1976] compared 15-20 gpm of high-expansion foam to 19 gpm of water at a belt transfer point. Compared to water, the foam averaged 30% more dust reduction. Mukherjee and Singh [1984] found that foam released from a longwall shearer drum cut the dust 50% compared to conventional sprays on the drum. Also, the system used only half the water. The drawback of foam is high cost.

The benefits of improved mixing and uniformity of wetting have also been obtained with foam. Foam effectiveness was far greater when it was mechanically mixed in with the coal [Mukherjee and Singh 1984] or silica sand [Volkwein et al. 1983]. Page and Volkwein [1986] have published a comprehensive review of foam for dust control in mining and minerals processing.

DESIGN STAGE VENTILATION PLANNING

- **The quantity of air needed for dust control**
- **Whether to use exhaust or blowing ventilation**

When tunnel excavation is underway, major ventilation upgrades are usually not practical. However, for tunnels in the design stage, sufficient airflow must be planned into the design. Ideally, ventilation systems should be designed to achieve 100 ft/min air velocity throughout the tunnel, including the TBM and its trailing gear. This 100 ft/min must be regarded as a minimum if the rock has over 10% of crystalline silica. For large-diameter tunnels, 60 ft/min is the minimum. Other considerations, such as dilution of methane gas or diesel fumes, may require higher velocities.

Whether to use exhaust or blowing ventilation is always a key issue. Within the region of the TBM and trailing gear, exhaust ventilation is best for dust control. When exhaust ventilation is used, the zone of low air movement between the ventilation and dust collector ducts (see figure 7-6) is avoided, and both systems work together to maximize fresh air delivery. Between the rear of the trailing gear and the portal, the main ventilation system could be either exhaust or blowing. If the main ventilation system is exhaust, then the ventilation and dust collector ducts from the trailing gear must feed directly into it. If the main system is blowing, then some overlap with the TBM trailing gear systems must be maintained, as shown in figure 7-3.

Ventilation estimates must consider a realistic estimate of air leakage in the ductwork. In planning a tunnel ventilation system, a duct leakage of 20%-50% can be expected. The most common mistake in ventilation system design is the failure to consider enough leakage. Contractors should avoid using flexible, spiral-wound ventilation duct for any purpose other than as a short connection between sections of rigid metal duct. The pressure drop in spiral-wound duct is very high compared to smooth metal duct.

Finally, designers of ventilation systems must also plan to extract a sufficient quantity of air from the cutter head area behind the dust shield in order to prevent dusty air from leaking out. Myran [1985] has given the following recommendations on the amount of air that should be extracted:

Tunnel diameter, ft	Airflow range, cfm
10	4,000-6,000
15	7,000-10,000
20	12,000-17,000
25	19,000-26,000

These airflows can be hard to achieve because they require large fans and ductwork, not to mention large dust collectors. Why such high airflow from what is presumably an enclosed space? First, the stirring action of the large rotating cutter head creates considerable source turbulence, which disrupts the normal inflow of air that acts to contain the dust. Second, there is far less enclosure of the cutter head than a casual inspection of a TBM would indicate. Depending on the TBM design, the entire belt conveyor access space can be wide open. Also, there is open space when the grippers at the head expand to press out against the tunnel walls. In addition to raising the airflow, dust reduction efforts have focused on reducing the open space available for the dust to leak out by enclosing the conveyor tunnel and by installing single or even double sets of rubber dust seals between the grippers and TBM body.

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CHAPTER 8.—HOW TO FIND THE MAJOR DUST SOURCES

By Fred N. Kissell, Ph.D.,[77] and Jon C. Volkwein[1]

In This Chapter

- ✓ Instruments for measuring dust
- ✓ How to calculate the amount of dust from a source
- ✓ How to get a valid concentration measurement
- ✓ Sampling to assess control technology effectiveness

When there is more than one source of dust, sampling may be required to find which dust sources are most significant. Then, efforts to reduce dust can be concentrated where they will have the most impact.

This chapter explains how to perform dust source sampling. It describes two kinds of instruments that are available and discusses their limitations. It explains how environmental variables such as concentration gradients, dust dilution, and production changes can impact dust measurements. It also suggests practical ways to improve the validity of dust source measurements under adverse conditions, such as high-velocity airflow or the presence of water mist in the air.

Dust source sampling at coal mine longwalls and at tunnels is more complicated. Chapters 3 and 7 have more information on sampling in those circumstances.

TWO KINDS OF INSTRUMENTS FOR MEASURING DUST

Gravimetric samplers. The conventional gravimetric sampler is a good device for measuring dust because it is the instrument used for compliance measurements. This dust sampler consists of an air pump, a small cyclone that separates out the respirable size fraction of the dust cloud, and a filter to collect the respirable dust.

In coal mines, the Mine Safety and Health Administration (MSHA)-approved gravimetric sampler uses a 10-mm Dorr-Oliver cyclone operating at an airflow of 2.0 L/min [30 CFR[78] 74 (2002)]. A correction factor of 1.38 is applied to make the results consistent with the U.K. MRE sampler, the instrument on which the 2.0 mg/m^3 coal dust standard is based.

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[78]*Code of Federal Regulations.* See CFR in references.

In noncoal mines, the gravimetric sampler uses a 10-mm Dorr Oliver cyclone operating at 1.7 L/min. No correction factor is applied, consistent with MSHA's metal/nonmetal regulations [30 CFR 57.5001 (2002)].

In tunnels under construction, Occupational Safety and Health Administration (OSHA) regulations [29 CFR 1910.1000 (2002)] apply, so any gravimetric sampler with an OSHA-approved cyclone operating at the recommended flow rate is satisfactory.

To get the best possible accuracy with gravimetric samplers, sampling pumps must be calibrated [MSHA 1999], the cyclones must be clean and the filters must be weighed accurately. For accurate filter weighing, the filters must be desiccated to remove moisture, and the weighing must be done in a temperature- and humidity-controlled room. Extra attention is required if the amount of silica is being measured. Page et al. [2001] found that when the dust mass on the filter is below 0.5 mg, the silica error climbs rapidly. In such cases, it may be necessary to sample with one filter for several shifts to accumulate sufficient mass on the filter.

Even when these precautionary steps are followed, gravimetric dust samplers do not give very precise results when used under field conditions. Recent testing [Kissell and Sacks 2002] has shown that the measured dust concentration has a relative standard deviation (RSD) averaging 12% when samplers are placed within a few inches of each other at a fixed site underground. Under poor sampling conditions, such as outside in the wind and rain, RSD values as high as 50% have been found for a filter mass as high as 3.5 mg [Page et al. 2001].

Direct-reading dust instruments. The most common direct-reading instruments measure dust using a light-scattering technique. These instruments are valuable for short-term relative comparisons, such as comparing dust levels with a fan turned on and then turned off or comparing dust levels at two adjacent locations. Direct-reading instruments can also discern if a background dust source will cloud data interpretation. However, since dust levels are constantly rising and falling as mining proceeds, multiple readings must always be taken to ensure that a representative dust level is being measured.

Dust concentration values from direct-reading instruments cannot be interpreted as absolute gravimetric values. Direct-reading instruments that use light scattering are too sensitive to shifts in the size distribution of the dust, as well as a host of other factors that cause errors [Williams and Timko 1984; Smith et al. 1987; Tsai et al. 1996]. In field use, when compared to gravimetric samplers, measurement errors of 100% in direct-reading dust instruments are not unusual [Page and Jankowski 1984]. These errors are especially high at concentrations under 0.5 mg/m^3.

Lastly, direct-reading dust instruments based on light scattering can be adversely affected by water mist in the air. Water mist causes them to show a dust level much higher than the actual level. Adding a mist eliminator designed by Cecala et al. [1985][79] can correct this problem. The

[79] A commercial version of the mist eliminator (Model 3062 Diffusion Dryer) is available from TSI, Inc., Shoreview, MN.

mist eliminator consists of a 24-in-long wire-mesh tube surrounded by calcium sulfate desiccant

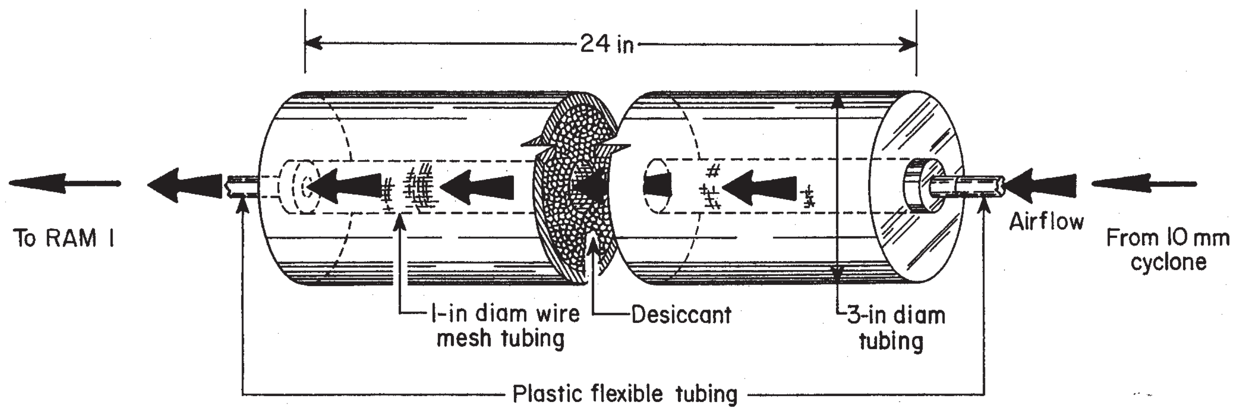

Figure 8-1.—Mist eliminator for direct-reading instruments that use light scattering [Cecala et al. 1985].

(figure 8-1). It is placed between the detector and the 10-mm cyclone used to preclassify the respirable size range and removes water mist without trapping dust.

The most useful direct-reading dust instruments collect a gravimetric filter sample along with an electronic record of the average light-scattering value. The users of such instruments can then make the comparisons needed to assess the validity of the light-scattering value.[80]

HOW TO CALCULATE THE AMOUNT OF DUST FROM A PARTICULAR SOURCE

Calculating the amount of dust from a particular source is not complicated. The dust concentrations upwind and downwind of the source are measured. Also, the volume of air passing the source is obtained by measuring the air velocity and cross-sectional area of the airway. The difference in the dust concentration values multiplied by the air volume gives the mass of dust generated by the source. This mass of dust can be calculated in terms of unit of time (mg/min) or unit of production (mg/ton), if production data are available [Volkwein 1979].

Another approach to calculating the amount of dust from a source is to turn the dust source on and off, if it is practical to do so. The dust concentration can be measured by a direct-reading instrument or by two packages of gravimetric samplers alternately turned on and off along with the dust source. The amount of dust produced by the source is then calculated from the difference in the readings. The problem is obtaining a valid concentration measurement.

[80]Currently, only one direct-reading sampler is approved for use in underground coal mines—the personal DataRAM made by Thermo Anderson, Smyrna, GA.

OBTAINING A VALID CONCENTRATION MEASUREMENT

Many environmental factors can invalidate dust source measurements.

To avoid sampling errors caused by environmental factors, review the following dust sampling checklist.

DUST SAMPLING CHECKLIST

1. Is there little to no airway concentration gradient?
2. Is the sampling location within 100 ft of the dust source?
3. Is there no air dilution between the dust source and the sampling location?
4. Is the air velocity past the source and past the sampling location at least 50 ft/min but not over 800 ft/min?
5. Is the type and amount of material mined during sampling representative of normal mining conditions?

If the answer to all of the above questions is "yes," then dust sampling may be done without further precautions other than keeping the instruments at least 3 ft above the mine floor.[81] If the answer to any question is "no" or "I don't know," then the following sampling precautions must be considered.

Checklist item No. 1: Sampling in airways with a concentration gradient. Many sampling locations have large concentration gradients. At such locations, the measured concentration changes as the sampler is moved. In fact, moving the sampler a foot one way or the other may change the dust concentration reading more than any other factor. For example, Kost and Saltsman [1977] showed that a gravimetric sampler located 3 ft in front of a continuous miner operator may indicate a respirable dust concentration twice that of the operator's, whereas only a few feet behind the operator the indicated concentration may be half. This reflects a concentration gradient observed by moving closer to or farther away from the dust source.

[81] People and passing equipment will kick up dust, making floor samples invalid.

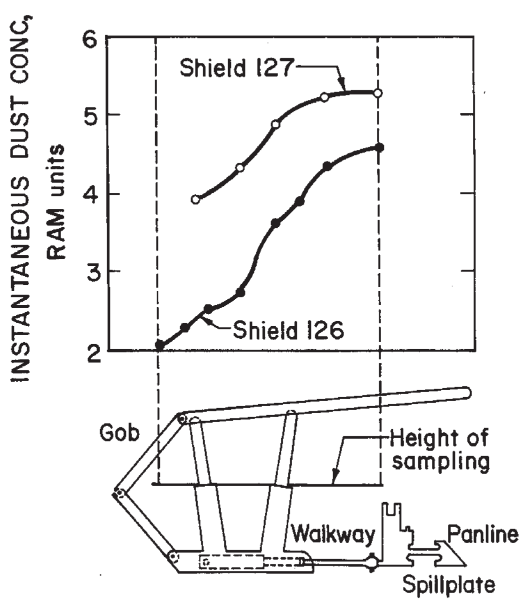

Figure 8-2.—Two gob-to-spillplate dust concentration gradients measured downwind of a longwall shearer [Kissell et al. 1986].

Other concentration gradients can be observed by moving from side to side in an airway. Such side-to-side concentration gradients exist because the dust cloud from the source has not fully mixed into the airstream.[82] The concentration gradient at longwall faces demonstrates this incomplete mixing. The disparity in concentrations depends on the distance between the source (the shearer) and sampling point. Figure 8-2 shows two cross-sectional concentration gradients measured at least 200 ft downwind of the shearer. Even at this distance, shearer dust, mainly in the panline and spillplate, has not dispersed equally into the walkway and area around the support legs.

Because concentration gradients are so common in underground operations, any sampling program to measure the amount of dust produced by a source should test for gradients first. This testing is accomplished by using a direct-reading instrument, moving it back and forth across the airway, or by using three or more gravimetric samplers spaced evenly across the airway. When concentration gradients are found, multiple samplers must be used to obtain valid results.

Checklist item No. 2: Sampling within 100 ft of the source to avoid dust deposition problems. A way to reduce the impact of dust gradients across mine entries might be to move farther downwind from the source so that the dust has more time to mix evenly into the airstream. However, this does not work in practice because turbulent deposition of dust particles causes a decrease in the concentration over relatively short distances. For example, in experiments on a 7-ft-high U.K. longwall face, Ford [1976] found that 45% of a 4-µm particle size dust cloud was deposited within a distance of 600 ft. At other longwalls where face heights were lower, deposition increased. In a U.S. study over a similar 600-ft distance in an uncluttered mine airway, Bhaskar et al. [1988] measured 38% deposition of respirable dust at air velocities over 300 ft/min and 67% deposition at an air velocity of 165 ft/min. Because of this high deposition rate, dust sampling aimed at calculating a source emission should be done within 100 ft of the source.

Checklist item No. 3: Sampling where air dilution has lowered the dust concentration. The validity of sampling results is also affected if the airstream being sampled is not representative of the dust source. For example, when sampling is done downwind of mining machines, the measured concentration is not always a reliable indicator of the amount of dust produced by that

[82]In some places, such as behind a coal mine line curtain, there may be a top-to-bottom gradient. Vertical gradients are likely when the air passage height is greater than the width, especially when the dust source releases heat.

machine. The intake air is likely to contain some dust even before it reaches the machine, so the amount of intake dust must also be measured and subtracted from the downwind measurement.

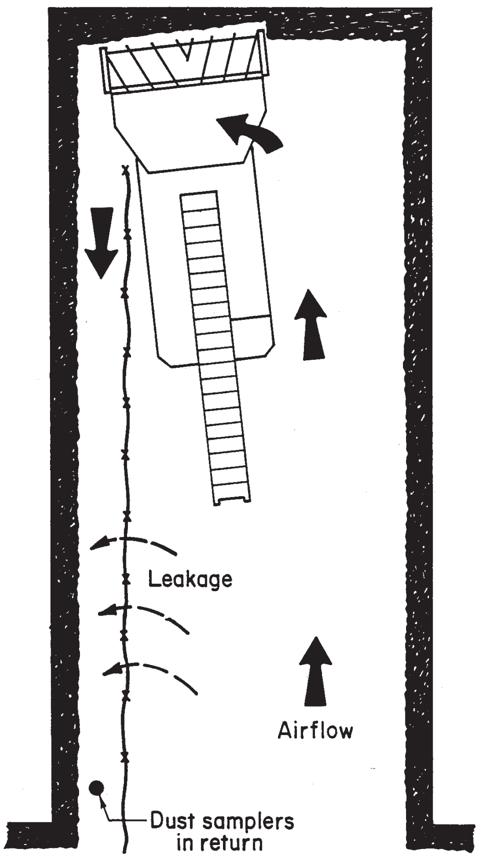

Figure 8-3.—Air in return diluted by line curtain leakage [Kissell et al. 1986].

Also, if air is gained or lost between the source and sampling point, corrections must be made. Line curtain leakage (figure 8-3), a common occurrence on continuous miner faces, is an example of how air is gained, thereby diluting the dust level measured in the return. As the heading advances, the amount of air gained will increase; in fact, a leakage of 50% is common. To calculate a machine dust emission rate in this case, it is necessary to multiply the measured concentration by the airflow at the sampling point. Comparisons can then be made on the basis of dust weight per unit time or per ton of material mined.

If air is lost between the source and the sampling point, no change in dust concentration will occur. However, the machine emission rate cannot be calculated unless it is known exactly how much air was lost.

Checklist item No. 4: Sampling in a low-velocity airflow under 50 ft/min. In workplaces where the airflow is less than 50 ft/min, the magnitude of the source can be *roughly* assessed by moving a direct-reading instrument alternately toward and away from it. This movement must be repeated many times, preferably from different directions, to ensure that any observed increases in dust level result from getting closer to the source rather than from an extraneous factor, such as a change in production.

Checklist item No. 4: Sampling in high-velocity airflow over 800 ft/min. In air streams with velocities up to 300 ft/min, neither the air velocity nor the cyclone inlet orientation has any impact on the dust concentration measured by the sampler [Caplan et al. 1973]. However, at air velocities over 300 ft/min, both the air velocity and the cyclone inlet orientation have an impact. Cecala et al. [1983] found that when the Dorr-Oliver cyclone inlet[83] is pointed directly into the wind, it oversamples when the air velocity exceeds 800 ft/min. At 2,000 ft/min, it oversamples by 35%. When the cyclone inlet is at a right angle to the wind or pointed downwind, it undersamples when the air velocity exceeds 300 ft/min.

[83]Strictly speaking, it is the vortex finder clamp that is pointed directly into the wind. The inlet enters the cyclone at a slight angle.

Cecala et al. [1983] also tested a shielded cyclone to see if a shield would reduce the over- and undersampling. The shield was a 1-in-wide strip of aluminum sheet bent into a cylinder. This cylinder was then wrapped around the top of the cyclone and bolted to the hole in the back of the vortex finder clamp (figure 8-4). Testing showed that the shield successfully reduced both the over- and undersampling to within 14% of the true value up to the highest velocity tested (2,000 ft/min).

Another way to sample high-velocity airstreams is to use an isokinetic probe, in which the velocity of the air entering the probe is matched to that of the airstream [Quilliam 1994]. However, because the equipment is more specialized and less portable, isokinetic sampling is more suited to labs and industrial sites than underground mines.

Checklist item No. 5: Sampling during changes in the type of material cut and changes in production. In coal mines, cutting rock bands in the coal will cause a wide variation in dust levels. A rock band is a band of rock, typically shale, layered within the coal seam. The amount of dust generated by cutting the rock band is much greater than that from cutting the coal, so even a minor rock band will cause dust levels to increase substantially.

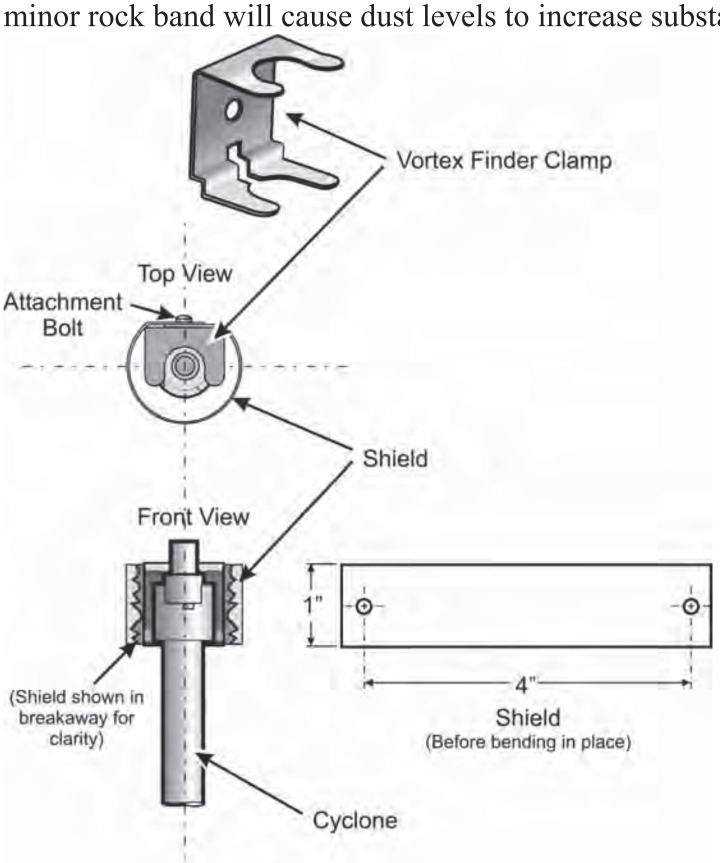

Figure 8-4.—Cyclone shield for high-velocity air streams.

Variations in production also cause substantial dust level changes. Shift-to-shift changes in production by a factor of two are common in all types of mines. Dust concentration values may be corrected for shift production when production changes are due to incidents such as equipment breakdowns. In this case, a lower shift dust concentration is due to less mining time. However, if shift production is low because of hard cutting through rock, dust levels may be higher due to the rock itself. If the concentration level data are then corrected for production, the errors will be magnified greatly. The only course of action is to sample when the type and amount of material mined are representative of normal mining conditions.

In-depth information on dust instrumentation and measurements can be obtained from Baron and Willeke [2001]. Raymond [1998] describes the equipment and procedures used by MSHA to maintain a modern dust sample weighing facility. Parobeck and Tomb [2000] describe MSHA procedures to measure the silica content of mine dust samples.

SAMPLING TO ASSESS CONTROL TECHNOLOGY EFFECTIVENESS

Most mine operators depend on compliance sampling to assess whether any control technology that they installed works as promised. Although the methods described above require more effort, they are a better way to measure control technology effectiveness simply because it is easier to measure a change in a dust source when that source is isolated from other dust sources. However, it pays to keep in mind that the relative standard deviation of gravimetric samplers under typical field conditions is 12%. Additional error is contributed by environmental variables such as production changes and concentration gradients. In addition to these errors, the evaluation of a dust control method is constrained by the combined error of measurements with and without controls. For these reasons, assessment of dust control effectiveness is limited to those technologies that give at least a 25% change in dust levels.

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CHAPTER 9.—DUST RESPIRATORS IN MINES AND TUNNELS

By Fred N. Kissell, Ph.D.,[84] and William A. Hoffman[85]

In This Chapter

- ✓ MSHA regulations for coal mines
- ✓ MSHA regulations for metal/nonmetal mines
- ✓ OSHA regulations for tunnel construction
- ✓ Types of respirators used in mines and tunnels
- ✓ Filter materials and filter efficiencies
- ✓ Donning, seal checking, and maintenance
- ✓ Filter service life

and

- ✓ Respirator information resources

In many cases, engineering controls are not adequate to achieve satisfactory dust levels, so respirators must be used. This chapter explains the Federal regulations governing the use of dust respirators in mines and tunnels and describes the most common dust respirators used. Filter materials and filter efficiencies for respirators are discussed. This chapter also gives some guidelines for respirator use and recommends sources for more dust respirator information. Respirator effectiveness in reducing dust exposure usually exceeds the effectiveness of most engineering control methods.

RESPIRATOR REGULATIONS

Different regulations govern respirator use in coal mines, metal/nonmetal mines, and tunnels under construction.

Coal mines under Mine Safety and Health Administration (MSHA) jurisdiction. Coal mine operators are required to meet dust standards using only engineering control methods. Typical engineering control methods include ventilation and water sprays. Respirators are not regarded as an engineering control method, so respirators cannot be used in lieu of engineering controls.

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However, if dust levels exceed the 2.0 mg/m^3 coal dust standard,[86] approved respirators must be made available[87] to workers [30 CFR[88] 70.300] while new engineering controls are being instituted. Respirators must also be provided to workers exposed to high-inhalation hazards for short periods.[89]

Coal mine operators may also choose to establish a respiratory protection program, as set forth by the American National Standards Institute (ANSI Z-88.2-1969)[90] [ANSI 1969; 30 CFR 72.710]. Such programs must include written procedures containing provisions for training, fit-testing, maintenance, recordkeeping, and a requirement that users be clean-shaven [MSHA 1995]. According to MSHA, if there is a respiratory protection program, the existence of such a program may form the basis for further extensions of abatement times or help to create an argument that a violation is less serious. However, a program will not prevent the issuance of citations for exceeding the dust standard.

Metal/nonmetal mines under MSHA jurisdiction. MSHA metal/nonmetal regulations are somewhat less restrictive than the coal regulations. Removal of dust by engineering controls remains the required method. However, when accepted engineering control measures have not been developed or when the dust standard is exceeded on an occasional basis, respiratory equipment may be used without a citation being issued, provided that all of the following requirements are met:

1. The respirators used must be approved by NIOSH under 42 CFR 84.
2. A respiratory protection program, as set forth by ANSI Z-88.2-1969 [ANSI 1969], is or has been instituted [30 CFR 56.5005; 30 CFR 57.5005].
3. When respiratory protection is used in atmospheres immediately dangerous to life, a second worker with backup equipment and rescue capability is required.

Tunnels under Occupational Safety and Health Administration (OSHA) jurisdiction. Under OSHA, engineering controls are also the required method of dealing with dust. However, OSHA regulations permit respirators to be used in place of engineering controls if engineering controls are not feasible or while engineering controls are being instituted [29 CFR 1910.134(a)(1)].

If respirators are used, a respiratory program is required to ensure that respirators are used properly and employees are protected [29 CFR 1910.134(c)]. This program has several required elements. The major ones are [OSHA 1998a]:

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[86]If the coal contains silica, the standard is lowered according to a formula prescribed by MSHA.
[87]Operators must also maintain a supply of respirators consistent with this need.
[88]*Code of Federal Regulations.* See CFR in references.
[89]In the MSHA program policy manual, the term "short periods" is interpreted as the time required to drill three or four holes for trolley hangers, to drill shot holes in a roof fall, etc.
[90]The current version is ANZI-88.2-1992, but the MSHA regulations are based on the 1969 version.

1. A worksite-specific document explaining the respiratory protection program.
2. Selection of a designated administrator who is qualified to oversee the program.
3. A medical evaluation to determine the employee's ability to use a respirator.
4. Fit-testing of respirators to ensure minimal leakage.
5. Training in respirator use and care, particularly "user seal checks" by the wearer.

The OSHA "Voluntary Use" Program. For workplaces that are in compliance with dust standards, employers can permit their workers to wear air-purifying respirators under a "voluntary use" arrangement if they choose to do so [29 CFR 1910.134(c)(2)]. In this case, a program document, a medical evaluation, and respirator maintenance are all still required. No training is required [OSHA 1998b], but employees must be provided with advisory information [29 CFR 1910.134 appendix D]. Fit-testing is not necessary [OSHA 1998c], and less experience is required of the program administrator.

Some of the voluntary use program requirements (program document, medical evaluation, and respirator maintenance) do not apply to workers who voluntarily use dust masks [OSHA 1998b]. However, users of dust masks must be provided with the advisory information in 29 CFR 1910.134 appendix D.

TYPES OF RESPIRATORS USED IN MINES AND TUNNELS

Mine operators usually choose half-mask respirators, dust masks, or air helmets equipped with particulate filters.[91] Half-mask respirators and dust masks are convenient for confined surroundings. Air helmets are suitable when more space is available, such as at longwall faces in high coal.

Half-mask replaceable-filter respirators. Half-mask replaceable-filter respirators (figure 9-1), also known as reusable half-masks, consist of a filter-holding unit, fabricated from molded plastic or rubber, that contains intake and exhaust valves. Soft rubber is used to form a facepiece around the filter-holding unit, which forms a seal against the wearer's face. This seal prevents dust-laden air from bypassing the filter as the user inhales. *If* the facepiece seal is leak-tight, the respirator should remove 90% or more of the respirable dust.

[91] All must be NIOSH-approved under the requirements of 42 CFR 84. The half-mask replaceable filter respirators and the dust masks are classified as "air-purifying respirators" (APRs); the air helmet is classified as a "powered air-purifying respirator" (PAPR) because it is powered by a small fan.

Although the half-mask replaceable-filter respirators do a reasonable job of dust removal when the facepiece seal is leak-tight, the seal can occasionally cause skin irritation. These respirators also interfere with conversation and may interfere with eyeglasses or goggles.

Figure 9-1.—Half-mask replaceable-filter respirator.

Many different types of filter materials are available for half-mask respirators. Some filter materials are degraded by oil mist. The replaceable filter cartridges are designated according to their level of oil resistance, as follows:

Type **N** filters are **N**ot resistant to oil;
Type **R** filters are oil-**R**esistant up to one shift; and
Type **P** filters are oil-**P**roof.

For coal dust or for mineral dusts such as silica, any of these types of filters is satisfactory. Some mines have oil mist sources; the most common are percussion drills. These mines should use type R or type P filters.

The dust (or mist) collection efficiency of filter materials also varies; the efficiency is specified along with the oil resistance. Filter cartridges are available in three efficiency levels: 95%, 99%, and 99.97%, designated as 95, 99, and 100. For example, an N95 filter is 95% efficient; an N100 filter is 99.97% efficient.

Actually, filter efficiencies for respirable dust are much higher than the specified filter efficiency. This is because the specified filter efficiencies are measured using the size of particles that are most likely to get through the filters—about 0.3 μm in diameter. Most respirable dust is larger than this, which makes it easier to filter. Thus, a filter that is 95% efficient for 0.3 μm particles will exhibit a much greater efficiency for respirable dust.

The most commonly purchased filter types are N95s and P100s. Type 95 filters usually have a lower cost and lower breathing resistance than type 100 filters.

While filter efficiencies may be very high, it does not follow that workers are protected with the same degree of efficiency.[92] For instance, the rule-of-thumb efficiency for half-mask respirators is 90% for respirators that give a good fit. This is lower than the filter efficiency because some leakage at the seal against the wearer's face usually occurs. For example, during one respirator

[92] Keep in mind that efficiency numbers quoted in respirator catalogs only refer to filter efficiency.

evaluation program [Cole 1984], half-mask respirators were tested on four longwall sections. The dust exposure of workers was reduced by 92%.

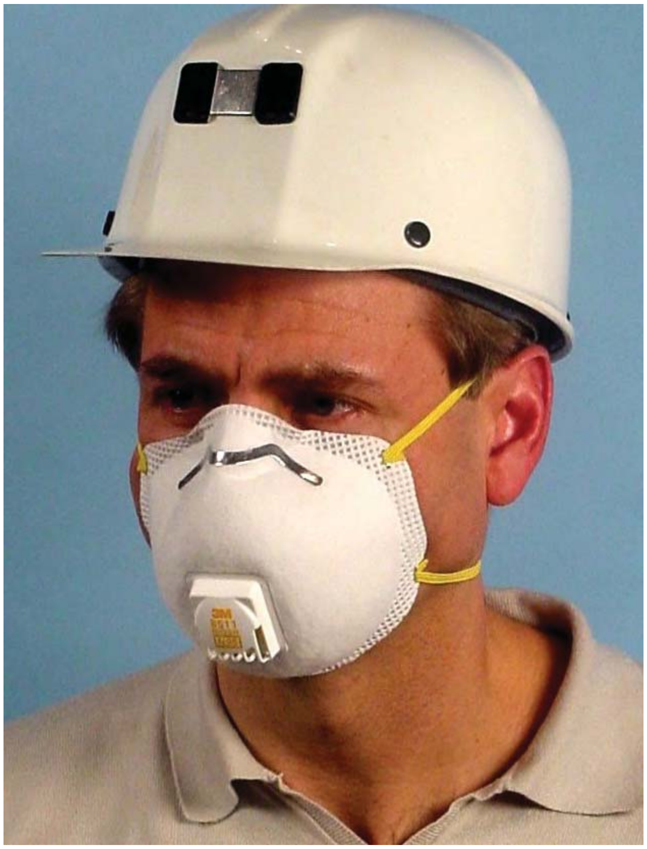

Figure 9-2.—Dust mask, also called a filtering face-piece.

Dust masks. Dust masks (also known as filtering facepiece respirators) (figure 9-2) have a lighter and simpler design than half-mask respirators. The entire mask is fabricated from filter material and covers the mouth and nose, similar to a surgical mask. Dust masks offer some advantages compared to the replaceable-filter respirators. In particular, they are more comfortable and require no maintenance. However, dust masks usually do not form as tight a seal against the wearer's face as half-masks with soft rubber seals, which allows more leakage. As a result, they are often much less effective than half-masks.

Dust masks are certified by NIOSH under the 42 CFR 84 respirator certification tests. These standards only require a test of the filter material and do not assess how well the mask seals against the wearer's face. As a result, this certification is no guarantee that the mask will perform well. In a recent study of dust masks [CDC 1998], the average dust reduction was only 67%.[93]

In the mining industry, half-mask respirators are used far more than dust masks because their dust reduction efficiencies are much higher.

Air helmets. The air helmet (figure 9-3) is a redesigned hard hat equipped with a battery-powered fan, filtering system, and face visor, thus providing protection for the head, lungs, and

[93]The study got much better results after fit-testing was performed, and individuals who failed the fit-test were dropped from the study. The authors of the study then concluded that fit-testing was necessary if dust masks were to be used. Nevertheless, any organization that goes to the trouble and expense of fit-testing its workers is better off with half-mask replaceable-filter respirators.

The 67% figure for dust masks is low compared to other types of respirators, but it is still better than the dust reduction produced by many engineering controls.

eyes within one unit. Other advantages are a lack of breathing resistance, the ability to accommodate facial hair, and no fit-testing requirement for their use.

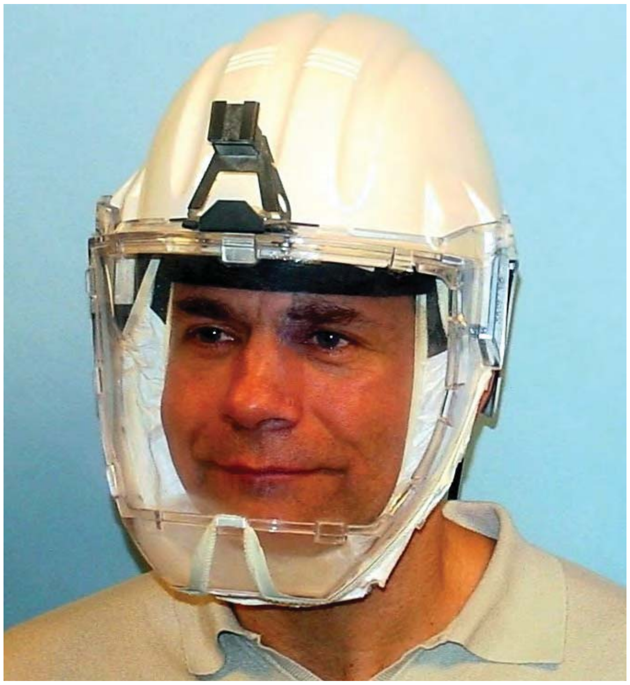

Figure 9-3.—Air helmet.

Although air helmets are slightly larger and heavier than conventional hard hats (they typically weigh about 3 lb), wearer acceptance has been favorable in high coal seams (particularly at longwalls) and in many hard-rock mines.

A small fan is mounted in the rear of the helmet to draw dust-laden air through a filtering system. The filtered air is directed behind a full-face visor and over the wearer's face. Exhaled air and excess clean air exit the helmet at the bottom of the face visor. Face seals are provided along both sides of the visor to limit contamination from outside air. The fan is externally powered by a rechargeable battery worn on the miner's belt. Filter life varies from one to eight shifts depending on the dust level at the worksite [Parobeck et al. 1989].

The effectiveness of the air helmet depends in part on the mine air velocity outside of the helmet and the direction of air impact on the helmet [Cecala et al. 1981], because high air velocities push dust particles past the face seals. For example, at a longwall face with an air velocity of less than 400 ft/min, air helmets reduced respirable dust by an average of 84%. However, at another longwall with an air velocity of 1,200 ft/min, the air helmet was not as effective; dust reduction averaged 49%. In both cases, the sampling included some periods when the face visor was raised. Raising the visor reduces the helmet's effectiveness.

RESPIRATORS FOR DIESEL EXHAUST

Diesel exhaust, both the particulate and the organic vapors, have become more of a concern in recent years. Half-mask respirators will filter both the diesel particulate and the organic vapors when equipped with the proper cartridge or cartridge combination. A common cartridge designnation is Organic Vapor/P100, or OV/P100. Half-mask respirators will not protect the eyes from irritating fumes. Eye-irritating fumes are best handled by installing a catalytic converter on the engine [Schnakenberg and Bugarski 2002].

DONNING, SEAL CHECKING, AND MAINTENANCE

When putting on the respirator, the wearer should follow the manufacturer's instructions. Comfort is as important as a tight seal. The wearer may need to try different size respirators or respirators from different manufacturers before finding one that conforms to his or her facial structure.

Once a respirator is donned, a seal check is necessary to ensure there are no leaks that would degrade the respirator's effectiveness. Either the positive- or negative-pressure check described below[94] or the respirator manufacturer's recommended user seal check method must be performed.

Seal checking is important for a respirator to be effective.

Positive-pressure seal check. To perform a positive-pressure seal check, the wearer closes off the exhalation valve and blows gently into the facepiece. The face fit is satisfactory if a slight positive pressure can be built up inside the facepiece without any evidence of outward leakage of air at the seal. For most respirators, this method of leak testing requires the wearer to first remove the exhalation valve cover before closing off the exhalation valve.

Negative-pressure seal check. To perform a negative-pressure seal check, the wearer closes off the inlet opening of the canister or cartridge by covering it with the palm of the hand or by replacing the filter seal. Next, the wearer inhales gently so that the facepiece collapses slightly, then the breath is held for 10 sec. If the facepiece remains in its slightly collapsed condition and no inward leakage of air is detected, the tightness of the respirator is satisfactory. However, the inlet opening of some filter cartridges cannot be sealed with the palm of the hand. In such cases, the test can be done by covering the inlet opening of the cartridge with a thin latex glove.

During the seal check, the respirator wearer should pay the most attention to the region around his or her nose because it is the most likely place for leaks. Also, there should be no interference with eyeglasses.

Respirator maintenance. Basic respirator maintenance is simple. The wearer should check to ensure that the filter cartridges are undamaged, the inhalation and exhalation valves are in working order, no straps are slipping or broken, there are no tears or deformities in the facepiece, and the respirator is reasonably clean.

FILTER SERVICE LIFE

Regular replacement of filters is an important part of respirator use [NIOSH 1997]. Normally, filters should be replaced when breathing resistance increases. Another approach is to replace filters when the filter loading reaches 200 mg of dust. Using this filter loading approach, if a

[94]From OSHA regulations at 29 CFR 1910.134 appendix B-1: User Seal Check Procedures.

worker breathes 10 m^3 per shift and the dust concentration is 5 mg/m^3, the loading is 50 mg per shift, or 25 mg per filter if there are two filters. The two filters would then be good for eight shifts.
If oil mist is present, N-series filters should not be used. R-series filters should be used for one shift, and P-series filters should be changed in accordance with the manufacturer's recommendations.

RESPIRATOR RESOURCES

Many organizations on the Internet are good sources of information on respirators and respiratory protection programs.

NIOSH has respirator publications at www.cdc.gov/niosh/respinfo.html. The two most useful are the *NIOSH Guide to the Selection and Use of Particulate Respirators Certified Under 42 CFR 84* [NIOSH 1996] at www.cdc.gov/niosh/userguid.html and the *NIOSH Guide to Industrial Respiratory Protection* [Bollinger and Schutz 1987] at www.cdc.gov/niosh/87-116.html.

OSHA has a downloadable *Small Entity Compliance Guide for the Revised Respiratory Protection Standard* at www.osha.gov/Publications/secgrev-current.pdf. Also, OSHA has a series of photographs that can be used for training at
www.osha.gov/RespiratorOutreach/Powerpoint/Html/RespStd/sld001.htm.

The International Safety Equipment Association provides a useful buyer's guide at www.safetyequipment.org. The International Society for Respiratory Protection (www.isrp.com.au) provides information on respiratory protection. The society publishes a quarterly journal and convenes periodic conferences.

In addition to publications on the Internet, the American Conference of Governmental Industrial Hygienists (www.acgih.org) sells a *Respiratory Protection Program and Record Keeping Kit* as publication No. 9278CB. The American Industrial Hygiene Association (www.aiha.org) sells *Respiratory Protection: A Manual and Guideline* as stock No. 439-PC-01.

Respirator fit-testing and other respirator-related services are readily available for hire.

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COMMONWEALTH OF KENTUCKY

BEFORE THE PUBLIC SERVICE COMMISSION

In the Matter of:

INVESTIGATION OF KENTUCKY UTILITIES	**)**	
COMPANY'S AND LOUISVILLE GAS AND	**)**	**CASE NO. 2015-00194**
ELECTRIC COMPANY'S RESPECTIVE NEED	**)**	
FOR AND COST OF MULTIPHASE	**)**	
LANDFILLS AT THE TRIMBLE COUNTY	**)**	
AND GHENT GENERATING STATIONS	**)**	

REBUTTAL TESTIMONY OF
DAVID S. SINCLAIR
VICE PRESIDENT, ENERGY SUPPLY AND ANALYSIS
KENTUCKY UTILITIES COMPANY AND
LOUISVILLE GAS AND ELECTRIC COMPANY

Filed: September 10, 2015

Q. Please state your name, position and business address.

A. My name is David S. Sinclair. I am Vice President, Energy Supply and Analysis of Kentucky Utilities Company ("KU") and Louisville Gas and Electric Company ("LG&E") and an employee of LG&E and KU Services Company, which provides services to LG&E and KU (collectively "Companies"). My business address is 220 West Main Street, Louisville, Kentucky 40202. I submitted direct testimony in this proceeding on August 6, 2015, which contained a statement of my qualifications, experience, job responsibilities, and previous testimony before the Commission.

Q. What is the purpose of your rebuttal testimony?

A. The purpose of my testimony is to rebut John Walters's testimony on behalf of Sterling Ventures ("Sterling"). In his direct testimony, he is simply incorrect that: (i) it was uneconomical for the Companies to dispose of gypsum from the Ghent plant at an on-site landfill rather than shipping it to Sterling's mine for disposal; (ii) disposing of Trimble County's coal combustion residuals ("CCR") at Sterling's mine is less expensive than at an on-site landfill; and (iii) this Commission should revoke the previously granted certificate of public convenience and necessity ("CPCN") to build the CCR landfill at Trimble County and the associated transportation facilities to move CCR from the treatment facility to the landfill. I will demonstrate that his analysis is in error and that accepting his recommendations to this Commission would increase costs and impair the ability of the Companies to reliably serve our customers' electricity needs.

Q. Are you sponsoring any exhibits?

A. Yes. I am sponsoring the following exhibit to my rebuttal testimony, which is a collection of six analysis and work-paper Excel files. One of the files does not contain confidential information and is being filed publicly with my testimony; the other five files contain confidential information and are being filed subject to a petition for confidential protection that is also being filed with the Commission today:

Rebuttal Exhibit DSS-1	Collective exhibit of the Companies' PVRR analysis and work-papers re Sterling Ventures' Warsaw barge-unloading proposal

<u>Ghent CCR Disposal</u>

Q. Do you agree with the assertion in Mr. Walters's direct testimony that sending Ghent's gypsum to Sterling would have saved KU's customers a "substantial amount of money"?[1]

A. No. Mr. Walters's conclusion is based entirely on the presumption that KU could have maintained and utilized Ghent's existing gypsum stack in perpetuity, thus avoiding approximately $53 million in capital expenditures on gypsum CCR treatment facilities and $9.5 million in annual O&M expenses related to disposing of the gypsum in the on-site landfill.[2] As Mr. Voyles states in his rebuttal testimony, constructing the CCR treatment facility for gypsum was necessary to address long-term environmental and operational risks associated with the gypsum stack.[3] Therefore, Mr. Walters is simply incorrect to assert that the gypsum stack could have

[1] Walters Direct Testimony, page 5, lines 18-21.
[2] *Id.*
[3] Voyles Rebuttal Testimony at 10-11.

been operated in perpetuity, thus avoiding the construction of new gypsum treatment and handling facilities.

I would also point out that Mr. Walters fails to mention in his testimony that to achieve the alleged O&M savings, it would cost approximately $10.7 million annually to move gypsum from Ghent to the Sterling mine. Therefore, using the Sterling mine to dispose of Ghent's gypsum beginning in 2012 would have cost the Companies $1.2 million annually ($10.7 million less $9.5 million) in net O&M costs.

Q. Do you believe it was appropriate for the Companies to continue with the Ghent gypsum-related projects and the Ghent landfill project in general after receiving Sterling's offer in late 2011?

A. Absolutely. In 2009 the Companies performed a robust analysis of the need for CCR storage at Ghent, including gypsum, which was the foundation for the 2009 ECR plan approved by the Commission. Once approved, the Companies proceeded to begin executing on that plan. Even though engineering, procurement, and construction was underway on the gypsum-related projects by late 2011, the Companies thoroughly evaluated Sterling's offer and concluded that it was not a least-cost option.

The Companies' decision to continue with the Commission-approved Ghent landfill project was therefore prudent, and Sterling's proposal to dispose of Ghent's gypsum at its facility was not the least-cost alternative, despite Mr. Walters's protestations and flawed analysis.[4]

Q. In his discussion of Ghent in his direct testimony, Mr. Walters questions the Companies' ability to properly calculate revenue requirements using Strategist by comparing its results to the revenue requirements the Companies presented

[4] Sinclair Direct Testimony page 6, lines 15-21.

to the Commission as part of their obligation to provide ECR billing impacts. Do you agree with his conclusions?

A. Certainly not. Mr. Walters asserts that the lower first-year annual revenue requirements from the Companies' ECR bill impact analysis compared to the first-year annual revenue requirements shown in the revenue requirement analysis used to justify the Ghent landfill somehow indicates a problem with the Companies' cost-benefit analysis supporting the project. This alleged inconsistency is actually the result of different book-life assumptions for the landfill between the two analyses; it is not an indication of a problem with the Strategist model, the Companies' ability to use it, or the Commission's reliance upon it when evaluating this case. As I explained in response to Sterling Ventures' Supplemental Data Request No. 10 ("SV 2-10"), although a project's assumed book life can have a material impact on revenue requirements in any given year, it does not have a material impact on the present value of capital revenue requirements when comparing alternatives over their full lives. Therefore, because the Companies' cost-benefit analysis supporting the Ghent landfill assumed a shorter book life, its first-year revenue requirements are naturally greater than the ECR bill impact analysis, which assumed a longer book life. But that difference in assumptions neither supports an assertion that the Strategist model or the Companies' use of it produces inaccurate results, nor does it undermine the Companies' conclusion that proceeding with the Ghent landfill project was lower-cost than disposing of Ghent's gypsum in Sterling's mine.

Q. What is your recommendation concerning Mr. Walters's request that the Commission should disallow certain cost recovery for the Companies related to the Ghent landfill?

A. I respectfully recommend that the Commission reject Mr. Walters's request. As the Companies have shown, building the entire Ghent CCR treatment and transport facility as it did was lower cost than pursuing the Sterling option for gypsum disposal, resulting in savings for customers. Therefore, there is no reason to disallow any cost recovery associated with the Ghent landfill.

Trimble County CCR Disposal

Q. Have the Companies previously evaluated the revenue requirements associated with the Warsaw dock alternative described by Mr. Walters and Mr. Gardner in their direct testimony?

A. No. As I stated in my direct testimony and in response to Commission Staff's Second Request for Information No. 18 ("PSC 1-18") and SV 2-27, all of the Companies' prior analyses of the Sterling disposal alternative were based on developing a CCR barge off-loading facility closer to Sterling's mine and using a pipe conveyor to move CCR to their mine.[5]

Q. Why didn't the Companies evaluate the revenue requirements associated with the Warsaw dock alternative?

A. As Mr. Voyles explained in his direct testimony, the Companies did not believe it would be practicable to truck large quantities of CCR down ten miles of public roads—past schools, businesses, and homes—for forty years or more.[6]

[5] *See* Sinclair Direct Testimony at 13-16.
[6] Voyles Direct Testimony at 15.

Q. Despite the impracticability of trucking large quantities of CCR from the Warsaw dock to the Sterling mine, have the Companies recently evaluated the revenue requirements associated with the Warsaw dock alternative in response to the claims in Mr. Walters's direct testimony that using the Warsaw dock alternative would provide large savings compared to the Trimble County landfill?

A. Yes. Even though the Companies continue to believe the Warsaw dock alternative is impracticable, the Companies conducted an analysis to examine the claims in Mr. Walters's direct testimony that using the Warsaw dock alternative would have a PVRR between $16 million and $104 million lower than the PVRR for the Companies' proposed Trimble County landfill.[7] The Companies' analysis of the Warsaw dock alternative started with the information that was used in the analysis that was performed in response to PSC 1-18. That analysis was based on the Companies' latest information and compared the PVRR of the on-site Trimble County landfill to disposal at the Sterling mine. It showed that the 30-year PVRR of the on-site landfill was between $49 million to $55 million lower than the Sterling alternative (see Table 1 below).[8]

[7] Walters Direct Testimony at 19.
[8] Companies' Response to Commission Staff's First Requests for Information No. 18 (July 16, 2015); Sinclair Direct Testimony, page 10 lines 1-3, Table 4.

Table 1 – 30-year PVRR Results (Reflecting Companies' 75% Ownership Share, $2014, $Millions)

Fuel Consumption	Beneficial Use	Onsite Landfill PVRR	Sterling PVRR	PVRR Difference (Onsite Less Sterling)
Low Gas-Base Load	None	445	498	(53)
	Current	415	464	(50)
Mid Gas-Base Load	None	445	498	(54)
	Current	416	465	(49)
High Gas-Base Load	None	445	500	(55)
	Current	415	467	(52)

To address Mr. Walters's concerns that limiting the PVRR analysis to only 30 years somehow distorts the conclusions, I present in Table 2 below an updated version of Table 1 that reflects all years in the analysis workbook, which corresponds to a 66-year PVRR. As Table 2 below shows, the on-site landfill remains significantly lower cost than the Sterling alternative even after more than doubling the term of the analysis.[9]

Table 2 – 66-year PVRR Results (Reflecting Companies' 75% Ownership Share, $2014, $Millions)

Fuel Consumption	Beneficial Use	Onsite Landfill PVRR	PSC 1-18 Sterling PVRR	PVRR Difference (Onsite Less PSC 1-18 Sterling)
Low Gas-Base Load	None	521	574	(53)
	Current	501	544	(43)
Mid Gas-Base Load	None	520	573	(53)
	Current	503	545	(43)
High Gas-Base Load	None	521	575	(55)
	Current	503	547	(45)

[9] See also response to PSC 2-16(a) regarding the impact of calculating PVRR for 30 years versus the life of the landfill.

According to the direct testimony of Mr. Walters, moving to the Warsaw dock location will allow the Companies to eliminate approximately $94 million in capital ($2013; $261 million less $167 million) from the Sterling alterative.[10] Table 3 below compares shows the Sterling capital costs and the line items that he would eliminate.[11] The first two columns of data contain the Companies' cost assumptions from their response to the PSC 1-18, which cost assumptions concerned the Sterling alternative using a barge-unloading site several miles closer to the mine than the Warsaw site; the third column shows Warsaw-barge-unloading cost assumptions based on the capital eliminations Mr. Walters proposed in his direct testimony; the fourth column shows the Companies' corrections to Mr. Walters's proposed capital eliminations for the Warsaw-barge-unloading alternative:

[10] Walters Direct Testimony at 13-14, 18-19.
[11] *Id*.

Table 3 – Sterling Alternative's Capital Costs Reflecting Companies' 75% Ownership Share)

Item	PSC 1-18 ($2014)	PSC 1-18 Model Inputs ($2013)	Warsaw Assumptions Based on Walters Testimony ($2013)	Companies' Warsaw Assumptions ($2013)
CCR Treatment	137,694,058	132,398,133	132,398,133	132,398,133
CCR Pipe Conveyor	13,118,441	12,613,885	-	12,613,885
Onsite Haul Road	12,675,000	12,187,500	-	12,187,500
Barge Loading/Unloading	32,346,600	31,102,500	31,102,500	31,102,500
SV Pipe Conveyor/Haul Road	46,184,709	44,408,374	-	-
Site Preparation/Permitting				
Property	3,735,576	3,591,900	-	-
Clearing/Site Prep	4,999,020	4,806,750	-	-
Fencing	1,309,733	1,259,359	-	-
Wetland/Stream Mitigation	3,369,000	3,239,423	-	-
Cultural Resources/Bats	2,716,526	2,612,045	-	-
LGE/KU Overheads and Engineering Support	6,976,320	6,708,000	-	5,088,754
Total Site Prep/Permitting	23,106,175	22,217,476	-	5,088,754
Barges	6,375,000	6,129,808	3,505,735	3,505,735
Total	271,499,983	261,057,676	167,006,368	196,896,507

Moving to the Warsaw dock site will also impact O&M expenses by eliminating the costs of the pipe conveyor but adding the trucking costs from the dock to their mine.[12] Table 4 shows the changes in O&M expenses.

Table 4 – Sterling O&M Expense ($2013, $/Ton)

Cost Item	PSC 1-18 ($2013)	Warsaw Option ($2013)
Pipe Conveyor to Barge Loading	0.04	0.04
Barge Loading	0.68	0.68
Barge Transport	2.50	2.50
Barge Unloading	1.02	1.02
Pipe Conveyor to Truck Loading	0.04	-
Truck Hauling to Mineshaft	0.99	-
Sterling Tipping Fee	8.76	14.02
Total	14.03	18.26

[12] Walters Direct Testimony at 19.

Q. What is the impact of making all of the changes proposed by Mr. Walters?

A. As can be seen in Table 5, if one assumes that all of the changes proposed by Mr. Walters are appropriate (and they are not), then the 66-year PVRR of disposing of CCRs at the Sterling mine decreases by between $59 million and $72 million. This would indicate that the 66-year PVRR of the Sterling alternative using the Warsaw dock site could be $4 million to $29 million lower than the Trimble County landfill, notwithstanding the feasibility issues discussed by Mr. Voyles in his rebuttal testimony.

Table 5 – 66-year PVRR Results (Reflecting Companies' 75% Ownership Share, $2014, $Millions)

Fuel Consumption	**Beneficial Use**	**Onsite Landfill PVRR**	**PSC 1-18 Sterling PVRR**	**Sterling Warsaw PVRR**	**PVRR Difference (Onsite Less PSC 1-18 Sterling)**	**PVRR Difference (Onsite Less Sterling Warsaw)**
Low Gas-Base Load	None	521	574	514	(53)	7
	Current	501	544	472	(43)	29
Mid Gas-Base Load	None	520	573	513	(53)	7
	Current	503	545	474	(43)	28
High Gas-Base Load	None	521	575	516	(55)	4
	Current	503	547	478	(45)	25

Q. Do you believe that it is appropriate to make all of the assumption changes proposed by Mr. Walters?

A. No. First, Mr. Walters's proposed changes ignore the cost at the Trimble County Generating Station of moving CCR from the treatment facility to the new CCR loading dock, as Mr. Walters himself has plainly stated: "No costs were assumed in Sterling's analysis for transportation between the CCR treatment facility and the barge load out facility."[13] Table 3 above reflects this by eliminating $12.6 million ($2013) for the Trimble County CCR pipe conveyor and $12.2 million ($2013) for the associated back-up haul road. But it is not practical or feasible to use the existing beneficial-reuse facilities at Trimble County to move the CCR because those facilities are designed for their unique needs, and in particular are designed to handle only a portion, not all, of the Trimble County coal units' CCR.[14] Therefore, if the Companies implemented the Sterling alternative, they would have to construct facilities (a pipe conveyor and associated haul road) to move the CCR from the CCR treatment facility to a barge-loading facility, and the associated capital investment of almost $25 million must be included in the cost of the Sterling alternative.

Second, also as shown in Table 3, Mr. Walters believes that the Companies can eliminate $6.7 million ($2013) of the Companies' overheads and engineering support related to the various facilities that would still be required to be constructed to implement the Sterling alternative. These overheads are associated with the entire project involving the CCR treatment and transport facilities and the landfill. Much of the project is independent of where the CCR finally goes, so for purposes of this analysis I have prorated the overhead and engineering support by comparing the Sterling Warsaw capital spending to the overall landfill capital spending. Therefore, I have included $5.1 million for the Companies' overhead and engineering support in the analysis of the Sterling Warsaw alternative.

Third and finally, Mr. Walters removes approximately $2.6 million ($2013) of capital expenses related to the barges necessary to move CCR from Trimble County

[13] Sterling Ventures' Response to Commission Staff's Second Requests for Information No. 16 (Sept. 3, 2015).
[14] *See* Companies' Response to Sterling Ventures' First Data Request No. 9 (July 16, 2015).

to the Warsaw site. Based on the Companies' experience in moving materials via barge, I believe this is not appropriate, but given the small amount of capital, I have left Mr. Walters's adjustment in the Companies' analysis.[15]

After correcting for Mr. Walters's inappropriate capital eliminations, the Warsaw alternative's 66-year PVRR increases by approximately $40 million. As shown in Table 6 below, properly accounting for the costs of the Warsaw site means that its 66-year PVRR is $10 million to $35 million greater than continuing with the on-site Trimble County landfill.

Table 6 – 66-year PVRR Results (Reflecting Companies' 75% Ownership Share, $2014, $Millions)

Fuel Consumption	Beneficial Use	Onsite Landfill PVRR	PSC 1-18 Sterling PVRR	Companies' Warsaw PVRR	PVRR Difference (Onsite Less PSC 1-18 Sterling)	PVRR Difference (Onsite Less Companies' Warsaw)
Low Gas-Base Load	None	521	574	549	(53)	(28)
	Current	501	544	507	(43)	(6)
Mid Gas-Base Load	None	520	573	548	(53)	(28)
	Current	503	545	509	(43)	(6)
High Gas-Base Load	None	521	575	551	(55)	(30)
	Current	503	547	512	(45)	(10)

In addition, if the alternatives are evaluated on the same 30-year PVRR basis used in all of the other previous analyses in this case, then the onsite landfill remains the least cost alternative. As can be seen in Table 7, the PVRR of proceeding with the Trimble County landfill is $3 million to $23 million lower cost than the Sterling alternative at the Warsaw site.

[15] *See* Companies' Response to Sterling Ventures' Supplemental Data Request No. 25 (Sept. 3, 2015).

Table 7 – 30-year PVRR Results (Reflecting Companies' 75% Ownership Share, $2014, $Millions)

Fuel Consumption	Beneficial Use	Onsite Landfill PVRR	Companies' Warsaw PVRR	PVRR Difference (Onsite Less Companies' Warsaw)
Low Gas-Base Load	None	445	464	(19)
	Current	415	418	(3)
Mid Gas-Base Load	None	445	465	(20)
	Current	416	419	(3)
High Gas-Base Load	None	445	468	(23)
	Current	415	422	(7)

Q. Mr. Walters claims in his direct testimony that the Companies are biasing their analysis by not properly accounting for future beneficial use. Is this true?

A. No. As I explained in my direct testimony, regardless of the levels of future beneficial use, the Sterling alternative has a higher PVRR than the landfill alternative. Furthermore, as I stated in response to PSC 2-16(b), Mr. Walters was incorrect when he asserted in his direct testimony that the Companies assumed future beneficial use volumes were limited to existing contracts.[16] All of the analyses the Companies have presented in this case have clearly stated the volume of beneficial use assumed. As can be seen in Tables 6 and 7, the volume of future beneficial use does not change the conclusion that the PVRR of Sterling's Warsaw site is more expensive than continuing with the Trimble County landfill. Moreover, Sterling's tipping fee increases from $16.25 per ton to $17.90 per ton at the volumes disposed when beneficial use is assumed to continue.[17] The consideration of a higher Sterling tipping fee would only make the landfill alternative more favorable.

[16] Companies' Response to Commission Staff's Second Request for Information No. 16(b) (Sept. 3, 2015).
[17] Sterling Ventures' Response to Companies' Supplemental Data Request No. 18 (Sept. 3, 2015).

Q. In your direct testimony, you stated that there were other risks associated with the Sterling alternative that were not quantified.[18] Does your analysis of the Warsaw site alternative address any of those risks?

A. No, even though moving the location of the barge-unloading facility into the town of Warsaw and moving the CCR via truck rather than a pipe conveyor would likely increase the risks I discussed. Nonetheless, this updated analysis continues to make assumptions highly favorable to Sterling: (i) the Sterling mine would have adequate disposal capacity for the entire study life, which is questionable; (ii) there would be no environmental constraints on Sterling's ability to dispose of CCR, which the Companies believe to be incorrect; and (iii) Sterling's mine would remain open and in business throughout the periods analyzed. Addressing all of these risks would only increase the costs of an already uneconomic alternative, so we did not evaluate them.

Q. In addition to the risks you describe above, Sterling appears to believe the Companies should make all of the capital investments and bear all of the risk associated with transporting CCR from the Trimble County Generating Station to Sterling's trucks in Warsaw.[19] Do you believe this is appropriate?

A. No. The Companies have not invested any capital dollars on behalf of any beneficial reuse vendor for facilities not on the Companies' own generating-station property, and have invested in beneficial-reuse facilities on their own property only for facilities that could be used by other vendors or for other purposes. What Sterling proposes is therefore novel and far riskier than any of the Companies' current beneficial-reuse arrangements, namely that the Companies should invest millions of

[18] Sinclair Direct Testimony at 12.
[19] Sterling Ventures' Response to Commission Staff's Second Request for Information No. 2 (Sept. 3, 2015).

dollars in a Warsaw barge-unloading facility that would become useless to the Companies if Sterling did not perform under a hypothetical disposal contract or if other lower cost beneficial use opportunities were to arise in the future. But as with the other risks I discussed in my immediately preceding answer, because the Sterling alternative is uneconomical without quantifying this risk, I have not attempted to quantify it in this analysis.

Q. You stated in your direct testimony that you believed Sterling's concept of unloading barges in Warsaw, Kentucky, was not a better alternative than the Trimble County landfill even though the Companies had not formally evaluated it.[20] Now that the Companies have analyzed Sterling's Warsaw-barge-unloading concept, does it change your prior opinion that it is economically inferior to the Companies' proposed and Commission-approved landfill at Trimble County?

A. No. Even though Sterling's Warsaw-barge-unloading concept would reduce capital costs, the higher variable operating costs associated with trucking more than offset those savings. Moreover, as Mr. Voyles discussed in his direct testimony and reiterates in his Rebuttal Testimony, the Warsaw-barge-unloading concept is fraught with feasibility difficulties that likely make it impracticable.[21]

Q. Throughout this proceeding, Sterling and Mr. Walters have implied that the Companies' analysis methods and assumptions associated with the disposal of Trimble County CCRs have been inappropriate, misleading, incomplete, and biased.[22] How do you respond to these criticisms?

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[20] *Id.* at 16.
[21] *See, e.g.,* Voyles Direct Testimony at 15; Voyles Rebuttal Testimony at 13, 15-21.
[22] *See, e.g.,* Walters Direct Testimony at 16-20.

A. It is my responsibility to ensure that my employees are properly trained and have the necessary tools to perform the financial analysis necessary to support high quality decision-making. Furthermore, the analysts and management team in my group bring a wealth of education and work experience to bear on every project we evaluate. It is our responsibility to evaluate projects and alternatives to determine the most robust option for reliably serving our customers' energy needs in a least-cost manner consistent with safe and reliable operation. I believe my team and I have demonstrated to this Commission in numerous cases, including integrated resource planning reviews and CPCN applications that we take our responsibilities seriously and that we have lived up to our responsibilities. Our group has endeavored to be forthcoming and transparent with the Commission on the execution of our responsibilities. I have every confidence in the analysis that has been performed by my group related to Trimble County CCR disposal and that they can be relied upon by the Companies and the Commission in assessing the alternatives.

<u>Consequences of Delaying Trimble County CCR Treatment Facility and Landfill</u>

Q. Mr. Walters recommends in his direct testimony that the Commission revoke the CPCN for the Trimble County landfill and the transport facilities from the CCR treatment facility to the landfill. Do you agree with his recommendations?

A. Absolutely not. If the Commission accepts Mr. Walters's recommendation, then it virtually assures that customers will pay higher costs in the near term since the Companies would be forced to essentially start the disposal evaluation process over again. As I stated in my direct testimony, if the Trimble County landfill is delayed beyond April 2019, the Companies' ability to operate the Trimble County coal units would be contingent on their ability to transport the station's CCR to beneficial use markets or to an offsite landfill.[23] Those annual costs were estimated to range from approximately $17 to approximately $27 million, depending on the beneficial use assumption.[24] Furthermore, based on all of the CCR disposal analysis that has been performed by the Companies, it is highly likely that the CCR transport and Trimble County landfill would again be the least-cost option. Thus, knowing what we know at this point in time, having customers incur reliability and cost risks only to arrive at the same spot would not be a prudent decision.

Q. What is your recommendation to the Commission regarding the Trimble County landfill CPCN and associated cost recovery, which the Commission granted in the Companies' 2009 ECR proceedings?

A. As I stated in my direct testimony, all the Companies' analyses have shown that the PVRR of the Trimble County landfill is less than the Sterling alternative or retiring and replacing the Trimble County coal units. Nothing in our financial analysis of the Warsaw alternative changes that conclusion: proceeding with the construction of the Trimble County landfill and associated CCR treatment and transportation facilities is the most robust and least-cost alternative to serve our customers. Furthermore, the risks and costs of further delaying this project are significant. Therefore, I respectfully recommend that the Commission reject Sterling's request and instead reaffirm the Companies' existing CPCN and ECR cost-recovery authority.

Q. Does this conclude your testimony?

A. Yes, it does.

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[23] Sinclair Direct Testimony at 16-17.
[24] *Id.* at 20-21.

VERIFICATION

COMMONWEALTH OF KENTUCKY)
) **SS:**
COUNTY OF JEFFERSON)

The undersigned, **David S. Sinclair**, being duly sworn, deposes and says that he is Vice President, Energy Supply and Analysis for Kentucky Utilities Company and Louisville Gas and Electric Company and an employee of LG&E and KU Services Company, and that he has personal knowledge of the matters set forth in the foregoing testimony, and that the answers contained therein are true and correct to the best of his information, knowledge and belief.

David S. Sinclair

David S. Sinclair

Subscribed and sworn to before me, a Notary Public in and before said County and State, this 10th day of September 2015.

Judy Schooler (SEAL)
Notary Public

My Commission Expires:

JUDY SCHOOLER
Notary Public, State at Large, KY
My commission expires July 11, 2018
Notary ID # 512743

Attachment in Excel

The attachment(s) provided in separate file(s) in Excel format.

Attachment
Confidential

The entire attachment is Confidential and provided separately under seal.

Attachment
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Attachment
Confidential

The entire attachment is Confidential and provided separately under seal.

COMMONWEALTH OF KENTUCKY

BEFORE THE PUBLIC SERVICE COMMISSION

In the Matter of:

INVESTIGATION OF KENTUCKY UTILITIES	**)**	
COMPANY'S AND LOUISVILLE GAS AND	**)**	**CASE NO. 2015-00194**
ELECTRIC COMPANY'S RESPECTIVE NEED	**)**	
FOR AND COST OF MULTIPHASE	**)**	
LANDFILLS AT THE TRIMBLE COUNTY	**)**	
AND GHENT GENERATING STATIONS	**)**	

REBUTTAL TESTIMONY OF
GARY H. REVLETT
DIRECTOR, ENVIRONMENTAL AFFAIRS
KENTUCKY UTILITIES COMPANY AND
LOUISVILLE GAS AND ELECTRIC COMPANY

Filed: September 10, 2015

Q. Please state your name, position and business address.

A. My name is Gary H. Revlett. I am the Director of Environmental Affairs for Kentucky Utilities Company ("KU") and Louisville Gas and Electric Company ("LG&E"). I am employed by LG&E and KU Services Company, which provides services to LG&E and KU (collectively "the Companies"). My business address is 220 West Main Street, Louisville, Kentucky, 40202. My Direct Testimony in this matter was filed on August 6, 2015 and a copy of my professional history and education was attached to that testimony as Appendix A.

Q. What is the purpose of your Rebuttal Testimony?

A. The purpose of my Rebuttal Testimony is to respond to John W. Walters, Jr.'s and J. Steven Gardner's August 6, 2015 Direct Testimony filed on behalf of Sterling Ventures ("Sterling"). Specifically, I address: (1) Mr. Walters' and Mr. Gardner's assertion[1] that placing coal combustion residuals ("CCR") in Sterling's mine would qualify as beneficial use under the Environmental Protection Agency's CCR Final Rule and that the Kentucky Division of Waste Management has reached a similar conclusion; and (2) Mr. Gardner's assertion that placing CCR in its mine creates minimal permitting requirements.

Q. Do you agree with Mr. Walters and Mr. Gardner that placing CCR in the Sterling mine would qualify as beneficial use under the CCR Final Rule?

A. No. As I explained in my Direct Testimony, placing CCR in the Sterling mine would not be beneficial use as defined under the CCR Final Rule. I will not repeat here the detailed explanation I provided in my Direct Testimony, but it does bear repeating that placement of CCR in the Sterling mine: (1) would not provide the claimed

[1] See Mr. Walters' Direct Testimony, pp. 20-23 and Mr. Gardner's Direct Testimony, pp. 2-5.

functional benefit of improved ventilation; (2) would not substitute for the use of virgin material; and (3) would be used in excess quantities. Additionally, Sterling has not demonstrated that it would meet the fourth criterion for beneficial use related to increased environmental impacts, especially with respect to areas to be mined over the next 34 years.

Q. Have the Companies engaged expert consultants to analyze Sterling's claim that placing CCR in the Sterling mine would constitute beneficial use under the CCR Final Rule?

A. Yes. The Companies have filed rebuttal testimony of Richard Kinch and John Feddock. Mr. Kinch recently retired from the Environmental Protection Agency. Before that retirement, he was instrumental in drafting, supervising, and finalizing the beneficial use aspect of the CCR Final Rule. Mr. Kinch concludes, without question, that placement of CCR generated at Trimble Station in the Sterling mine would not be beneficial use under the CCR Final Rule, but rather would be disposal and thus subject to all requirements for new CCR landfills. Mr. Feddock is a mining engineer with extensive experience in underground limestone mining and an expert on mine ventilation. In his rebuttal testimony, he concludes that: (1) disposal of CCR generated at Trimble Station in the Sterling mine will not provide an energy savings or any functional benefits as claimed by Sterling; (2) Sterling has overstated its available and future CCR disposal capacity and its ability to continue mining at even its current rate to create additional voids is speculative and uncertain; and (3) there are numerous flaws and concerns with Sterling's generalized plans for transporting and placing CCR in its underground mine.

Q. Do you agree with the statement on page 21 of Mr. Walters' Direct Testimony that the officials at the Kentucky Solid Waste Branch met with Sterling in June 2015 "to confirm that KDWM believed that the new CCR regulations would not affect Sterling's ability to beneficially reuse CCR in its limestone mine?"

A. Mr. Walters asserts that Sterling met with Todd Hendricks, a geologist at the Kentucky Solid Waste Branch and Robin Green, Solid Waste Branch Permit Administration Supervisor, in June 2015. To the extent any such meeting occurred, I was not there and cannot speak as to what was or was not said by anyone at the meeting. As I explained in my Direct Testimony, when I became aware of the positions Sterling was taking regarding beneficial use and the Kentucky Division of Waste Management's ("KDWM") position on that issue, I contacted Bruce Scott, Commissioner of the Kentucky Department for Environmental Protection ("KDEP") and Tony Hatton, Director of KDWM. An organizational chart for KDEP is attached as Rebuttal Exhibit GHR-1. As shown on the chart, the Solid Waste Branch is a branch of KDWM and KDWM is a division of KDEP. Commissioner Scott's e-mail response to me was attached to my Direct Testimony. Commissioner Scott's response is clear that KDEP has not taken any position regarding whether CCR can be beneficially used at the Sterling mine, and that, at this time, Kentucky has no permitting jurisdiction to implement the CCR Final Rule. Therefore, I disagree with the contention that KDWM has confirmed that placement of CCR in Sterling's mine as beneficial use will not be affected by the CCR Final Rule.

Q. Do you agree with Mr. Gardner's assertion on pp. 5-6 of his Direct Testimony that placing CCR in Sterling's mine will have minimal environmental impacts and few permitting requirements?

A. No. Sterling has not developed its concept of placing CCR in its mine in sufficient detail or conducted sufficient studies and investigations of impacts to streams and the Ohio River to allow anybody to make supported conclusions about the level of environmental impacts or permitting requirements. For example, Sterling claims that "three methods have been *envisioned* to transport the CCR from the surface to the interior of the mine . . . ." (emphasis added).[2] Those methods are: (1) dumping CCR down a shaft and then hauling it by truck to various voids in the mine and pushing it into place with tractors; (2) conveying CCR from a material transfer station into the mine and into articulated trucks which will haul CCR to various voids using existing ramps; and (3) trucking CCR from a barge unloading site into the mine on what would be newly constructed ramps within the mine to various voids. Sterling may *envision* these methods, but has offered nothing in the way of legitimate study or quantitative analysis that any of those methods are feasible in practice. Additionally, Sterling has not provided sufficient detail on what would be required in the way of barge loading/unloading upgrades to handle the amount of CCR material at issue.

Depending on the method used to place CCR in the mine and the level of upgrades necessary to the surface operations and a barge facility, Sterling may be faced with significant permitting requirements. For example, Mr. Gardner appears to agree that the Sterling proposal would involve a surface disturbance of 307 acres

[2] See Mr. Gardner's Direct Testimony, p. 15.

impacting 15,521 linear feet of streams and .17 acres of wetlands.[3] Given those facts, it is likely that Sterling would have to apply for and receive a Clean Water Act Section 404 permit from the United States Army Corps of Engineers.

My experience with the 404 permit process is that it can be extremely long and exhaustive. The Companies' current 404 permit application process for the Trimble landfill is a good example of how the CWA 404 permitting process can take several years. Sterling would need to conduct the necessary studies and investigations to support the permit application, assess the impact on 15,521 feet of streams, conduct the alternatives analysis, and submit the application for review and approval by the Army Corps. A separate water quality certification would also have to be obtained from the Kentucky Division of Water. CWA Section 404 permit coverage would also have to be obtained for the impacts to the Ohio River at the barge loading (at Trimble Station) and unloading facilities that need to be constructed. I believe that is true for the Warsaw barge unloading facility as well as for a greenfield site near the mine that LG&E evaluated in its 404 permit application Supplement to Alternatives Analysis because extensive upgrades would be required to make the Warsaw site suitable for large-scale material handling operations.

In addition to 404 permit process and 401 water quality certifications, the facilities to support the barging, trucking, staging, and placing of CCR in Sterling's mine could or would require: modification of Sterling's special waste facility permit; stream floodplain construction permits; material handling permits; modification of Sterling's minor source air emission permit; trucking or hauling permits; and a Kentucky Pollution Discharge Elimination System general storm water discharge

[3] Mr. Gardner's Direct Testimony, p. 6.

permit. To say the least, these requirements are significant and not minimal as Mr. Gardner suggests.

Q. What are your conclusions?

A. Mr. Walters' and Mr. Gardner's assertion that placing CCR in Sterling's mine would qualify as beneficial use under the CCR Final Rule is erroneous. KDEP has not taken any position regarding whether CCR material can be beneficially used pursuant to the CCR Final Rule at the Sterling mine, and that, at this time, Kentucky has no permitting jurisdiction to implement the CCR Final Rule. Mr. Gardner's assertion that placing CCR in its mine creates minimal permitting requirements is also erroneous.

Q. Does this conclude your testimony?

a. Yes.

VERIFICATION

COMMONWEALTH OF KENTUCKY)
) SS:
COUNTY OF JEFFERSON)

The undersigned, **Gary H. Revlett**, being duly sworn, deposes and says he is the Director, Environmental Affairs for LG&E and KU Services Company, and that he has personal knowledge of the matters set forth in the foregoing testimony, and the answers contained therein are true and correct to the best of his information, knowledge and belief.

Gary H. Revlett

Gary H. Revlett

Subscribed and sworn to before me, a Notary Public in and before said County and State, this 10th day of September 2015.

Judy Schooler (SEAL)
Notary Public

My Commission Expires:

JUDY SCHOOLER
Notary Public, State at Large, KY
My commission expires July 11, 2018
Notary ID # 512743

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Division for Air Quality (1st Floor)
Division of Waste Management (2nd Floor)
Division of Water (4th Floor)

300 Fair Oaks Lane
Commissioner's Office
Division of Compliance Assistance
Division of Enforcement
Division of Environmental Program Support

100 Sower Boulevard
Environmental Services Branch (laboratory)
502-564-6120

Revised 05/15/15

COMMONWEALTH OF KENTUCKY

BEFORE THE PUBLIC SERVICE COMMISSION

In the Matter of:

INVESTIGATION OF KENTUCKY UTILITIES	**)**	
COMPANY'S AND LOUISVILLE GAS AND	**)**	**CASE NO. 2015-00194**
ELECTRIC COMPANY'S RESPECTIVE NEED	**)**	
FOR AND COST OF MULTIPHASE	**)**	
LANDFILLS AT THE TRIMBLE COUNTY	**)**	
AND GHENT GENERATING STATIONS	**)**	

REBUTTAL TESTIMONY OF
RICHARD J. KINCH
CONSULTANT

Filed: September 10, 2015

Q. Please state your name, position, and business address.

A. My name is Richard J. Kinch. I am an independent environmental consultant. Previously, I had a 41 year career with the U.S. EPA, which ended on January 2, 2015. During my career at EPA, I established EPA's program dealing with the beneficial use of nonhazardous industrial wastes, including coal combustion residuals (CCR) and the Coal Combustion Products Partnership, which involved EPA, the Department of Transportation, the Department of Energy, the Department of Agriculture, the American Coal Ash Association, and the Utilities Solid Waste Action Group. Prior to leaving EPA, I was Chief of the Industrial Materials Reuse Branch, and had primary responsibility for the development of the beneficial use aspects of EPA's CCR Final Rule[1], which was signed by the EPA Administrator on December 19, 2014, and published in the Federal Register on April 17, 2015. Thus, I was the key person at EPA addressing beneficial use from the inception of EPA's efforts, through the development of the CCR Final Rule. My business address is 7471 Jayhawk Street, Annandale, VA 22003. A statement of my professional history and education is attached to this testimony as Appendix A.

Q. Have you previously testified before this Commission?

A. No.

Q. What is the purpose of your testimony?

A. Based on long-standing experience and expertise regarding EPA actions pertaining to the beneficial use of coal ash, I will factually identify why the placement of CCR at the Sterling Ventures' limestone mine does not qualify as a beneficial use under EPA's CCR Final Rule. In addition, I will explain the interaction between State and

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[1] 80 FR 21302, April 17, 2015.

Federal requirements pertaining to CCR, describe the consequences of Sterling Ventures needing to comply with the CCR Final Rule landfill requirements, and identify the vulnerability to citizen suits if placement of CCR in the Sterling Ventures mine occurred under the current claim of beneficial use.

Q. What materials did you examine in assessing whether Sterling's plan is beneficial use?

A. There was an extensive collection of materials reviewed prior to completing the assessment, including communications between Sterling Ventures and LG&E/KU; EPA regulations, preambles, and docket information; State of Kentucky requirements; and testimony of key stakeholders regarding the CCR Final Rule. A listing of the materials considered is provided in Appendix B.

Q. Please provide a summary of how the CCR Final Rule addresses beneficial use, especially as it pertains to placing CCR within a mining site.

A. While EPA's CCR Final Rule primarily addresses the disposal of CCRs in landfills and surface impoundments; EPA was also faced with distinguishing beneficial use from disposal, and in that context adopted specific positions related to placement of CCR in mines, and criteria. The basic lines of distinction in the CCR Final Rule that address beneficial use are:

a. Coal mining operations were excluded from the rule. This was not a determination that CCR use in coal mines was a beneficial use or disposal, but rather an acknowledgement that the Department of the Interior would separately develop appropriate regulations to address such practices.

b. With regard to mining operation involving sand and gravel pits and quarries, EPA was faced with several damage cases and believed that filling these types of mining units with CCRs was inherently like disposal, and therefore included such operations within the definition of a landfill.

c. There are some beneficial uses, such as the use of FGD Gypsum as an ingredient in the manufacture of wallboard that are outside the scope of solid wastes addressed by the rule. Under the Resource Conservation and Recovery Act, the statutory authority pertains to solid wastes. This exclusion is described as follows in the CCR Final Rule:

> "As EPA noted in the proposed rule, for some beneficial uses, CCR is a raw material used as an ingredient in a manufacturing process that have never been ''discarded,'' and thus, would not be considered solid wastes under the existing RCRA regulations. For example, synthetic gypsum is a product of the FGD process at coal-fired power plants. In this case, the utility designs and operates its air pollution control devices to produce an optimal product, including the oxidation of the FGD to produce synthetic gypsum. In this example, after its production, the utility treats FGD as a valuable input into a production process, i.e., as a product, rather than as something that is intended to be discarded. Wallboard plants are sited in close proximity to power plants for access to raw material, with a considerable investment involved. Thus, FGD gypsum used for wallboard manufacture is a product rather than a waste or discarded material. This use and similar uses of CCR that meet product specifications would not be regulated under the final rule."[2]

d. For anything else, including the Sterling Ventures plan, EPA established a definition of beneficial use with 4 criteria[3]…

> "Beneficial use of CCR means the CCR meet all of the following conditions:

[2] 80 FR 21347, April 17, 2015.
[3] 80 FR 21469, April 17, 2015

> (1) The CCR must provide a functional benefit;
>
> (2) The CCR must substitute for the use of a virgin material, conserving natural resources that would otherwise need to be obtained through practices, such as extraction;
>
> (3) The use of the CCR must meet relevant product specifications, regulatory standards or design standards when available, and when such standards are not available, the CCR is not used in excess quantities; and
>
> (4) When unencapsulated use of CCR involving placement on the land of 12,400 tons or more in non-roadway applications, the user must demonstrate and keep records, and provide such documentation upon request, that environmental releases to groundwater, surface water, soil and air are comparable to or lower than those from analogous products made without CCR, or that environmental releases to groundwater, surface water, soil and air will be at or below relevant regulatory and health-based benchmarks for human and ecological receptors during use."

Q. Do State of Kentucky permit decisions, developed under Kentucky's beneficial reuse program for special wastes, help ensure compliance with EPA's CCR Final Rule?

A. No, compliance with a State permit will not constitute compliance with the CCR Final Rule. Sterling Ventures mentions the ability to rely on state determinations regarding beneficial use, and references comparisons to EPA's National Pollutant Discharge Elimination System (NPDES) program under the Clean Water Act (CWA):

> "The NPDES program's purpose, authorization and enforcement structure is substantially similar to that created by the EPA under the new CCR regulations."[4]

There are severe errors in this comparison. The CWA authorizes EPA to delegate implementation of the NPDES program to states. These states can then issue

[4] Confidential 20140806_2_Walters_Filed-Testimony_ w_Apendices.pdf

permits, and under the CWA, compliance with the permit constitutes compliance with the CWA. The CWA specifically states that "[c]ompliance with a permit issued pursuant to this section shall be deemed compliance" with CWA provisions addressing effluent limitations and their enforcement. 33 U.S.C. § 1342(k). Note, while the NPDES permit, under the CWA, provides a shield, courts have placed limits on the extent of the "shield." But, by and large, the permittee is not violating the regulation, if the permittee is meeting its NPDES permit conditions. The EPA CCR Final Rule is a very different matter. While EPA delegates, to states, implementation of Federal hazardous waste requirements, non-municipal non-hazardous waste disposal requirements pertaining to Conditionally Exempt Small Quantity Generators (CESQG), and municipal solid waste, there is no statutory authority to delegate implementation of nonhazardous industrial solid waste regulations. The CCR Final Rule is self-implementing, and the enforcement is provided by citizen suits. Thus, the industry is subject to dual Federal and State regulations, which may in some cases, be inconsistent. This situation is clearly spelled out in the preamble to the final CCR rule:

> "Because the regulations have been promulgated under sections 1008(a), 4004(a), and 4005(a) of RCRA, the rule does not require permits, does not require states to adopt or implement these requirements, and EPA cannot enforce these requirements. Instead, states or citizens can enforce the requirements of this rule under RCRA's citizen suit authority; the states can also continue to enforce any state regulation under their independent state enforcement authority." (80 FR 21309, April 17, 2015)

Even if there were similar statutory authority, the process does not work as described by Sterling Ventures. After issuing a rule, EPA would require delegated states to adopt equivalent or more stringent requirements. At this time, the Kentucky beneficial reuse requirements for CCR are simply not equivalent to those in the CCR Final Rule. Furthermore, while Sterling references a State determination that placement of CCR is beneficial use, such a determination was made prior to the issuance of the Federal regulations, and there is no indication that the State determination was in any way intended to be an interpretation of Federal requirements. Even the concept of reaching conclusions based on the proposed rule would simply be speculation. The final rule differs from the proposal in significant ways. Furthermore, in correspondence with Mr. Gary Revlett of LG&E, Mr. Bruce Scott, Commissioner of KDEP, stated that they have not taken an official position regarding whether Sterling Ventures' plan complies with the CCR Final Rule. Mr. Scott's position is quoted in Mr. Gary Revlett's direct testimony.

Sterling Ventures cannot utilize the prior State actions as a basis to claim compliance with the CCR Final Rule, which will be enforced by citizen suits. As indicated above, there is no statutory authority that requires delegation or provides a compliance "shield." The current State requirements are not equivalent or more stringent than the CCR Final Rule, the State opinions were made prior to the issuance of the CCR Final Rule, and the State has not made an official interpretation of the Federal rule.

Q. Have EPA, State authorities, industry, and environmental groups acknowledged the complexities and inconsistencies of a dual Federal and State regulatory structure of CCR?

A. Yes, EPA, States, industry, and environmental groups have all spoken to the dual Federal and State regulation of CCR. Mathy Stanislaus, the Assistant Administrator for the Office of Solid Waste and Emergency Response, testified before the U.S. House of Representatives' Subcommittee on Environment and the Economy on March 24, 2015.[5] In that testimony, he recognized a slight non-mandatory level of coordination between Federal and state requirements stating:

> "We are committed to working closely with our state partners on rule implementation and, as a major component of this, we are encouraging states to revise their Solid Waste Management Plans (SWMPs) and submit the revisions to the EPA for approval."

But, the CCR Final Rule acknowledges:

> "…EPA approval of a State SWMP does not mean that the state program operates "in lieu of" the federal program as EPA does not have the authority to make such a determination." (80 FR 21431, April 17, 2015)

The testimony of Michael G. Forbeck, P.E., President, Association of State and Territorial Solid Waste Management Officials, highlighted the limitations faced by state officials:

> "The rule's self-implementing requirements will set up the situation of a dual State and federal regulatory regime, in which the owner or operator of a CCR disposal facility would need to fully comply with the self-implementing national minimum standards and existing State requirements, even if the State requirements meet or exceed the national minimums.
>
> The use of an EPA-approved State Solid Waste Management Plan (SWMP) as the mechanism to deal with the issue of dual regulatory authority will not fully alleviate dual implementation of State and federal standards, since the approved SWMP would not operate "in lieu of" the federal standards."[6]

[5] http://democrats.energycommerce.house.gov/sites/default/files/documents/Testimony-Stanislaus-EE-2015-03-24.pdf

[6] http://democrats.energycommerce.house.gov/sites/default/files/documents/Testimony-Forbeck-EE-Coal-Ash-2015-03-18.pdf

The industry association, the Utility Solid Waste Action Group, represented by their Executive Director, James Roewer testified before the U.S. House of Representatives' Subcommittee on Environment and the Economy on March 24, 2015:

> "Among other things, the fact that state coal ash regulations cannot operate in lieu of the federal rule means that coal ash facilities must comply with dual and potentially inconsistent federal and state regulations for the same material."[7]

Senior attorney Frank Holleman, with the environmental group, Southern Environmental Law Center, expresses their view:

> "The reality is that the state agencies are very reluctant and will not, as we have seen, enforce the law by themselves against the most politically powerful and wealthy institutions in the state legislative capitols," said Holleman. "We want to have adequate minimum standards that the citizens can enforce if the bureaucrats don't."[8]

The dual State and Federal regulatory structure may not be desired by some parties, but all the major parties involved in the CCR rulemaking understand the structure, and environmental groups expect to exercise their enforcement authority under citizen suits.

Q. Did the lack of statutory authority to delegate implementation of the CCR Final Rule impact the environmental requirements within the CCR Final Rule in ways that could adversely affect Sterling Ventures ability to manage CCR?

A. Yes, there are no provisions in the CCR Final Rule that provide states with the authority to adjust requirements based on the site-specific conditions, which might

[7] http://democrats.energycommerce.house.gov/sites/default/files/documents/Testimony-Roewer-EE-Coal-Ash-2015-3-18_0.pdf

[8] https://www.southernenvironment.org/news-and-press/news-feed/testimony-before-senate-committee-reaffirms-need-for-strong-epa-coal-ash-rule

justify alternative actions. While some flexibility was provided by requiring certification of a qualified professional engineer, EPA dismissed more extensive flexibility that might be provided if there was authority to delegate the program to States:

> Under both the subtitle C and part 258 programs, EPA can rely on subsequent proceedings to develop the information necessary to support such tailoring. This is clearly neither contemplated nor authorized under the regulatory program relevant to this rule.[9]

Thus, if the Sterling Venture plan constitutes disposal, there is no regulatory mechanism that provides sufficient flexibility or State based proceeding that can waive the rule's requirements for a liner, groundwater monitoring, closure, and post-closure care based on Sterling Ventures site-specific circumstances.

Q. Does Sterling Ventures appropriately and consistently reference its plan for managing CCR as beneficial use rather than disposal?

A. While Sterling Ventures claims their plan constitutes beneficial use, their own language (e.g., "the Sterling landfill" [10] and "Sterling's underground disposal plan" [11]) frequently reflects that its plan is an alternative disposal scheme that functions as a landfill. Mr. John N. Voyles, Jr.'s rebuttal testimony further addresses Sterling Ventures references to their plan as disposal, and is important in highlighting the actual nature of the Sterling Ventures plan. The CCR Final Rule makes clear that beneficial use is more than an alternative to disposal, and that the mere presence of a guise of beneficial use is not sufficient:

[9] 80 FR 21398, April 17, 2015.
[10] Sterling's Ventures Formal Complaint, 20 May 2015, p. 21.
[11] Mr. Gardner's Pre-Filed Direct Testimony, 6 August 2015, p. 5

> "This criterion is designed to ensure that the material performs a genuine function in the product or use; while it need not improve product performance when compared to the material for which it is substituting, CCR must genuinely be a necessary component of the product. In other words, there must be a legitimate reason for using CCR in the product other than the fact that it is an alternative to disposal of the material, e.g., the material fulfils material specifications." (80 FR 21349, April 17, 2015)

> "EPA recognizes that several proven damage cases involving the large-scale placement, akin to disposal, of CCR have occurred under the guise of ''beneficial use''—the ''beneficial'' use being the filling up of old quarries or gravel pits, or the re-grading of landscape with large quantities of CCR. EPA did not consider this type of use as a ''beneficial'' use in its May 2000 Regulatory Determination, and still does not consider this type of use to be covered by the exclusion." (80 FR 21330, April 17, 2015)

Sterling Ventures' language supports that the primary objective is to fill 90% of the mine voids with massive volumes of CCR, and the motivation is the collection of potentially over $300 million in tipping fees.

Q. Does Sterling Ventures' plan comply with the first beneficial use criterion, "The CCR must provide a functional benefit"?

A. No, the large volume (up to 33.4 million cubic yards) of CCR to be placed in the Sterling Ventures' mine does not provide a legitimate functional benefit. Sterling Ventures' claim is that placement of CCR will eliminate air voids in the mine, thus providing the functional benefit of effectively and efficiently directing air to working areas of the mine. The company has stated that:

> "Yes, Sterling has built a concrete baffle in its mine to replace a barrier using mined stone as a baffle. Sterling also

> uses mined stone, plastic curtains, or a combination of both to block and direct airflow." [12]

The difficulty is that Sterling provides no indication that filling massive mine voids with material is a means by which Sterling Ventures can direct air flow. The mention of plastic curtains highlights how ventilation needs can be addressed simply, and without the use of millions of tons of CCRs. Certainly, to the extent Sterling wants to add CCRs to concrete in producing concrete baffles similar to the prior structure, such a use would provide a functional benefit for the material necessary to construct the concrete baffles. In this case, while there is an argument for some type of wall structure or curtain to direct air flow, the great mass of material behind the "wall of CCR" does not have a functional benefit. When considering up to 33.4 million cubic yards, this large volume of material constitutes a disposal practice, not beneficial use.

Consideration of how Sterling Ventures' plan might actually be implemented further negates the concept that the CCR would have a legitimate functional benefit. There is no factual support to indicate that Sterling Ventures' current operation fails to meet ventilation needs based on existing controls, such as a concrete baffle, plastic curtains, etc. As described, it appears Sterling will replace existing ventilation controls with massive quantities CCRs, which will be placed in a manner that maximizes the filling of voids within the mine, not in a manner that minimizes material necessary for ventilation of the active limestone mining area. A functional benefit is not derived by replacing existing controls that already provide ventilation control, or installing controls whose need has not been established.

[12] SV_Response_to KU-LGE Data Request 071615.pdf

In addition, the simple use of unencapsulated CCR for ventilation benefits is an ineffective choice. Unlike a curtain or concrete baffle, the CCR binding properties are not conducive to building a simple thin structure to redirect air flow, and the fine particulate nature of CCRs could readily generate fugitive dust concerns, which would negatively impact air quality in the mine, and pose greater ventilation concerns. The CCR rule confirms the problems with fugitive dusts by establishing one of the first requirements for landfills being the development of a fugitive dust control plan. As an expression of the breadth of the concern, the preamble to the CCR rule states:

> "Similarly, absent dust control measures, such as the conditioning of CCR, both CCR landfills and CCR piles have the potential to generate significant amount of fugitive dust. Indeed, CCR piles are generally more susceptible to the creation of fugitive dusts. And contrary to the commenters' contention about the absence of damage cases, the single most frequent issue presented during the public hearings was the allegation by individual citizens of damage caused by fugitive dusts from neighboring CCR facilities. (80 FR 21356, April 17, 2015)

Furthermore, the basic concept by Sterling Ventures, that inactive areas are closed off so that ventilation can be directed "effectively and efficiently directing air to working areas of the mine", is poorly executed in its plan. Placement of CCR in the mine will turn an inactive area of the mine into a working area, with its own ventilation needs. Thus, the concept of providing a functional benefit for limestone mining is flawed.

Based on the above assessment, Sterling Ventures' plan fails to provide a legitimate functional benefit – the volume of CCR is totally out of line with the need for ventilation control, there appears to be a replacement of existing ventilation controls and the dusting nature of the material and placement could pose greater ventilation burdens.

Q. Does Sterling Ventures' plan comply with the second beneficial use criterion, "The CCR must substitute for the use of a virgin material, conserving natural resources that would otherwise need to be obtained through practices, such as extraction;"?

A. No, Sterling Ventures' plan is not a legitimate substitute for the use of virgin materials. With regard to this criterion, Sterling Ventures claims:

> "The CCR substitutes for concrete, steel and other materials used to construct air stoppings in the mine, as well as substantially reducing the amount of electricity required to run ventilation fans to move air in the mine, thereby reducing the environmental consequences of additional electric generation."[13]

The existing practices conducted to achieve the stated benefit are identified as:

> "Yes, Sterling has built a concrete baffle in its mine to replace a barrier using mined stone as a baffle. Sterling also uses mined stone, plastic curtains, or a combination of both to block and direct airflow.." [14]

> While a very small amount of CCRs might provide some functional replacement, the volumes of CCRs are totally out of line with practices Sterling would engage in for air flow, if not for tipping fees sought. Thus, while CCR could legitimately be a partial replacement for cement in a concrete baffle, the Sterling plan has little to do with being a legitimate substitute for the use of virgin material.

> If Sterling Ventures had to acquire non-waste material to fill 90% of the mine voids to address ventilation, there would be a claim that the CCR substitutes for a virgin material. But, there is no support for such a practice, and the $10.50+ per ton tipping fee supports that this is not a replacement for virgin materials – it is a disposal plan. In

[13] SV_Response_to KU-LGE Data Request 071615.pdf
[14] SV_Response_to KU-LGE Data Request 071615.pdf

> the preamble to the CCR Final Rule, EPA references material in a beneficial use being a valuable product and the concept of "buyers":
>
> "However, this does not describe the majority of CCR, which are unambiguously wastes; after generation in the boiler, they are placed into landfills or surface impoundments. While they may subsequently be dredged from these units and reused, placement in a landfill or surface impoundment presents prima facie evidence of discard. At the time the material is placed into the unit, the utility is not treating the material as a valuable product or otherwise seeking to protect the material for use. Although the material may subsequently be reused if a buyer is found, the material is originally placed in the unit with the intent to let it remain in place if no buyer is found. The waste designation does not change merely because a material in a surface impoundment or landfill may in the future be beneficially reused." (80 FR 21348, April 17, 2015)

While the concept of a buyer is not a sole consideration in EPA's evaluation – Sterling Ventures is not a buyer of the CCR, nor are they even taking the material for free, or using the material to produce a more valuable product – they reflect the true value of the material by charging a $10.50+/ton tipping fee. This tipping fee is functionally a waste disposal construct, and there is nothing in the description of its plan that describes a management process that supports the concept that the CCR is a valuable product or intermediate. As a relative measure, the gate rate at the Arrowhead landfill in Perry County, AL, which received coal ash from the TVA Kingston spill, was $24/ton.[15] This is more than the Sterling Ventures request, but the precise tipping fee TVA negotiated for its large volume has not been disclosed, and the Sterling Ventures tipping fee largely reflects avoiding all the associated landfill regulatory costs such as a liner, groundwater monitoring, and closure.

[15] http://blog.al.com/spotnews/2012/09/alabama_landfill_rules_make_du.html

As for the claim of "substantially reducing the amount of electricity to run ventilation fans to move air in the mine, the fact that Sterling has existing ventilation controls also significantly fails to support that the use of CCRs is "conserving natural resources that would **otherwise need to be obtained** through practices, such as extraction." Thus, not only is the massive use of coal ash for the relatively minute mass necessary for ventilation controls not substantiated, the use of any coal ash to merely replace a functioning ventilation control fails to meet this criterion. The energy consumed by ventilation could actually increase due to air quality issues associated with:

- Fugitive dust from the CCR,
- Diesel fumes generated by equipment necessary for placement of the CCR,
- Possible removal of the existing concrete baffle and plastic curtains to more fully access voids for the placement of CCR.

Furthermore, a process-wide view also provides a very negative perspective on the claim of an energy savings. Sterling Ventures' standard practice of constructing a concrete baffle, using plastic curtains, etc. would have an energy requirement that is minute compared to transporting and placing up to 33.4 million cubic yards of CCR in the mine. Sterling's plan is simply not an energy saving concept, and when looking at the overall cost of CCR placement, such figures would greatly exceed expenditures on standard ventilation controls.

Based on the above assessment, Sterling Ventures' plan for placing up to 33.4 million cubic yards in its mine is not a legitimate replacement for the minute volume of material that Sterling Ventures adds to the mine for ventilation control, nor does it provide an overall energy savings. In the case where CCR could be replacing materials that are part of the existing ventilation controls, there is no replacement of virgin materials that would otherwise need to be obtained.

Q. Does Sterling Ventures' plan comply with the third beneficial use criterion, "The CCR must meet relevant product specifications, regulatory standards or design standards when available, and when such standards are not available, the CCR is not used in excess quantities;"?

A. Sterling Ventures provides two different claims regarding this criterion:

> There are no product specifications relevant to Sterling's beneficial use of CCR. Sterling's requirement to maintain an active mining operation prevents excess quantities of CCR beyond what is necessary to fill voids in mined out, abandoned areas of the mine.[16]
>
> And
>
> Use of the CCR under the Sterling plan would meet regulatory and design standards for mine ventilation.[17]

The language of the first claim for this criterion is actually more on target with Sterling Ventures prime objective – "what is necessary to fill voids in mined out, abandoned areas of the mine." This is not a statement of what is necessary for air flow. Rather, it is a statement of Sterling Ventures' objective to dispose massive volume of CCR generated at LG&E's Trimble County Station. Sterling's capacity analysis is also in line with the thought that as voids are created, they simply become space for disposing of CCR. So, while there is "no excess" from a disposal perspective, the construct from a beneficial use perspective is predominantly the use

[16] Pre-Filed Direct Testimony of John W. Walters, Jr. on Behalf of Sterling Ventures, LLC, August 6, 2015
[17] Pre-Filed Direct Testimony of J. Steven Gardner PE on Behalf of Sterling Ventures, LLC, August 6, 2015

of CCR in excess quantities. The basic guideline is whether the practice is something the user would do using non-CCR materials. In this case, there is no support that Sterling Ventures would bring other materials in massive quantities into the mine to fill the voids – a conclusion that is borne out by the call for a $10.50+ tipping fee, which again is reflective of a disposal action.

Within the EPA rulemaking, there are strong expressions of concern with regard to the placement of large volumes of CCR relative to the claimed functional benefit:

> "This criterion was intended to address both the legitimacy of the use and the potential environmental and human health consequences associated with the use of excess quantities of CCR, particularly unencapsulated CCR. If excessive volumes of CCR are used—i.e., greater than necessary for a specific project— that calls into question whether the purpose of the application was in fact a sham to avoid compliance with the disposal regulations." (80 FR 21350, April 17, 2015),

> "EPA explained that in the case of agricultural uses, CCR would be expected to meet appropriate standards, constituent levels, prescribed total loads, application rates, etc." (80 FR 21347, April 17, 2015), and

> "Fly ash used as a stabilized base course in highway construction is part of many engineering considerations, such as the ASTM C 593 test for compaction, the ASTM D 560 freezing and thawing test, and a seven day compressive strength above 2760 kPa (400 psi). If excessive volumes of CCR are used—i.e., greater than were necessary for a specific project,—that could be grounds for a determination that the use is not beneficial, but rather is being disposed of." (80 FR 21347, April 17, 2015).

In the case of Sterling Ventures proposed efforts to achieve the desired functional benefit, at most a very small percentage of the material could be part of some structure that provides air flow benefit – beyond that, the vast majority is not providing a functional benefit and is simply slated for disposal, under the claimed guise of beneficial use. Given industry practices for air flow, the beneficial use claim is analogous to the use of CCR for road base and making the road base hundreds of feet high – as indicated above, the preamble to the CCR Final Rule rejects such practices as beneficial use.

Based on the above assessment, Sterling Ventures' plan fails to comply with the third beneficial use criterion. The plan to fill 90% of the mine voids is not a process focused on improving ventilation to the active limestone mining areas, is not a legitimate replacement for standard ventilation controls, and involves the use of CCR in massive excess.

Q. Does Sterling Ventures' plan comply with the fourth beneficial use criterion, which includes the need to demonstrate that environmental releases to groundwater, surface water, soil and air will be at or below regulatory and health-based benchmarks for human and ecological receptors during use?

A. There are interesting features associated with the Sterling Ventures mine from an environmental perspective, but the information provided, including its beneficial use permit application, is insufficient to determine if the fourth criterion is met. Sterling Ventures claims that given the geology of the mine and the strata between the surface and the mining levels, once the CCR is placed in the mine, there will be no environmental contact possible with groundwater, surface water, soil or air. EPA's rule references guidance and standards (e.g., ASTM E2277–03 and USWAG's ''Engineering and Environmental Guidance on the Beneficial Use of Coal Combustion Products in Engineered Structural Fill Projects''), which illustrate that more substantial information and analysis are expected. It is recognized, however, that Sterling Ventures identifies features, such as placement occurring beneath the groundwater table and separation by impermeable bentonite layers, that are potentially advantageous and outside the considerations of the named guidance and standards. Within EPA's Hazardous Waste Program, there is a provision for a no migration petition from the land disposal prohibitions, and in July 1992, there was a draft guidance document: "No Migration Variance to the Land Disposal Prohibitions: A Guidance Manual for Petitioners", which can be found on the http://nepis.epa.gov/ site. This 94 page document provides far more robust guidance on the kind of information that would be needed to factually support the type of environmental claims made by Sterling. For example in the Geology section (page 24), the guide calls for the inclusion of the following components along with maps and other supporting documentation:

Structure. Density, distribution and orientation of faults, folds, and fractures

Subsurface Geology. Identification lithologic descriptions, and thicknesses of all geologic formations underlying the region, available geophysical surveys, well logs, and boring logs

Geomorphology. Discussion of present surface features, processes that could affect surface features, and subsurface features that may be implied

Geologic Stability. Potential for earthquakes and degree of resulting ground motion, faulting, landslides, subsidence, creep, and other types of earth movement

Based on the very limited information provided, Sterling Ventures' compliance with the fourth beneficial use criterion is inconclusive.

Q. Is Sterling Ventures' plan to manage CCR at its limestone mine beneficial use or disposal?

A. The Sterling plan is not a beneficial use based on the criteria contained in the CCR Final Rule. The first 3 of the 4 beneficial use criteria are not met. While the features of the site appear to be very promising regarding the 4th criteria, there is insufficient information provided, and all four criteria must be met for the operation to be beneficial use. There are 3 key factors, each of which could independently lead to a determination that the proposed Sterling plan is disposal.

First, the vast quantities of CCRs (up to 33.4 million cubic yards) to be placed are not a legitimate use as compared to the small volume of a concrete baffle, plastic screens, etc. to address ventilation needs. There is no indication that standard practice at the Sterling Ventures mine is to completely fill inactive sections with material as a ventilation enhancement for the active limestone mining activity. Thus, the massive volume of CCR does not have a function benefits or replace virgin material that would otherwise need to be extracted – the plan constitutes excess use of material.

Second, the energy usage of transporting and placing up to 33.4 million cubic yards of material would vastly exceed the claimed ventilation energy savings. There would also need to be ventilation to the active CCR disposal areas, and in addition, unencapsulated CCR is prone to generating fugitive dusts which could impact air quality. Thus, this scheme is far from an energy saving endeavor or a practice that is well suited for air quality, and the overall cost of placing the up to 33.4 million cubic yards of CCRs at the Sterling Ventures' mine would far exceed the cost of standard ventilation controls such as a concrete baffle and plastic curtains.

Third, the placement of CCRs would open up inactive segments of the mine that will need ventilation, could duplicate ventilation benefits addressed by existing ventilation controls associated with the active limestone mining. As described, there is no evidence that the CCR fill will be minimized to address the ventilation needs of the limestone mining, including utilization of existing ventilation controls. The mere replacement of existing controls with CCR does not constitute "conserving natural resources that would otherwise need to be obtained through practices, such as extraction."

Thus, the disposal regulations in the CCR Final Rule would need to be met, if the CCRs are to be placed in the Sterling Ventures mine. From an environmental perspective, it is possible that with additional information, the site could be deemed to be environmentally protective as a disposal option. The difficulty is the CCR Final Rule has no flexibility to alter the requirements in consideration of Sterling Ventures site specific features, and the added burden of the rule would very likely preclude use of the Sterling Ventures site for the disposal of coal ash.

Q. Are there other EPA regulatory materials that similarly reflect EPA's considerations in distinguishing whether a practice is a legitimate use or one that must comply with waste management regulations?

A. Yes, EPA thinking in the area of whether a material's use constitutes waste management is similarly illustrated in the Hazardous Waste Program's Definition of Solid Waste Rule, and in the Nonhazardous Secondary Materials rule, which addresses whether combustion of a material is regulated as waste combustion or if the material is a legitimate ingredient or fuel source.

In the Definition of Solid Waste Rule for the use of hazardous materials, concepts similar to those in the CCR Final Rule occur within the 4 legitimacy criteria:

> Factor 1: Legitimate recycling must involve a hazardous secondary material that provides a useful contribution to the recycling process or to a product or intermediate of the recycling process.
>
> Factor 2: The recycling process must produce a valuable product or intermediate.
>
> Factor 3: The generator and the recycler must manage the hazardous secondary material as a valuable commodity when it is under their control.
>
> Factor 4: The product of the recycling process must be comparable to a legitimate product or intermediate." (80 FR 1719, January 13, 2015)

The Nonhazardous Secondary Materials Rule, specifies legitimacy criteria for nonhazardous secondary materials used as an ingredient in combustion units (40 CFR Part 241.3(d)(2)):

> (2) Legitimacy criteria for nonhazardous secondary materials used as an ingredient in combustion units include the following:
>
> (i) The non-hazardous secondary material must be managed as a valuable commodity based on the following factors:
>
> (A) The storage of the non-hazardous secondary material prior to use must not exceed reasonable time frames;
>
> (B) Where there is an analogous ingredient, the non-hazardous secondary material must be managed in a manner consistent with the analogous ingredient or otherwise be adequately contained to prevent releases to the environment;

> (C) If there is no analogous ingredient, the non-hazardous secondary material must be adequately contained to prevent releases to the environment;
>
> (ii) The non-hazardous secondary material must provide a useful contribution to the production or manufacturing process. The nonhazardous secondary material provides a useful contribution if it contributes a valuable ingredient to the product or intermediate or is an effective substitute for a commercial product.
>
> (iii) The non-hazardous secondary material must be used to produce a valuable product or intermediate. The product or intermediate is valuable if:
>
> (A) The non-hazardous secondary material is sold to a third party, or
>
> (B) The non-hazardous secondary material is used as an effective substitute for a commercial product or as an ingredient or intermediate in an industrial process.
>
> (iv) The non-hazardous secondary material must result in products that contain contaminants at levels that are comparable in concentration to or lower than those found in traditional products that are manufactured without the nonhazardous secondary material.

Thus, concepts within the CCR Final Rule such as providing a “functional benefit” are analogous to “providing a useful contribution.” Likewise, providing a “substitute for the use of a virgin material” is similar to “used as an effective substitute”, and other concepts in the CCR Final Rule have analogous provisions in the Definition of Solid Waste Rule, and the Nonhazardous Secondary Materials Rule. These other rules further support EPA thinking on the criteria for beneficial use within the CCR Final Rule.

Q. In recent testimony by Mr. Steven Gardner,[18] Sterling Ventures presents new justifications, roof support and future mining of CCR for beneficial use by others. What are your thoughts on those newly introduced concepts?

A. These new claims are unsupported, flawed, and speculative. In the recent testimony of Mr. Steven Gardner of Sterling Ventures, a new claim of beneficial use is made:

> "Backstowing of the CCR will also provide additional long-term roof support within the mined out areas."

There is, however, no support provided that there are subsidence problems with the mine, that Sterling is being required to fill mine voids, that Sterling is committed to fill the mine voids absent the use of CCRs with a $10.50+ tipping fee, or that the CCR would be placed in a manner that provides needed roof support.

Also, in Mr. Gardner's testimony is the statement:

> "Having the CCR in an area that can easily be recovered for traditional beneficial uses will avoid the mining of those materials at some date in the future."

While EPA has expressed value in such an activity by postponing closure requirements for landfills where CCR is being removed for beneficial use, the mining of the CCR from the Trimble landfill could also occur. Mere speculation on future use, more than 3 decades from now, is not a meaningful consideration within the context of the beneficial use criteria. Furthermore, plans for effective use of CCR in the future should involve separate placement of CCR components (fly ash, bottom ash, and FGD Gypsum). There are no references to such plans by Sterling Ventures.

In basic terms, Sterling Ventures' plan has a prime objective of disposing up to 33.4 million cubic yards of CCR and receiving over $300 million for that service.

[18] Pre-Filed Direct Testimony of J. Steven Gardner PE on Behalf of Sterling Ventures, LLC, August 6, 2015

This is disposal. The main beneficial use claim of ventilation and these newly added claims are hollow attempts to avoid the applicable disposal requirements of the CCR Final Rule.

Q. How might citizen groups to react to the placement of CCR at the Sterling Ventures' limestone mine?

A. With regard to citizen groups, which are of prime importance because enforcement of the Federal CCR Final Rule is through citizen suits, I strongly believe that all of the citizen groups that I have engaged in the development of the CCR Final Rule, would view the Sterling plan as disposal, not beneficial use. In March 2011, the main environmental groups interested in coal ash issues, EarthJustice, the Environmental Integrity Project, and the Sierra Club indicated their opposition and skepticism regarding the placement of CCRs in mines being considered beneficial use:

> "Much of the touted "beneficial use" of ash is simply filling mines, quarries and other low areas to avoid disposal costs."
>
> (http://earthjustice.org/sites/default/files/CoalAshMythFactSheetMar2011.pdf)

Citizen groups also expressed concerns about "beneficial use" in comments to the proposed rule regarding operations using more than 5,000 tons. If the Sterling plan is implemented, these citizen groups could well take notice of up to 33.4 million cubic yards of CCR, share all the concerns mentioned above, see the touted "beneficial use" as a ruse for Sterling to collect tipping fees, and LG&E and KU as being complicit, and potentially take legal action.

Q. Does this conclude your testimony?

A. Yes, it does.

VERIFICATION

COMMONWEALTH OF VIRGINIA)
) **SS:**
COUNTY OF FAIRFAX)

The undersigned, **Richard J. Kinch**, being duly sworn, deposes and says he is an independent environmental consultant, and that he has personal knowledge of the matters set forth in the foregoing rebuttal testimony, and the answers contained therein are true and correct to the best of his information, knowledge and belief.

RICHARD J. KINCH

Subscribed and sworn to before me, a Notary Public in and before said County and State, this 8TH day of September, 2015.

LYNNA J. AGUILAR
Notary Public
Commonwealth of Virginia
My Commission Expires 2-28-19
Commission ID# 7129715

(SEAL)
Notary Public

My Commission Expires:

02/28/2019

APPENDIX A

Richard J. Kinch
Consultant
7471 Jayhawk Street
Annandale, VA 22003

Education

University of Rochester
1970 | Bachelor of Science, Chemical Engineering

University of Massachusetts
1974 | Master of Science, Environmental Engineering

Experience

April 1974 – December 2014 | Chief, Industrial Materials Reuse Branch
U.S. Environmental Protection Agency, 1200 Pennsylvania Avenue, NW, Washington, DC 20460

Supervisory Responsibilities: As chief of various branches within EPA's Office of Solid Waste and Emergency Response (1990 -2014), responsibilities included:

- Land Disposal Restrictions – Federal regulations for the treatment of hazardous wastes prior to disposal.
- Hazardous Waste Combustion – Air emission requirements for the combustion of hazardous wastes.
- Special Wastes – Regulations, policy, and Agency interpretations regarding the Resource Conservation and Recovery Act as it pertains to solid wastes from the following:
    - Fossil Fuel Combustion
    - Mining and Mineral Processing
    - Oil and Gas Exploration and Production
    - Cement Kiln Dust
- Industrial Material Reuse – Guidance and regulation to support the environmentally effective beneficial use of various non-hazardous industrial residuals, specifically including:
    - Coal Combustion Residuals
    - Spent Foundry Sands
    - Chat (a lead mining residual)
    - Iron and Steel Slags
    - Pulp and Paper
    - Scrap Tires
- Municipal Solid Wastes Disposal Regulations
- Guidance for the Management of Non-hazardous Industrial Wastes

Non-Supervisory Responsibilities: As a Chemical Engineer in EPA's Office of Water (1974 – 1990), responsibilities included:

- Effluent Limitations Guidelines – Established Federal wastewater discharge regulations for industrial facilities, including:
    - Metal Finishing
    - Pulp & Paper
    - Rubber Manufacturing
    - Photographic Processing
    - Sugar Processing
- General Pretreatment Regulations – Coordinated a collaborative effort of EPA, states, industry, municipalities, and environmental groups to upgrade the General Pretreatment Regulations.
- Special Assistant to the Director of the Office of Water Enforcement and Permits
- Water Enforcement – Developed enforcement policy and guidance, and coordinated enforcement efforts with EPA Regions, states, and municipalities.

APPENDIX B

There was an extensive collection of materials reviewed prior to completing the assessment, including:

a. Sterling Ventures and LG&E/KU communications on this matter, specifically, over 1000 pages contained in the following files/reports:

   i. SV_Response_to KU-LGE Data Request 071615.pdf

   ii. SV_Response_to_Staff_Data_Request_071615.pdf

   iii. 20150616_PSC_ORDER.pdf

   iv. 20150616_Sterling Ventures, LLC_Complaint Part I.pdf

   v. 20150522_LGE-KU_Joint_Application_5-22-15.pdf

   vi. Sterling Ventures toUSACE.pdf

   vii. Attachment_Response_A-3History.xlsx

   viii. Attachment_Response_A-12_Ghent_PVRR.xlsx

   ix. Attachment_Response_A-31_Exhibit -5_PVRR.xlsx

   x. Walters, John W, Jr. "Trimble County Generating Station Landfill Permit, Project ID No. LRL-2010-711-kjs." Letter to Kimberly J. Simpson, USACE. 4 June 2015.

   xi. Boone, Samuel A.B. "Gypsum Removal." Letter to Kenny Tapp. 19 July 2010.

   xii. Walters, John W, Jr. “Re: CCPs/Trimble County Landfill.” Message to Paul Puckett. 24 September 2014. E-mail.

   xiii. Walters, John W, Jr. “Re: Sterling Ventures Gypsum Proposal.” Message to Jeff Joyce. 19 January 2012. E-mail.

xiv. Boone, Samuel A.B. "FGD Gypsum Disposal – Ghent Generating Station." Letter to Jeff Joyce. 13 September 2011.

xv. Pre-Filed Direct Testimony of John W. Walters, Jr. on Behalf of Sterling Ventures, LLC, August 6, 2015

xvi. Pre-Filed Direct Testimony of J. Steven Gardner PE on Behalf of Sterling Ventures, LLC, August 6, 2015

xvii. Testimony of Robert M. Conroy, Director, Rates, Kentucky Utilities Company and Louisville Gas and Electric Company

xviii. Testimony of Gary H. Revlett, Director, Environmental Affairs, Kentucky Utilities Company and Louisville Gas and Electric Company

xix. Testimony of David S. Sinclair, Vice President, Energy Supply and Analysis, Kentucky Utilities Company and Louisville Gas and Electric Company

xx. Testimony of John N. Voyles, Jr., Vice President, Transmission and Generation Services, Kentucky Utilities Company and Louisville Gas and Electric Company

b. EPA's CCR Final Rule, including regulatory language, preamble language, and supporting documentation contained in Docket Number: EPA-HQ-RCRA-2009-0640.

c. Ancillary documents considered:

i. EPA's hazardous waste rulemaking pertaining to the definition of solid waste[1]. While not directly applicable, this rulemaking lays out in considerable detail EPA thoughts regarding the distinguishing

[1] 80 FR 1694, January 13, 2015.

characteristics between waste disposal and legitimate use as an ingredient or product.

ii. EPA's Nonhazardous Secondary Materials rule[2] – while this rule focuses on a different construct, distinguishing whether the combustion of nonhazardous secondary materials involves a legitimate fuel versus waste burning, some of the basic constructs that EPA uses to make such distinctions may be informative and pertinent.

iii. EPA's proposed rule for cement kiln dust (CKD)[3] – while not directly applicable, cement kiln's use limestone as a raw material, have been known to dispose of CKD (also, a combustion residual) in limestone mines, and thus there may be some meaningful information associated with placing combustion residuals in limestone mines.

iv. EPA's Land Disposal Restrictions Rule (40 C.F.R Part 268), which includes a specific provision for "no migration petitions." While this rule pertains to hazardous waste, and the CCR Final Rule did not provide for a "no migration petition", the Sterling Ventures claim of no impacts to surface waters, groundwater, and air has significant similarities to a no migration claim, and the regulatory requirement and associated guidance for supporting such claims may be informative.

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[2] 78 FR 9112, February 7, 2013.
[3] 64 FR 45632, August 20, 1999.

v. Congressional testimony by EPA's Assistant Administrator, Mathy Stanislaus[4], as well as testimony from the Association of State and Territorial Solid Waste Management Officials[5], the Utility Solid Waste Action Group[6], the Southern Environmental Law Center[7], and the Environmental Council of States[8] regarding the House Bill titled "Improving Coal Combustion Residuals Regulation Act." This testimony addresses comments regarding the functioning of state programs under EPA's final CCR Final Rule, that may help clarify or correct statements made regarding the functioning of State programs relative to the CCR Final Rule.

vi. Kentucky's current special waste regulations that address beneficial reuse of CCR, permit requirements for special waste permits, including CCR landfill disposal permits, and the design and operating requirements for special waste landfills:

http://www.lrc.ky.gov/kar/401/045/010.htm
http://www.lrc.ky.gov/kar/401/045/060.htm
http://www.lrc.ky.gov/kar/401/045/070.htm
http://www.lrc.ky.gov/kar/401/045/030.htm
http://www.lrc.ky.gov/kar/401/045/110.htm

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[4] http://democrats.energycommerce.house.gov/sites/default/files/documents/Testimony-Stanislaus-EE-2015-03-24.pdf

[5] http://democrats.energycommerce.house.gov/sites/default/files/documents/Testimony-Forbeck-EE-Coal-Ash-2015-03-18.pdf

[6] http://democrats.energycommerce.house.gov/sites/default/files/documents/Testimony-Roewer-EE-Coal-Ash-2015-3-18_0.pdf

[7] https://www.southernenvironment.org/news-and-press/news-feed/testimony-before-senate-committee-reaffirms-need-for-strong-epa-coal-ash-ru

[8] http://democrats.energycommerce.house.gov/sites/default/files/documents/Testimony-Paylor-EE-Coal-Ash-2015-03-18.pdf

COMMONWEALTH OF KENTUCKY

BEFORE THE PUBLIC SERVICE COMMISSION

In the Matter of:

INVESTIGATION OF KENTUCKY UTILITIES	**)**	
COMPANY'S AND LOUISVILLE GAS AND	**)**	**CASE NO. 2015-00194**
ELECTRIC COMPANY'S RESPECTIVE NEED	**)**	
FOR AND COST OF MULTIPHASE	**)**	
LANDFILLS AT THE TRIMBLE COUNTY	**)**	
AND GHENT GENERATING STATIONS	**)**	

REBUTTAL TESTIMONY OF
ROBERT M. CONROY
DIRECTOR, RATES
KENTUCKY UTILITIES COMPANY AND
LOUISVILLE GAS AND ELECTRIC COMPANY

Filed: September 10, 2015

Q. Please state your name, position, and business address.

A. My name is Robert M. Conroy. I am the Director of Rates for Kentucky Utilities Company ("KU") and Louisville Gas and Electric Company ("LG&E") and an employee of LG&E and KU Services Company, which provides services to LG&E and KU (collectively "Companies"). My business address is 220 West Main Street, Louisville, Kentucky 40202. My Direct Testimony in this matter was filed on August 6, 2015 and a copy of my professional history and education was attached to that testimony as Appendix A.

Q. What is the purpose of your rebuttal testimony?

A. The purpose of my rebuttal testimony is to respond to John W. Walters, Jr.'s August 6, 2015 direct testimony filed on behalf of Sterling Ventures ("Sterling"). Specifically, I address: (1) Mr. Walters' recommendation at pages 1 and 26 of his testimony to revoke the Certificate of Public Convenience and Necessity ("CPCN") authorizing the construction of a landfill at the Trimble County Generating Station ("Trimble Landfill"); (2) Mr. Walters' recommendation at pages 1 and 26 of his testimony to deny full cost recovery of the landfill at the Ghent Generating Station ("Ghent Landfill"); (3) Mr. Walters' contention at pages 8-9 of his testimony that the Companies should use his "spreadsheet analysis" rather than Strategist to assess and compare various alternatives; and (4) Sterling's inappropriate use of Commission proceedings to attempt to negotiate the contract it seeks with the Companies.

Q. Do you agree with Mr. Walters that the Commission should revoke the CPCN authorizing construction of the Trimble Landfill?

A. No. In Case Nos. 2009-00197 and 2009-00198, after a thorough investigation and a public and evidentiary hearing, the Commission issued a CPCN authorizing the construction of a multi-phase landfill for coal combustion residuals ("CCR") and related facilities, including CCR treatment and transport facilities, at the Trimble County Generating Station and recovery of the cost of the first phase of the Trimble Landfill through the Companies' environmental-cost-recovery ("ECR") mechanism. Although the capital cost of the Trimble Landfill has increased since the Commission issued that CPCN, it has always been and continues to be the least-cost feasible solution for managing CCR produced at the Trimble County Generating Station.

When the Commission issued the CPCN on December 23, 2009, it stated that the Trimble Landfill was "required for the long-term operation of both the existing generating unit, Trimble County Unit No. 1, and Trimble 2 … in the manner necessary to comply with the provisions of the Clean Water Act, the Resource Conservation and Recovery Act, and numerous state air quality environmental regulations which pertain to landfill operations. … Taken as a whole, the evidence indicates that the project is reasonable and cost-effective and will not result in a wasteful duplication of facilities and, therefore, we find that the requested CPCN should be granted."[1] That statement was accurate when made, has been accurate since then, and remains accurate today.

After the Commission issued its CPCN, the Companies were obliged to ensure that ongoing investment was prudent. In addition to the Commission's six-month and two-year ECR reviews under KRS 278.183, the Companies provided regular updates to Commission Staff verifying that continuing investments were prudent. Those

[1] See Case No. 2009-00197, Order at 8 (Dec. 23, 2009); Case No. 2009-00198, Order at 6.

meetings occurred on November 4, 2010, June 14, 2013, and February 5, 2015.[2] Moreover, as Mr. Sinclair explains in his Direct and Rebuttal Testimonies, within the past year, the Companies have continued to analyze the prudence of the Trimble Landfill and have concluded that, even with the cost increases, it continues to be the least-cost feasible alternative.

Q. Do you agree with Mr. Walters that the Commission should limit or disallow cost recovery of the Ghent Landfill?

A. No. In Case Nos. 2009-00197, the Commission issued a CPCN authorizing the construction of a multi-phase landfill for CCR at Ghent, including CCR treatment and transport facilities, and the recovery of the cost of the first phase of the Ghent Landfill through KU's ECR mechanism. Although the capital cost of the Ghent Landfill has increased since the Commission issued that CPCN, it has always been and continues to be the least-cost feasible solution for managing CCR produced at the Ghent County Generating Station.

When the Commission issued the CPCN on December 23, 2009, it stated that the Ghent Landfill was "required for the long-term operation of the station's four coal-fired generating units in the manner necessary to comply with the provisions of the Clean Water Act, the Resource Conservation and Recovery Act, and numerous state air quality environmental regulations which pertain to landfill operations."[3] That statement was accurate when made, has been accurate since then, and remains accurate today. The four coal-fired generating units at the Ghent Station continue to

[2] Copies of the slides the Companies presented at each meeting were attached to the May 22, 2015 Joint Application in this consolidated case as Exhibit 4.
[3] Case No. 2009-00197, Order at 7 (Dec. 23, 2009).

be an essential component of the Companies' generation fleet and typically some of the first units the Companies economically dispatch to meet base load requirements.

After the Commission issued its CPCN, KU was obliged to ensure that ongoing investment in the Ghent Landfill was prudent. In addition to the Commission's numerous six-month and two-year ECR reviews under KRS 278.183 since then[4], KU provided regular updates to Commission Staff verifying that continuing investments were prudent. Those meetings occurred on November 4, 2010 and June 14, 2013.[5] As I explained in my Direct Testimony and supported with examples, if any investment, including investment in the Ghent Landfill had become imprudent, KU would have ceased the investment prior to placing it into service in 2014. The Ghent Landfill continues to be the least-cost feasible alternative for managing CCR from the Ghent Generation Station.[6]

Q. Do you agree that the Companies should use Mr. Walters' spreadsheet analysis to assess various alternatives?

A. No. At pages 8-9 of his testimony, Mr. Walters contends that the Companies should use his Excel "spreadsheet analysis" rather than the Strategist model for comparing and analyzing various alternatives to meet a particular need. As I explained in my Direct Testimony in this case, the companies have used the Strategist model for comparing and analyzing various alternatives for solving a problem for the past two decades.

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[4] See Verified Joint Application of Louisville Gas and Electric Company and Kentucky Utilities Company for a Declaratory Order, pp. 9-10, Footnote 12 (filed May 22, 2015)

[5] Copies of the slides the Companies presented at each meeting were attached to the May 22, 2015 Joint Application in this consolidated case as Exhibit 4.

[6] See Mr. Sinclair's Rebuttal Testimony, pp. 2-5.

I explained in my Direct Testimony that Mr. Walters' spreadsheet analysis is based on Excel files used by the Companies in Case Nos. 2009-00197 and 2009-00198 to calculate the estimated annual impact on Total E(m), Jurisdictional E(m), and the incremental billing factor associated with the inclusion of the projects contained in the 2009 ECR Plan in the ECR mechanism over a five-year period. The incremental billing factor was used to estimate the bill impact only for purposes of providing the Companies' customers with public notice of the proposed change in rates.

At best, these Excel files produce a hand-calculation specific to the operation of the ECR mechanism of the annual revenue requirement for a project. On the other hand, the Strategist model the Companies use (as demonstrated in Mr. Sinclair's Direct and Rebuttal Testimony) has been presented to the Commission in many CPCN cases and Integrated Resource Plans for years and endorsed by Commission Staff.[7] Mr. Walters' may be more comfortable working with his Excel spreadsheet instead of Strategist given his complete lack of experience with Strategist,[8] but that does not mean that the Companies should abandon the tried and true Strategist model for comparing alternatives and the consistent results it produces.[9]

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[7] See, e.g., *In the Matter of: Joint Integrated Resource Plan of Louisville Gas and Electric Company and Kentucky Utilities Company*, Case No. 2011-00140, Staff Report at 44 (March 13, 2013)("The scope and depth of [the Companies'] reserve margin analysis, as well as the supply-side and demand-side screening analyses, are well developed and informative. The Staff concludes that the overall integration and optimization approach used by LG&E/KU is thorough, well-documented and reasonable in all respects.); See also, *In the Matter of: Joint Integrated Resource Plan of Louisville Gas and Electric Company and Kentucky Utilities Company,* Case No. 2008-00148, Staff Report (Oct. 28, 2009).

[8] See Sterling's September 3, 2015 Response to Item No. 19 of the Companies' Supplemental Data Requests.

[9] Mr. Walters' reliance on a witness's testimony in a matter before the Colorado Public Utilities Commission for the proposition that his spreadsheet analysis should be used instead of Strategist is misplaced (Walters' Direct Testimony, pp. 8-9). Although Mr. Walters quoted that utility witness accurately, that witness's opinion is immaterial to this proceeding, especially in light of the fact that the Companies have used Strategist for years with excellent results and with Commission Staff endorsement.

Q. Do you have an opinion for the Commission on the disposition of Sterling's Complaint?

A. Yes. Without question, Sterling's May 20, 2015 tendered Complaint and subsequent activity in this consolidated proceeding have been for business purposes. Sterling's mine is not a customer of the Companies. Understandably, Sterling is interested in its bottom line rather than the Companies' obligation to provide reliable service to its customers. This fact is best proven by Sterling's refusal to operate its mine as a CCR Landfill if placing CCR in its mine is not "beneficial use" under the EPA's CCR Final Rule. Moreover, the documents in Mr. Voyles' Rebuttal Collective Exhibit 1 demonstrate that Sterling is a disappointed bidder, now attempting to use this proceeding to further its own business interests.

As explained in Mr. Revlett's Direct Testimony, if placing CCR in Sterling's mine is not found to be beneficial use,[10] then Sterling would have to meet the onerous requirements of operating a CCR Landfill as defined under the CCR Final Rule. Sterling has been clear that it is not willing to operate as a CCR Landfill. Instead, Sterling says that it will continue to take the Companies' CCR for a 3-5-year period and transport it to a CCR Landfill (including the Ghent Landfill). Such a scenario would result in an unacceptable risk to the Companies' ability to operate the Trimble County Generating Station. Due to permitting difficulties, it has been six years since the Commission issued the CPCN authorizing the construction of the Trimble Landfill and construction still has not commenced. Given that length of time, it is clear that a 3-5–year period in which Sterling would transport CCR to some other

[10] See also Richard Kinch's September 10, 2015 Rebuttal Testimony. Mr. Kinch is perhaps the country's foremost authority on what constitutes beneficial use under the CCR Final Rule. He establishes without question that Sterling's placement of CCR in its mine would not qualify as beneficial use.

location results in an unacceptable operational risk for the Companies and its customers.

Mr. Sinclair's Direct and Rebuttal Testimonies demonstrate that the Trimble Landfill has been and remains the least cost feasible solution for handling CCR in the decades ahead among all alternatives, including Sterling's proposal. Mr. Voyles' Direct and Rebuttal Testimonies demonstrate that: (1) the Companies have carefully considered and developed a detailed operating plan for the Trimble Landfill; and (2) the Sterling proposal to place CCR is ill-considered, fraught with uncertainty and risk, and results in unacceptable risk. Mr. Revlett's Direct and Rebuttal Testimonies demonstrate that placing CCR in the Sterling mine would not be beneficial use under the CCR Final Rule and Mr. Kinch's expert opinion in his Rebuttal Testimony establishes that fact without a doubt. Indeed, Sterling recently stated, "If there had been any indication by the [KDWM] Staff, or the EPA, that the new CCR regulation prohibited the proposed beneficial use, Sterling would not have proceeded."[11] Given the Companies' clear demonstration that Sterling's offer would not be beneficial use, Sterling should not be permitted to "proceed" any further. Finally, Mr. Feddock's Rebuttal Testimony demonstrates that the Sterling mine does not currently have the storage capacity Sterling claims and that the Sterling mining and ventilation plans are not conducive to the placement of CCR in the volumes that are expected in the future.

The Commission has a long history of denying intervention to "unsuccessful bidders" in cases arising under KRS 278.020 for CPCNs. As recently as last year, the

[11] See Sterling's September 3, 2015 Response to Item No. 21 of the Commission's Supplemental Data Requests.

Commission confirmed that policy. In Case No. 2014-00002,[12] the Commission denied intervention to three separate "unsuccessful bidders" on the basis that their intent was driven by their "unsuccessful bidder" status. Each bidder sought to sell the Companies electricity and had submitted bids to do so which the Companies rejected as not being least cost. One of the benefits of that Commission policy is to prevent entities from using Commission cases in furtherance of their business interests. Naturally, Sterling seeks to further its business interests, but a Commission proceeding is not the appropriate forum to do so.

Q. Do you have a recommendation for the Commission?

A. Yes. I recommend that the Commission grant the declaratory relief the Companies sought in their Joint Application, namely, the issuance of a declaratory order affirming the ongoing validity and sufficiency of the Trimble Landfill CPCN (for the entire landfill) and environmental cost recovery authority (for Phase I of the landfill) the Commission granted in Case Nos. 2009-00197 and 2009-00198. I further recommend that the Commission terminate its investigation of this matter and dismiss Sterling's Complaint.

Q. Does this conclude your testimony?

A. Yes, it does.

[12] *In re the Matter of: Joint Application Of Louisville Gas And Electric Company And Kentucky Utilities Company For Certificates Of Public Convenience And Necessity For The Construction Of A Combined Cycle Combustion Turbine At The Green River Generating Station And A Solar Photovoltaic Facility At The E.W. Brown Generating Station*, Case No. 2014-00002, Orders of March 18, 2014 and March 31, 2014.

VERIFICATION

COMMONWEALTH OF KENTUCKY)
) SS:
COUNTY OF JEFFERSON)

The undersigned, **Robert M. Conroy**, being duly sworn, deposes and says that he is Director - Rates for LG&E and KU Services Company, and that he has personal knowledge of the matters set forth in the foregoing testimony, and that the answers contained therein are true and correct to the best of his information, knowledge and belief.

Robert M. Conroy

Subscribed and sworn to before me, a Notary Public in and before said County and State, this 10th day of September 2015.

Judy Schooler (SEAL)
Notary Public

My Commission Expires:

JUDY SCHOOLER
Notary Public, State at Large, KY
My commission expires July 11, 2018
Notary ID # 512743