REFLECTIONS ON PROGRESS WITH MINE DUST CONTROL AND DUST CONTROL TECHNOLOGY

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INTRODUCTION

It is obviously impossible to provide a detailed historical or even present-day account of the control of dust in mines and dust control technology in the brief time allotted to me. Therefore, as a compromise this theme paper highlights major selected subject areas of scientific and technical knowledge that have culminated in the current degree of dust control and control technology in U.S. mines. What were the historical understandings and emphases; what types of knowledge were gained through laboratory and applied research that permitted us to effectively implement dust control strategies through either voluntary or regulatory societal mechanisms? In different nations there has been a shared concern with this occupational problem, and the contributions to understanding have been multinational. Bear with me if I tend to oversimplify; it is my belief that at times we must sit back and take a long look at what has been called the "drum roll of history." This enables us to discern "the big picture" from the many necessary and essential details that punctuate progress in any field of human endeavor. It also enables us to better consider where we are at present and to define further, needed progress.

CONTROL OF MINE DUST

Recognition of Coal Workers Pneumoconiosis as a Disease State

The report by Bedford and Warner[1] in Great Britain in 1943 must be regarded as a major turning point in our understanding of the impact of inhaled coal dust and of dust control in mines in Great Britain. This report stimulated the adoption of airborne dust standards for "approved dust conditions" in conjunction with employment underground. No specific dust concentration limits or standards were set by law, but the adopted standards in the attainment of dust suppression continued for almost 30 years. The standards were the result of extensive studies of pulmonary disease in South Wales coal miners conducted by the Medical Research Council. These studies were conducted in five mines; they associated dust with x-ray abnormalities. The British later extended these studies to a larger number of mines, i.e., the so-called 25 Pit Studies.

The proposal for a standard was that not more than 10 milligrams per cubic meter of anthracite dust or 1 milligram per cubic meter of minerals other than coal for particles 5 microns or less in size, should be achieved. Note that the particle number standards for approved mine dust conditions introduced in Britain in 1949, remained basically the same until 1970, when gravimetric standards were introduced, again resulting from epidemiologic studies relating dust and pneumoconiosis. Thus, in Great Britain there was recognition of the disease state and adoption of standards for approved dust conditions.

In the United States, a major 1936 report by the Public Health Service[3] indicated that the term anthracosilicosis, as used, was a descriptive title for the form of pneumoconiosis commonly called miners' asthma. It was diagnosed by occupational histories, clinical examination and x-ray exams. The report indicated that the correlations "between exposure to dust and the evidence of constitutional changes left little doubt as to the etiological significance of the dust in the air breathed." Similar correlations were found between the silica exposure and the extent of pulmonary changes. Investigators concluded that employment in an atmosphere containing less than 50 million dust particles per cubic foot would produce a negligible number of cases of anthracosilicosis when the quartz content of the dust was less than 5%. This report was also an extraordinarily important one in that it lead to adoption of the standards for free silica in the United States, which are in effect to this day under our Occupational Safety and Health Act, if the user chooses to utilize midget impinger sampling and dust counting methods to evaluate dustiness.

My point in citing these two reports is to indicate that acknowledgement of the correlation between the disease state and the etiological agent is essential before control efforts can take place. In the 1950s the Commonwealth of Pennsylvania pioneered in studies of coal miners that lead to the recognition of the disease state of coal workers pneumoconiosis in bituminous coal miners, as contrasted to anthracite miners. Thus, the 1930's U.S. investigations resulted in differentiation between free silica in the dust causing silicosis, and miners' asthma occurring in hard coal mines. We spent another 25 years in the United States debating legitimacy of the disease state of coal workers pneumoconiosis, which seriously hampered efforts at dust control. In this regard, the British reached consensus on this point before we did.

The Physics of Dust

In order to control the dust associated with a disease, one must know a great deal about dust physical and chemical properties. Although there were scientific treatises on dust properties as early as 1934,[2,37] these volumes were very limited in the technical information provided that could be translated to the measurement and control of mine dust. The dust measurement techniques in effect during the 1930's were the midget impinger[16] developed in the United States, and the Kotze' Konimeter,[26] developed in South Africa. Gravimetric techniques were not extensively utilized to assess airborne dust for disease prevention until the late 1940's and 1950's. In fact, calibration of the impinger for coal dust particles (the only particles for which, to my knowledge, the instrument was ever calibrated) was reported by C.N. Davies in 1951.[9] The concept of aerodynamic particle size remained to be elucidated. However, even without these understandings enormous progress in mine dust reduction could be, and was made, as evidenced in South Africa in the 1930's through the 1950's.

The ability to advance beyond the qualitative understanding that inhalation of dust is dangerous to your health and that dust concentrations measured as described correlate with disease prevalence in exposed workers, also depends upon insights into the hygienically significant sizes of inhaled particles. The development of this area of understanding is my third selected critical area of knowledge for effective dust control.

Dust Deposition in the Human Respiratory Tract

Drinker and Hatch[11] traced the examination of particles in exhaled air to studies by Tyndall in 1882, and also cite a hygienic study by Saito in K.B. Lehmann's laboratory in 1912. Studies in the 1930's on nasal filtration by normal men were performed by Lehmann and by Torangeau and Drinker. The studies by Brown in 1931 were the first major studies on dust retention in man.[5] Experimental investigations by Davies,[8] Landahl and Hermann,[23] Van Wijk and Patterson[36] and Wilson and LaMer,[38] supplemented by theoretical calculations by Findeisen,[13] all advanced the state-of-the-art of particle size deposition in the human respiratory tract. The particle inhalation study that dictated U.S. views on deposition for two decades was that by Brown, et al., in 1950.[6] It was the major source of definitions for respirable dust in the U.S. and Europe, and for the very important report on dust deposition and retention in the human respiratory tract by the International Congress on Radiological Protection in 1966.[35]

These were the first of a long series of experiments, still continuing, to define the particle sizes of significance for chronic disease developing in the pulmonary compartment of the respiratory tract. The studies have been refined and there has been international agreement on the deposition curves in healthy men after inhalation at standard volume. The subject was reviewed by Lippman[24] and the new definitions of compartmental deposition in the human respiratory tract have been published.[27]

The significance of this work was that it provided a target in terms of the spectrum of particle sizes of hygienic importance in dusty environments, and enabled those interested in control to take aim at that target.

It should be noted that during all of this work the characteristic "size" of a particle was the projected area diameter, because the predominant instrument for viewing collected dust particles was the light microscope. In the light microscope one observes a silhouette, a two dimensional representation of a three dimensional object, the dust particle. Work performed at a later date would differentiate between the aerodynamic size of a particle and the silhouette size of the particle that one observes in the microscope. While this may appear to be a minor physical differentiation, it is of the utmost significance. It explains why we observe fibers 200 microns in length in the human pulmonary compartment; their aerodynamic size is equivalent to a less than 10 µm diameter sphere of unit density which could penetrate to that region of the respiratory tract. It took many years for the significance of the aerodynamic size to be recognized.

The understanding of dust aerodynamic behavior and deposition in the lung required decades to crystallize. The control of dust could progress, but there was great uncertainty if one was capturing the sizes appropriate to the disease state. An analogy is use of a shotgun versus a target rifle. The standardization of so called "respirable dust" and the development of an instrument to simulate that dust size waited until 1954 when B.M. Wright in England introduced the horizontal elutriator.[39] Dust control efforts were proceeding in all industrialized nations, but it is fair to say that permissible dustiness was far above the concentrations we have today in mines of industrialized nations. There was also great uncertainty in the long term benefits associated with the control efforts, because the largest particles have the greatest weight associated with them. There could be extensive reductions in dust measured in terms of weight per unit volume; there could, however, still be only conjectural impact on the disease state, because the smallest particles reaching the pulmonary compartment are associated with the least weight per particle.

West Germany began a series of epidemiologic studies in their mines in the search for the dust parameter that would best correlate with disease. They concluded that the surface area of the dust was an appropriate parameter and developed their dust measurement techniques accordingly. At a later date, they too would recognize the respirable dust concept with cyclone precollector sampling to determine respirable dust weight. During all the years of the 1950s and 1960s the British counted particles using a thermal precipitator instrument and reported their dust concentrations in numbers of appropriately sized particles per cubic centimeter of air.

Instruments to Measure Respirable Dust

It is interesting to peruse the first volnme of air sampling instruments entitled "The Encyclopedia of Instrumentation for Industrial Hygiene."[40] The volume is concerned with many different types of air sampling instruments. The cascade impactor, the midget impinger, and the electrostatic precipitator were the major instruments available for particulate sampling in 1956. Indeed, at a Governor's Conference in the Commonwealth of Pennsylvania in 1964 a leading U.S. industrial hygienist who was director of industrial hygiene for our major steel firm, and a previous President of the American Industrial Hygiene Association, stated publicly that the respirable dust concept then in vogue in England and Germany was not applicable to United States mines. Thus, one reason that efforts to develop instruments that would apppropriately sample respirable dust in coal mines did not rapidly progress in the U.S. was because the respirable dust concept was not readily accepted.

Subsequently, appropriate instruments were developed in the 1960s, utilizing a United States Atomic Energy Commission cyclone preseparator and the definition of the United States Atomic Energy Commission for respirable dust. It approximates the BMRC respirable dust acceptance curve defined by the horizontal elutriator.[20] These instruments approximated the accepted pulmonary deposition curve at that time, mainly based on the data of Brown et al.[5]

The dust standards in mines enforced in Great Britain during the period 1949 to 1970 were summarized by Chamberlain et al.[7] The British abandoned the particle counting standards in 1970 and adopted gravimetric standards. The introduction of gravimetric standards in the United States accompanied the Coal Mine Health and Safety Act of 1969.

The Mine Health and Safety Act of 1969 required that beginning June 30, 1970 the operator of each coal mine was required to maintain the average concentration of respirable dust in the active working at or below 3.0 milligrams per cubic meter. The standard was reduced to 2 milligrams per cubic meter after December 30, 1972 and has remained at this level.[32] Because of the difficulty of adapting to this standard an Interim Compliance Panel was authorized to issue a permit for non-compliance for a dust concentration as high as 4.5 milligrams per cubic meter while the standard was 3 milligrams per cubic meter, and for 3 milligrams per cubic meter when the standard was 2 milligrams per cubic meter. However, by December 30, 1975 the 2 milligrams per cubic meter was to be met. In the U.S. we are still not meeting that standard in all mines. The Mine Safety and Health Administration has developed an elaborate sampling procedure to insure compliance with this standard. The procedure involves sampling key occupations or key locations in the mine. The progress in dust control in mines has been achieved with a regulatory inspectorate for approximately 275,000 miners that equals the inspectorate of the U.S. Occupational Safety and Health Administration, which has responsibility for over 75 million workers at all types of worksites. Mine Safety and Health Administration inspectors in the United States visit every mine many times in a given year; the probability for a visit by an OSHA inspector to a workplace are, on the average, less than one in 50 for most businesses.

RISK LEVEL OF PRESENT STANDARD

Since 1982, there has been major emphasis on risk assessment in the regulatory process in the U.S.[30] The 1969 U.S. standard for permissible dustiness in mines was keyed to the British standard. It is interesting to review the risk level estimated to be associated with that standard. The interpretation of risk level can be derived from the British and the German epidemiological studies. In England the 25 pit study provided the data base.[22] In the British studies the quartz in the coal dust varied from 0.8% to 7.8% (respirable dust), with an average of 4.1%. The progression of the disease seemed to be associated with the quartz content of the respirable dust. Nonetheless, the probability of occurrence of 0/1 ILO classification x-ray for mean dust concentration of 2 milligrams per cubic meter for 35 years of exposure, is approximately 4%. The probability that a man starting with no pneumoconiosis (category 0/0) will be classified into 2/1 or higher after 35 years exposure to 2 milligrams per cubic meter is about 1 1/2% for low rank coal; 3% for high rank coal.[31] The U.S. estimate of CWP category 1 at 2 mg/m^3 is 9%; category 2 is 1–2%. In terms of current risk levels being discussed in the United States for other airborne contaminants, this is a somewhat high risk level. For example, the current estimate of risk at 0.2 fibers per cc for 35 years asbestos exposure is 0.7% for lung cancer and mesothelioma, with virtually zero risk of asbestosis. The 35 year time base for estimate of the risk is the same as that for respirable coal mine dust.

The German epidemiological studies occurred in 10 coal mines over a 10 year period.[29] A cumulative dust index was utilized based on light scattering measurement of the dust. Thus, the dust measurement was dependent on some function of the dust surface area. The German investigators related the Tyndallometric fine dust concentrations to the gravimetric fine dust concentrations measured with a cyclone/filter collecting device. They concluded that the ratio varied with coal rank; therefore, there was considerable uncertainty in a general correlation, but they did correlate by high, medium and low ranks of coal. Using the index developed, a cumulative dust value of 50,000 was associated with definite pulmonary change. The parameters influencing the conversion from light scattering to gravimetric measurements were a dirt concentration factor and the fineness factor of the dust, which influences the degree of forward scattering of light in the instrument. The concentration range of 0.9 to 1.5 milligrams per cubic meter as measured by the cyclone, was estimated to correspond to a cumulative fine dust concentration measured by light scattering of about 125,000. If I correctly interpret the publication describing these results, there would be a risk of about 5% of light to medium pulmonary changes with a 6,000 shift exposure to approximately 1.5 milligrams per cubic meter, indicating a risk level about that encountered in Great Britain and the U.S. These estimates are very intimately associated with the rank of coal and my conversions are therefore a rough estimate.

Chemical Composition of Dust and Coal Miners' Pneumoconiosis

The pathophysiology of coal miners pneumoconiosis is still not well understood. The presence of quartz in the dust is a confounding factor. The present tools for disease diagnoses, namely x-ray and pulmonary function testing, cannot differentiate in the living miner between silicosis and coal workers pneumoconiosis. There is considerable disagreement at the lowest ILO classifications re: the disease state. Promising efforts to understand the disease state, as reflected in the present research emphasis, appears to be correlation of residual dust components for dust retained in the lungs and analyzed post mortem, with components of the exposure dust.[34] In particular, there seems to be increasing emphasis in the United States on free silica content of mine dust. MSHA is increasingly stressing the silica content of the dust. The classification in 1986 by the International Agency for Research on Cancer of crystalline free silica as Class 2A gives further impetus to the emphasis on free silica.[33] The inability to estimate the free silica of the airborne dust on the basis of settled dust has long been known.[12] It is now possible to measure free silica in respirable dust samples with a sensitivity of 1–10 micrograms, depending on technique, and it is anticipated that with the IARC classification there will be a change of the current U.S. silica standard, which is presently stated as a sliding scale for permissible dustiness based on free silica content.

In summary, the control of dust in mining has witnessed enormous progress during the past 20 years, stimulated by increased regulation in many countries, including the U.S., and innovative development of standards in South Africa, Germany and England, standards preceded by extensive epidemiological investigations that provided an estimate of the risk levels associated with adopted numbers. Areas of knowledge that required development to efficiently implement dust reduction in mines were the deposition of dust in the respiratory tract and the physics of dust, the latter required for instrument development and sensitive analytical techniques to measure the dust collected. Different nations took different approaches to the evaluation of dustiness but almost all now utilize gravimetric methods, for both feasibility and for scientific reasons. When compared to risk levels associated with standards now being adopted for other airborne contaminants in the United States, there is need to further consider the airborne respirable mine dust standard. Recent classification by IARC of crystalline free silica as a Class 2A carcinogen strongly suggests the need to better understand the exposure to and impact of free silica in coal mine dust, in particular. Having discussed selected topics in the control of mine dust, I will now briefly look at the progression of dust control techniques in mines. What are the technologies that have brought about this progress and how much further can we exploit these technologies, or are other "understandings" needed to make further progress?

DUST CONTROL TECHNOLOGY

Ventilation

The Office of Technology Assessment in its 1984 report Controlling Hazards in the Workplace[27] introduced the terminology of the "hierarchy of controls," with engineering controls at the top of the hierarchy and administrative procedures and work practices following; personal protective equipment is the last intervention to control exposure. Among the engineering controls are control at the source and control by substitution. The seven engineering controls listed by OTA are shown in Table I. In 1950 in a review of literature on dusts,[14] the authors quote Harrington, a 1934 reference[18] with regard to the control of dust in mines. Harrington indicates that ventilation, fire protection and prevention, health, safety and efficiency are very closely interlocked in mines. He indicates that ventilation is perhaps the major route for control of hazards in mining, both in metal and nonmetal mines, permitting the worker to exert himself in comfort at maximum physical capacity without endangering his health. He focuses very heavily on "the best remedy for the dust menace in mines, other than preventing its formation, is the universal coursing of currents of air to remove the dust, as it has been proved that the very fine, most dangerous dust in metal mines remains suspended..." Harrington indicates that spraying devices available to reduce dust while drilling may be effective if used intelligently. However, they may even intensify the air dustiness if used without intelligence and, unfortunately, the latter is generally the case. He points to the availability of efficient water drills. Harrington also indicates that while finely divided dust "in mines is probably the chief cause of miners consumption, it is now recognized that there may be other factors of almost equal influence, such as high temperatures and humidities, harmful gases, and lack of air movement; all of these defects are readily remedied by ventilation." Table II is a summary of approaches or "lines of attack" for dust control in mines, as presented by Hamilton in 1972.[17] It differs little from Harrington's approach.

Table I

OTA Hierarchy of Controls: Engineering Controls
Elimination
Substitution
Isolation
Enclosure
Ventilation
Process Change
Product Change

Table II

"Lines of Attack" for Dust Control in Mines[17]

1. Removal and dilution of dust by ventilation.
2. Contol of the formation and dispersion of dust by attention to the method of mining and the way in which machines are operated.
3. Application of water, either to limit the dispersion of dust into the air, or to suppress airborne particles.
4. Use of exhaust ventilation to contain dust sources, followed either by ducting the dusting air to unoccupied parts of the mine, or by filtration before returning it to the main ventilation current.

The use of water in drilling and in mining has a long history. The British Coal Mines Act of 1911 required that a drill worked by mechanical power "shall not be used for drilling in ganister, hard sandstone, or other highly siliceous rock, the dust from which is liable to give rise to fibroid phthisis, unless a water jet or spray or other means equally efficient is used to prevent the escape of dust into the air."[21]

Water

Water has also been used, particularly in Western Europe to infuse the coal seam prior to drilling. Coal piles have been wetted after blasting and after cutting. Permanent use of water is not possible because moisture can be detrimental to certain processes in minerals and in some mines limited quantities of liquid must be used if the product is to be marketed. Wetting agents have been added to water and in recent years droplets have been electrified during spraying to increase contact with the dust. Foams has also been utilized, the theory being that dust particles will be trapped in the individual cells of the foam and subsequently wetted by the liquid as the cells collapsed.

The development of our understanding of aerosols and particles owes much to the concerns of mining. In particular, the work of the Safety in Mines Researcb Establishment in Sheffield, England and the Bergbaustaubsverein and the Silicosisforscungs Institut in the Ruhr were major contributors to the pool of knowledge of the physical properties of dust as reflected in compendium volumes such as that by Green and Lane.[15] Other summaries of particulate knowledge also reflect the contributions of investigators at these institutes who, although they were pursuing applied research, recognized the necessity for basic contributions on the physics and chemistry of dust. The names of Cartwright, Hodkinson, Davies, Robock, Hamilton and Timbrell immediately come to mind. It is not my purpose here to dwell on the specific research investigations that lead to progress in the control of mine dust. Rather, I believe it is possible to discern the trends in this area, as reflected in comparing a 1980's review published in the United States with the earlier literature on dust control in mines.

The review by Breslin and Niewiadomski[4] of the United States Bureau of Mines was published in 1984 and reviews progress in dust control technologies for U.S. mines from 1969 to 1982. In this report the authors stressed the control of dust formation, primarily. The relationship of coal cutting to the generation of airborne dust is highest on the priority list of the Bureau's dust control "understandings" for control technology. This is an extension of the innovative work by Hamilton in England.[17] The type of cutting bit, the depth of cut, the possibility for injecting water through the bit, the number of bits used, are all aspects of this research program. Because the mining methodology in the U.S. is shifting very rapidly to longwall production the applications of these techniques to the longwall operation both at the cutting site and upstream are focused upon. As indicated in the earlier statements by Harrington, the dust movement caused by the application of water is of great concern in these investigations. Ventilation is still our major workhorse in the dilution and removal of dust through both blowing and exhaust, but a substantial gain is achieved through the use of water injection and control of cutting.

The Bureau also focuses upon the use of dust collectors for trapping the dust; these operate both on scrubbing and filtration principles. The trapping of the dust after generation permits the use of the air without its burden of respirable mine dust. The largest fraction of work performed by the Bureau in these years was for in situ testing of these techniques after laboratory evaluation. A great deal has been learned about the equivalent volume of air cleaned versus water pressure as a function of different types of spray nozzles in the wet type scrubbers. Wetting agents have also been tested and there is some reported incremental gain due to their use. In the course of advancement of this technology the Bureau lists the following basic "understandings" whicb have come from this work.

- Laboratory studies showing the relationship between dust generation and the specific energy used to cut coal.
- Studies of deposition of aerosol on electrostatically charged surfaces.
- Experimental research on the dynamics of water drops impacted on surfaces.
- Development of laboratory apparatus for generating water drops of uniform size and for measuring drop size.
- Measurement of the adhesion force between dust particles and surfaces.
- Characterization of the physical and chemical properties in mine dust.
- Development of technology for automatic measurement of particle size, shape and composition using a scanning electron microscope.
- Studies of the efficiency of dust sampling inlets.
- Development of apparatus for generation of laboratory aerosols.
- Studies on the effect of water sprays on air movement and dust suppression.

The Bureau indicates that fundamental research was done with the ultimate long term goal of improving technology for control of dust in mines and that meant many of these areas of knowledge have applications in areas other than mining. The National Academy of Sciences in 1980 issued a report[25] in which the Academy directed the Bureau towards research which "should be directed more toward obtaining fundamental understanding of the origin, transport and characteristics of respirable coal mine dust." One could say this is expected from an Academy report, but I prefer to think that there is finally broad recognition of the need to understand fundamentals in order to develop technology.

The future goals of the dust control technology in the Bureau are also of interest. They are stated as:

- Optimization and in mine application of the new water spray system ("Shearer/Clearer") for longwall dust control.
- In-mine evaluation of new and emerging longwall dust control technology.
- Determination of the applicability and effectiveness of water powered scrubbers at longwall operations and on continuous miners.
- Completion of field evaluation and application of a mine worthy twin scrubber system for continuous miners.

- Development and testing of optimal ventilation systems for dust control during continuous miner operations.
- Redesign, testing, and application of an improved canopy-air curtain system in underground as well as surface operations.
- Development of a basic understanding of the formation of transport of dust during the cutting cycle for development of more effective controls.
- Development and testing of improved bagging machine dust controls, bag ceiling, cleaning and disposal techniques for the mineral processing industry.
- Development of dust suppression systems for cutter machines and other equipment used in conventional mining operations.
- Development of improved dust controls for conveyors, transfer points and stage loaders.
- Determination of cutting force in coal seam for use in development of deep cutting machines.
- Development and testing of improved personal dust exposure.

It would be interesting to compare these research goals for control of dust in mines with those of other nations commiting significant expenditures to development of dust control technology at the national level. As one reviews progress in this field over the past 50 years, it is striking that the impetus for sharing of information has come from the professionals and the professional associations and not through their governments. Thus, the first International Pneumoconiosis Conference was held in South Africa, very much due to the efforts of Dr. Beadle, who was preeminent in development of a dust control and medical surveillance program in South Africa. The inhaled particles and vapors series of conferences, a major stage for sharing of information by investigators and practitioners, was sponsored by the British Occupational Hygiene Society. The overlapping of many research program areas is apparent in the past. One wonders if we can become more efficient in our approaches to development of these new technologies. The scientific community will always share results, but the planning of research could greatly benefit by such an international effort.

It is impossible to not be struck by our utilization of the same workhorses for making progress with dust control in mines. We have reached the limit for bringing air to the face and diluting the generated dust. We are probably on the asymptotic portion of the curve for extracting greater efficiency from the application of water, either through the cutting tool or after the cut. We are in need of some new, innovative approaches. In view of the enormous progress over the last 2–3 decades with our understanding of disperse systems and aerosols, it would appear there is opportunity for introducing new and innovative ideas into dust control technology. There are analogies in other fields to this need. The treatment of hazardous waste is receiving major impetus because the major workhorse heretofore has been burial and storage in the ground, which has run its course and is associated with great risks for the future. New technologies are appearing and will undoubtedly have a major impact on the quantities of materials disposed of to ground by 1995. The Superfund Act and its recent renewal have stimulated this work. While the impression in England and perhaps also in the United States is that we have "solved" the problem of coal workers pneumoconiosis and dust in mines, in general, it is incumbent upon us to make clear that this is by no means true. We have made enormous progress, but it remains to bring our risk levels in concordance with those accepted for other work environments. Doing this efficiently requires knowledge and knowledge requires investment of funds.

On this note I would like to end. The story of dust control in mines has some logical development. It is troubling that the current perception is that the job is done, and that diversification of scientific effort and funds from this subject area is occurring in many countries. We must correct this erroneous perception in order to maintain and continue the hard won gains to date.

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