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Miners' Views About Personal Dust Monitors

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

hr	hour
in	inch
lb	pound
mg	milligram
mg/m^3	milligram per cubic meter
min	minute
oz	ounce

MINERS' VIEWS ABOUT PERSONAL DUST MONITORS

By Robert H. Peters,[1] Charles Vaught, Ph.D.,[2] Erica E. Hall,[3] and Jon C. Volkwein[2]

ABSTRACT

Coal workers' pneumoconiosis is the leading cause of death due to occupational illness among U.S. coal miners. This disease is caused by miners' exposure to excessive levels of respirable coal mine dust. A personal dust monitor (PDM) has recently been developed to provide near real-time feedback to miners regarding the level of respirable coal dust in the air they breathe. The main objective of this report is to document coal miners' reactions to this device and how they make use of the information it provides. It summarizes a field study by the National Institute for Occupational Safety and Health that documented the opinions of 30 miners at 4 underground coal mines concerning the use of PDMs.

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INTRODUCTION

Coal workers' pneumoconiosis (CWP) ("black lung") is the leading cause of death due to occupational illness among U.S. coal miners [Scott et al. 2004]. This disease is caused by miners' exposure to excessive levels of respirable coal mine dust. Although data on the prevalence of CWP in the United States indicate that it has declined substantially since 1970, new cases of CWP continue to be diagnosed [CDC 2006; Antao et al. 2005; CDC 2003]. CWP contributes to several hundred deaths in the United States each year [NIOSH 2005]. In 2004, federal black lung benefits totaling more than $726 million were paid to approximately 93,000 beneficiaries [OWCP 2007]. Data from the Mine Safety and Health Administration (MSHA) indicate that from the early 1980s to 2006 the underground coal mining industry experienced little change in level of exposure to respirable coal mine dust. In 1982, the mean value based on 86,000 samples from mine operators was 1.0 mg. In 2006, the mean value based on 26,000 samples from operators was 0.9 mg. During 1995–2006, 12% (40,790) of operator-collected designated occupation samples (337,066) and 15% (7,039) of MSHA inspector samples (47,966) exceeded the applicable dust standard [Niewiadomski 2007].

A personal dust monitor (PDM) has recently been developed through a collaboration involving the National Institute for Occupational Safety and Health (NIOSH), Bituminous Coal Operators' Association, United Mine Workers of America, National Mining Association, Thermo Fisher Scientific, Inc., and MSHA. This new device provides near real-time feedback to miners regarding the level of respirable coal dust in the air they breathe. The PDM has been field-tested at 10 mines and found to be at least as accurate as samplers currently in use [Volkwein et al. 2006]. As with the introduction of any new technology, it is very important to systematically document how workers react to it and make use of it. If miners know how to properly use the information that PDMs are capable of providing, they may be able to make adjustments to their workplace or work procedures that will reduce their exposure to respirable coal dust. There seems to be great potential. However, no one knows precisely how miners performing a wide variety of tasks and jobs are actually going to use this new information to reduce their exposure to dust.

By collecting and sharing information about how miners have begun to use PDMs, we hope to facilitate the effective use of this new technology to help prevent black lung disease. This report provides examples of (1) how miners use PDM information to discover the causes for exposure to high levels of respirable dust and (2) changes that miners are making in order to try to reduce their exposure. This report also summarizes a NIOSH field study that documented the opinions of a small number of mine safety directors and their staff who maintained the equipment for 4 weeks. The findings from interviews with 30 miners and 7 mine safety staff members are presented.

RESEARCH ON DETERMINANTS OF SELF-PROTECTIVE BEHAVIOR

What factors might prompt miners to consider taking actions to reduce their exposure to respirable dust? There is an extensive literature on factors that prompt people to engage in self-protective health and safety behaviors [Cohen 1987; Dillard and Pfau 2002; Glanz et al. 2002; McLeroy et al. 1988; Weinstein 1987]. McLeroy et al. [1988] suggest that a range of individual and environmental factors can influence behavior (and ultimately health). They organize these factors into the following levels of influence:

A. Intrapersonal/individual (e.g., knowledge, attitudes, and behaviors)
B. Interpersonal (e.g., family, social networks)
C. Organizational (e.g., workplace)
D. Community (e.g., relationships between organizations or institutions, and informal networks)
E. Public policy (e.g., local, state, and national laws and policies)

The following discussion attempts to summarize what is known about factors affecting workers' health-related behaviors at the intrapersonal/individual, interpersonal, and organizational levels and to explore how this knowledge can be applied to the prevention of CWP. The community and public policy levels are important considerations, but are beyond the scope of this report.

Intrapersonal / Individual Level

Researchers have found considerable empirical support for the Health Belief Model in explaining both behavior pertinent to prevention and behavior in response to symptoms or to diagnosed disease [Becker 1974; Janz and Becker 1984; Janz et al. 2002]. The findings from prospective studies are at least as favorable as those obtained from retrospective research. According to Janz et al. [2002], the Health Belief Model is considered a type of value-expectancy theory. This type of theory emphasizes the role of one's subjective hypotheses and expectations. Value expectancy theories hold that human behavior is a function of the subjective *value* of an outcome and of the subjective probability, or *expectation*, that a particular action will achieve that outcome. As shown in Figure 1, the components of the Health Belief Model include:

- A desire to avoid illnesses (value); and
- A belief that a specific health action available to a person would prevent or ameliorate illness (expectation).

The expectancy is further delineated in terms of the individual's estimate of personal susceptibility to and severity of an illness and of the likelihood of being able to reduce that threat through personal action.

Many investigations have helped to expand and clarify the Health Belief Model over the past 50 years [Rosenstock 1974; Kirscht 1974; Becker 1974; Janz and Becker 1984]. In general, it is now believed that people will take action to prevent, to screen for, or to control ill-health conditions if they regard themselves as susceptible to the condition, if they believe it would have potentially serious consequences, if they believe that a course of action available to them would be beneficial in reducing either their susceptibility to or the severity of the condition, and if they believe that the anticipated barriers to (or costs of) taking the action are outweighed by its benefits. For further definitions and commentary specifying key variables in the Health Belief Model, see Table 3.1 in Janz et al. [2002].

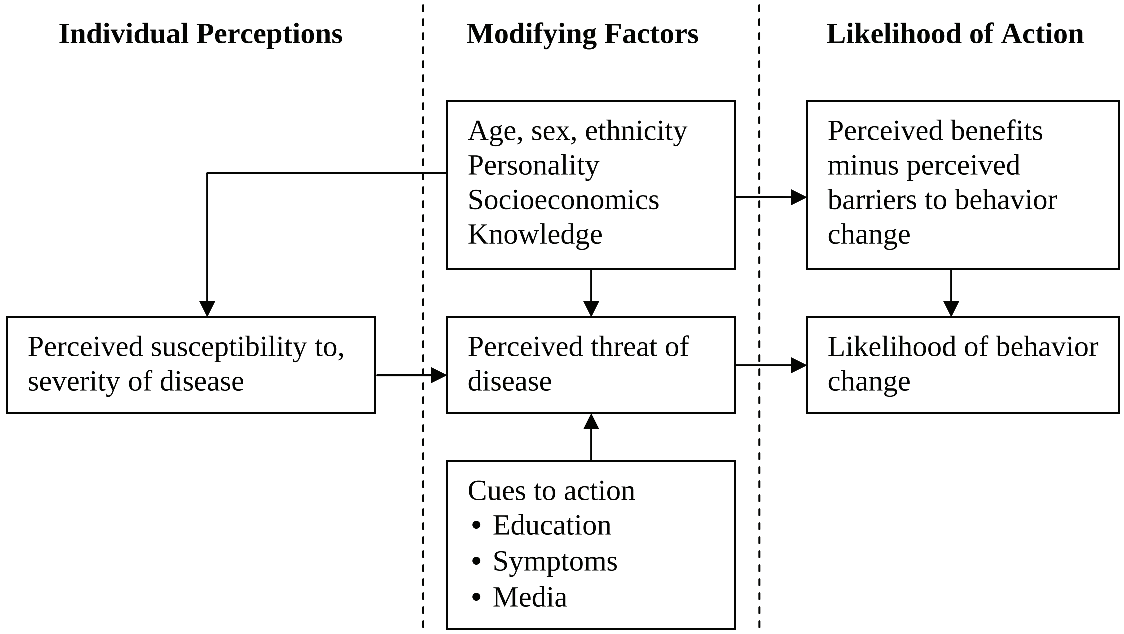

Figure 1.—Health Belief Model: components and linkages [Janz et al. 2002].

Perceived Susceptibility

This construct refers to one's perception of the risk of contracting a health condition. In the case of CWP, this dimension would include miners' personal estimates of susceptibility to CWP and/or acceptance of the diagnosis. The prevalence of CWP has declined over the past 30 years. This may have led some miners to believe that this disease is a thing of the past—something they no longer need to worry about.

Unfortunately, exposure to excessive respirable dust levels is still a significant threat to the health of many coal miners. As previously mentioned, CWP is listed as a contributing factor in the deaths of several hundred people in the United States each year.

Radiographic evidence of CWP disease progression was evaluated for underground coal miners examined through U.S. federal chest radiograph surveillance programs from 1996 to 2002 [Antao et al. 2005]. A case of rapidly progressive CWP was defined as the development of progressive massive fibrosis and/or an increase in small opacity profusion greater than one subcategory over 5 years. A total of 886 cases of CWP were identified among the 29,521 miners examined from 1996 to 2002, giving an overall crude prevalence of 3% for U.S. underground coal miners. Among the subset of 783 miners with CWP, who had had at least two radiographs, permitting progression to be evaluated, 277 (35.4%) were cases of rapidly progressive CWP. Progressive massive fibrosis was evident in 41 of these cases. Progressive massive fibrosis is a severe form of CWP in which large scars (at least ½ inch in diameter) develop in the lungs as a reaction to the coal dust. Progressive massive fibrosis may worsen even after exposure to coal dust stops. Lung tissue and the blood vessels in the lungs can be destroyed by the scarring.

Antao et al. [2005] found that the miners with rapidly progressive CWP were younger than those without rapidly progressive CWP, were more likely to have worked in smaller mines (defined as fewer than 50 employees), and also reported longer mean tenure in jobs involving work at the face of the mine (in contrast to other underground mining jobs). There was a clear tendency for the proportion of cases of rapidly progressive CWP to be higher in eastern Kentucky and western Virginia. Antao et al. [2005] conclude that, "Although the prevalence of CWP is declining in the United States, severe and rapidly progressive cases of the disease continue to occur among young miners. Of particular concern, miners with rapidly progressive CWP were significantly younger than other miners with CWP, strongly implicating recent mining conditions."

It is very important for miners to be made aware of situations in which they are being exposed to high levels of respirable dust. Particles of respirable dust are too small to be seen with the naked eye. Miners can be completely unaware that they are breathing a high concentration of these particles. PDMs should be a tremendous help in making miners aware of situations in which respirable dust is high. The greater the extent to which miners are aware of these situations, the greater the likelihood they will try to make changes to reduce their dust exposure.

Perceived Severity

This concept refers to one's feelings concerning the seriousness of contracting an illness, including evaluations of both medical and clinical consequences (e.g., death, disability, and pain) and possible social consequences (such as effects of the conditions on work, family life, and social relations). The combination of susceptibility and severity has been labeled the *perceived threat*.

The consequences of CWP are severe. This disease can have profound negative effects on one's quality of life and can significantly reduce life expectancy. Although respirable coal mine dust is relatively inert and does not provoke much reaction, it spreads throughout the lungs. Coal dust may block the airways. In simple black lung, coal dust collects around the small airways (bronchioles) of the lungs. Every year, 1%–2% of people with simple black lung develop progressive massive fibrosis, a more serious form of the disease. Progressive massive fibrosis may worsen even after exposure to coal dust stops.

Simple black lung usually does not cause symptoms. However, many people with this disease cough and easily become short of breath because they also have an airway disease, such as bronchitis or emphysema. The severe stages of progressive massive fibrosis, on the other hand, cause coughing and often disabling shortness of breath [Beers 2005].

It seems reasonable to expect that miners who know people who are suffering (or have died) from CWP are more likely to take action to prevent exposure to respirable dust. However, because the disease affects fewer people than it used to, fewer miners have any direct contact with the victims of CWP. It is important that coal miners be educated about CWP, including its causes and consequences.

Perceived Benefits

The *perceived health benefit* of taking various actions to reduce respirable dust exposure is the avoidance of a potentially very serious lung disease. The Health Belief Model argues that one's acceptance of personal susceptibility to a condition also believed to be serious (perceived threat) produces a force leading to behavior. The particular course(s) of action that miners will take depends on their beliefs regarding the effectiveness of the various available actions for reducing the threat of CWP.

There may also be some ancillary non-health-related benefits to performing the action. For example, the foreman of a mining crew might be motivated to take actions to reduce respirable dust in his/her crew's section in order to prevent the company from being cited and fined by MSHA. The foreman's motivation might also include a desire to be seen as a good supervisor or good person in general because he/she protects the crew from lung disease or to set a good example for the crew.

An individual exhibiting an optimal level of beliefs in susceptibility and severity would not be expected to accept any recommended health action *unless* that action was perceived as efficacious. PDMs should make it quicker and easier for miners to determine the extent to which any changes they make in their work routines or work environment are efficacious in reducing respirable dust levels. For example, if they make improvements to ventilation or dust control measures, they should soon see a significant drop in their respirable dust level.

Perceived Barriers

According to the Health Belief Model, the perceived negative aspects of a particular health action, or perceived barriers, may act as impediments to undertaking the recommended behavior. A kind of nonconscious cost benefit occurs, wherein the individual weighs the action's expected effectiveness against perceptions that it may be expensive, dangerous (having negative side effects or iatrogenic outcomes), unpleasant (painful, difficult, upsetting), inconvenient, time-consuming, etc. Thus, the combined levels of susceptibility and severity provide the energy or force to act and the perception of benefits (less barriers) provide a preferred path of action [Rosenstock 1974].

Discomfort or inconvenience. It is important to minimize any discomfort or inconvenience miners experience while wearing PDMs. Interviews with miners revealed a few things that might be changed with the design of the prototype PDM units to make them more comfortable to wear (presented later in this report).

Time and effort. It is assumed that miners are more apt to work in high respirable dust levels when they are in a hurry, and they believe that they can save some time by exposing themselves to high respirable dust levels in order to get something done quickly. This suggests that it is important to identify situations in which miners (1) are apt to be in a hurry to complete a task and (2) can save time by performing the task in an area of high respirable dust levels. Once identified, efforts should be made to redesign the equipment or work procedures so that (1) these situations arise less frequently and (2) when they do arise, it is unnecessary for employees to work in high levels of respirable dust—even if they are in a hurry to complete the task.

Likewise, it is assumed that the greater the perceived level of effort required to avoid high levels of respirable dust, the more apt miners are to work in it. Miners are responsible for performing many types of activities and have a limited amount of time and energy with which to get them done. This means that whether or not the miner chooses to avoid an area of high respirable dust levels may vary depending on the perceived importance of avoiding the dust versus the importance of performing various activities that they may feel compelled to complete within a certain period of time. Thus, their decision may depend on the amount of time and energy miners think they will need to avoid the high respirable dust levels relative to (1) the time and energy they think they will need to complete other activities for which they are responsible and (2) the time and energy they have available.

If miners find that they can reduce their respirable dust exposure by making simple changes that require little or no costs (expenditures of effort, energy, time, resources, etc.), most will do so. For example, they might learn that if they stand in a slightly different location while performing a task, their respirable dust exposure is lower. If miners cannot avoid being in high respirable dust levels at certain times, some will try to think of ways to reduce the concentration of respirable dust in the air.

Cues to Action

The concept of cues that trigger action has been discussed in various early formulations of the Health Belief Model. Hochbaum [1958], for example, thought that readiness to take action (perceived susceptibility and perceived benefits) could only be potentiated by other factors, particularly by cues to instigate action, such as bodily events, or by environmental events, such as media publicity. Janz et al. [2002] note that cues to action may ultimately prove to be important, but they have not been systematically studied: "The concept of cues as a triggering mechanism has been difficult to study in explanatory surveys; a cue can be as fleeting as a cough or the barely conscious perception of a poster."

Until now, miners' cues to action relative to CWP prevention may have included information from chest x-rays, advice or warnings from one's doctor, physical discomfort in the lungs, coughing, shortness of breath, or a perception of high levels of dust in the mine air. CWP is an insidious health problem. It often takes years to develop, and miners may not receive any cues to warn them that respirable dust is damaging their lungs. Miners may not experience any physical symptoms to warn them that they are developing CWP until the later stages of the disease. Also, since the dust particles that cause CWP are extremely small, miners may sometimes be unaware that these particles are in the air they are breathing.

The information from PDMs should serve as a very important cue to action. Wearing a PDM allows miners to see how their dust exposure varies throughout the course of their workday. They should soon learn what circumstances expose them to high dust levels. For example, once people who work on longwall crews begin wearing PDMs, they may realize that whenever they spend time inby the shearer, they are being exposed to respirable dust levels that are very high relative to being outby the shearer. Receiving real-time feedback about what causes high respirable dust exposure should help miners to become more cognizant of when they are in an unhealthy situation and, hopefully, to think about how they can prevent (or reduce time spent in) those situations.

Self-Efficacy

A growing body of literature supports the importance of self-efficacy in accounting for initiation and maintenance of behavioral change [Bandura 2004]. Self-efficacy is defined as "the conviction that one can successfully execute the behavior required to produce the outcomes" [Bandura 1977]. Self-efficacy is now generally thought to be a strong predictor of many health-related behaviors, particularly those that require significant skills to perform. For behavior change to succeed, people must (as the original Health Belief Model theorizes) feel threatened by their current behavioral patterns (perceived susceptibility and severity) and believe that change of a specific kind will result in a valued outcome at acceptable cost. They also must feel themselves competent (self-efficacious) to overcome perceived barriers to taking action.

It is expected that PDMs will enhance miners' perceptions of self-efficacy. It will hopefully give them a greater sense of control over their exposure to respirable dust. If they believe that they can do things to prevent exposure to high respirable dust levels, it may actually be easier to convince them that they should get chest x-rays. Over the years since its inception, rates of miner participation in NIOSH's free Coal Workers' X-ray Surveillance Program (CWXSP) have been rather low. A recent study estimates that only about 31% of miners employed at underground coal mines participate in the CWXSP [CDC 2003]. Some miners may have been discouraged by the idea of seeking out information about potential damage to their lungs because they believed there was very little they could do to reduce their respirable dust exposure (other than stop working as a coal miner). Evidence from focus groups recently conducted with coal miners about occupational hearing loss suggests that many miners do not want to have hearing screenings or tests because that would require recognition of the severity of their hearing loss [Murray-Johnson et al. 2004]. One miner stated, "I haven't had a hearing test in more than 15 years and I'm not planning on one. I don't even want to know."

Similarly, Leventhal et al. [2001] note that studies of people's response to fear-arousing communications tend to show that these interventions produced attitudinal and behavioral "avoidance." Thus intentions to drive safely and reports of decreases in cigarette smoking were enhanced by fear, whereas acts that could increase fear (e.g., taking a chest x-ray and perhaps discovering lung cancer) were inhibited by fear communications [Leventhal and Watts 1966]. Recent studies support the hypothesis that fear facilitates behaviors to prevent disease but *inhibits* behaviors to detect disease [Millar and Millar 1996]. In spite of this, efforts to change cognitions about health matters have often involved attempts to arouse fear [Leventhal 1970]. According to Protection Motivation Theory [Rogers and Prentice-Dunn 1997], the most persuasive communications are those that arouse fear while enhancing perceptions central to the Health Belief Model of the severity of an event, the likelihood of exposure to that event, and the efficacy of responses to that threat. According to Janz et al. [2002], "This view of the joint role of fear and reassurance in persuasive communication is generally accepted." However, Bandura [2004] believes that those who wish to help people reduce health-impairing habits through health communications need to put less emphasis on trying to scare people into health and more emphasis on providing people with the self-management skills and self-beliefs needed to take charge of their health habits. Stephenson et al. [2005] found that messages about coal miners' hearing loss prevention produced significantly greater self-reported adoption of hearing protection behaviors if they appealed to positive emotions rather than fear. Messages based on fear tended to stimulate psychological defensive mechanisms over time (e.g., denial) rather than producing the desired behavioral changes.

This suggests that simply telling miners that they are at risk of getting CWP and describing the ill effects of this disease may not, by itself, be enough to convince them to get a chest x-ray. They also need to be given information about how they can effectively protect themselves from exposure to respirable dust. Hopefully, if miners are given access to PDMs or other tools that can be used to protect themselves from respirable coal dust, they may be more willing to seek out information about the condition of their lungs, such as that provided by chest x-rays.

Other Variables

According to the Health Belief Model, diverse demographic, sociopsychological, and structural variables may affect the individual's perceptions and thus indirectly influence health-related behavior. Specifically, sociodemographic factors, particularly educational attainment, are believed to have an indirect effect on behavior by influencing the perception of susceptibility, severity, benefits, and barriers.

Miners, like all people, vary in their personality traits. Some are more averse to risk than others. Thus, some miners may have a stronger predisposition to avoid respirable dust and other health hazards than other miners. Age may be another important factor. Because CWP can take several years to develop, young miners may not initially take it as a serious threat to their health, especially those who do not plan to work as a coal miner for more than a few years. At the other extreme, miners who are nearing retirement may not be too concerned about coal dust causing further damage to their lungs. They know that they will soon be out of the dusty environment. Some may also realize that the damaging effects of respirable dust on their lungs is irreversible. After working for most of their lives in a dusty environment, there is nothing they can do to correct the damage. It is a problem they must simply learn to live with as best they can. Similarly, a study of hearing loss among miners by Murray-Johnson et al. [2004] recently found that age and longevity in the coal mining industry may serve as barriers to the use of hearing protection devices. Many miners reported ignoring their noise-induced hearing loss as it can be "hard to teach an old dog new tricks" and it was "probably too late to protect what I got."

In conclusion, several individual level factors seem to be important influences on one's decision to perform health-related behaviors. Fishbein et al. [2001] assert that, generally speaking, in order for a person to perform a given behavior, one or more of the following must be present:

1. The person forms a strong positive intention or makes a commitment to perform the behavior.
2. There are no environmental barriers that make it *impossibl*e to perform the behavior.
3. The person possesses the skills necessary to perform the behavior.
4. The person believes that the advantages of performing the behavior outweigh the disadvantages.
5. The person perceives more normative pressure to perform the behavior than to not perform it.
6. The person perceives that performance of the behavior is consistent with his or her self-image or values.
7. The person's emotional reaction to performing the behavior is more positive than negative.
8. The person perceives that he or she has the capabilities to perform the behavior under different circumstances.

The first three factors are viewed as necessary and sufficient for producing any behavior, while the remaining five are viewed as modifying variables influencing the strength and direction of intentions.

What does the foregoing discussion suggest about beliefs or conditions that might facilitate or inhibit miners from paying attention to PDM information?

Propositions about facilitators. Miners will be more likely to pay attention to PDM information if:

- They believe they have a lung problem or that they are susceptible to lung disease.
- They believe it is possible for them to significantly reduce their dust exposure. They have some control over their dust exposure.

- They believe that if they inform someone, others are capable and willing to do things to reduce their dust exposure (e.g., change the ventilation to their section).
- They believe that their company, supervisor, or coworkers would like them to find ways to reduce their dust exposure.
- They believe that they are being exposed to too much dust, and they expect to continue working in similar conditions for several more years.
- They want to prevent young people they care about (e.g., friends or relatives) from being exposed to too much dust.
- Nothing urgent is demanding or competing for their attention.
- They are just curious.

Propositions about inhibitors. Miners will be less likely to pay attention to PDM information if:

- They do not believe they are susceptible to lung disease.
- They do not believe it is possible for them to do their job without being exposed to high dust concentrations.
- They do not believe that others (engineers or management) are capable and/or willing to do things to reduce their dust exposure.
- They believe that it will upset people (e.g., their boss) if they say something about being overexposed to dust.
- They are already confident that they are not being exposed to high levels of respirable dust.
- They do not expect to work as a miner for much longer, or they do not expect to work in a job that exposes them to high dust levels for much longer.
- It would require a lot of extra effort/time to avoid high respirable dust levels.
- They are preoccupied with other more urgent demands for their attention.
- They rely on others to keep them from being overexposed (e.g., inspectors, supervisors, company engineers, or health and safety officials). They believe that others will soon figure out the best ways to reduce dust exposure, so they do not need to bother.
- They believe that it is inevitable that some miners are going to get lung disease no matter what (fatalism).

Interpersonal Level

The next higher level of factors influencing worker behavior with respect to health hazards is the interpersonal level. Underground coal miners usually work in small groups. Production crews usually comprise groups of 8–10 employees, and each group is physically isolated from the rest of the work force. The attitudes and actions of this small unit come to exert considerable influence on each individual in the crew. If peer pressure were used to discourage working in high respirable dust levels, it could have a sizable impact on most miners. On the other hand, peer influences may cause well-motivated and trained employees to take health and safety risks if such behavior will enhance their acceptance or status within the work group.

Hopefully, the presence of other people serves as an inhibiting factor. However, there may be situations in which the presence of others has the opposite effect. If miners believe that, in certain situations, their coworkers or foreman want them to do something that requires working in high respirable dust levels, then the presence of these individuals may actually make them *more* likely to do so.

Supervisor's priorities. Miners' perceptions of their immediate supervisor's attitudes about exposure to respirable dust are shaped over time through various communications and actions. These communications and actions may sometimes lead the employee to conflicting conclusions about what the supervisor expects regarding respirable dust exposure. In order to avoid creating any ambiguity about what is expected, it is important for supervisors to ask themselves the following questions:

- Have I communicated to all employees in the crew that I do not want them to expose themselves to high levels of respirable dust?
- Do I take whatever actions are necessary to stop miners from working in high respirable dust levels?
- Do I sometimes ignore miners who are in high levels of respirable dust?
- Do I sometimes set a bad example by spending time in high respirable dust levels myself?
- Do I sometimes ask miners to do things that are impossible to do without exposing themselves to high levels of respirable dust (e.g., telling a miner to quickly repair something on the longwall while the shearer is operating)?
- Do I frequently reprimand miners for inadequate productivity performance, but fail to say anything about inadequate health and safety performance?
- Do I praise miners for high coal production, but never say anything about good health and safety practices?

Over time, the first-line supervisors' attitudes about permitting persons in their crew to work in high respirable dust levels become shaped by the communications and actions of higher-level managers. Thus, it is important for higher-level mine managers to ask themselves many of the same questions. They must make it clear to first-line supervisors that the company expects all employees to avoid working in high respirable dust levels. Other people who may exert some influence on miners' level of concern over respirable dust include medical professionals, union officials, family, and friends.

Thus far, the discussion has focused on understanding factors that may prompt individual miners to consider taking action to reduce their exposure to respirable dust. The next section discusses factors that may prompt mining companies to consider taking action to reduce their miners' exposure to respirable dust.

Organizational Level

Sanctions and penalties are imposed on mining companies by government regulatory agencies whenever miners are found to be overexposed to respirable dust. Payments to the victims of black lung and their families are another form of economic penalty on mining companies. Steckler et al. [2002] argue that several other types of organizational level factors should be considered in efforts to enhance worker health because:

> (1) often, new health promotion programs are created and implemented within organizations—for example, a worksite physical fitness program for employees; (2) frequently, organizations adopt and implement new health promotion policies—for example, a school policy banning smoking on its campus; (3) usually, health promotion practitioners work within organizations

> that must change and adapt for the practitioner to be able to create and implement new programs, services, and policies; and (4) increasingly, health promoting organizations collaborate with other organizations in their communities to reach goals no single organization can accomplish alone. In all of these instances, the practitioner who understands the theories and principles of organizational change, and who has tools and skills for analyzing and facilitating change, is likely to be more successful than his or her counterpart who does not possess such knowledge and proficiencies.

The Stage Theory of Organizational Change explains how organizations innovate new goals, programs, technologies, and ideas. Kaluzny and Hernandez [1988] assert that, as organizations innovate, they pass through a series of steps or stages. Stage Theory emerges from two research traditions. The first extends from the work of Lewin [1951], who developed one of the earliest stage models. Lewin's model emphasizes factors that inhibit change efforts. It consists of three stages: (1) unfreezing of past behavior and attitudes; (2) moving by exposure to new information, attitudes, and theories; and (3) refreezing through processes of reinforcement, confirmation, and support for the change.

The second influence on the development of Stage Theory is Diffusion Theory. In the 1950s, Diffusion Theory focused on how individuals such as farmers, teachers, and physicians adopted innovations [Rogers 1983]. In the 1960s, innovation theorists realized that individuals often adopt innovations as members of organizations and that such individuals seldom adopt an innovation until it is first accepted by the organization.

Beyer and Trice [1978] have developed a comprehensive, well-defined model of Stage Theory that consists of seven stages:

1. *Sensing of unsatisfied demands on the system.* Some part of the system receives information indicating a problem or potential problem.
2. *Search for possible responses.* Elements in the system try to find alternative solutions.
3. *Evaluation of alternatives.* The various alternatives are compared.
4. *Decision to adopt a course of action.* An alternative is chosen from among those evaluated. Operative goals and means are specified, i.e., a strategy is adopted.
5. *Initiation of action within the system.* A policy or other directive for implementing the change is formulated. Resources necessary for implementation are acquired.
6. *Implementation of the change.* Resources are allocated for implementation. The innovation is carried out.
7. *Institutionalization of the change.* The innovation becomes part of routine organizational operations.

These seven stages may provide a useful way to think about how miners and mining organizations will use PDMs. This is discussed in more detail below.

It is important to consider organizational level factors that influence the use of PDMs because some important factors affecting miners' exposure to respirable dust may be beyond an individual miner's ability to control. For example, an individual miner must have others' help if the only way to reduce his/her respirable dust exposure is through the purchase of new equipment or supplies or through mine-wide changes in the ventilation system. It is very important that miners *believe* that their employer wants to know about situations in which they are being exposed to high levels of respirable dust. Obviously, whenever miners' end-of-shift average dust exposures are greater than the legal standard, the company should investigate and make whatever changes are necessary to reduce respirable dust. If the company knows that miners are being exposed to high respirable dust levels but fails to take action, miners may simply stop paying attention to their PDM altogether or may turn to regulatory agencies or their union representatives for help.

Mine managers, engineers (particularly those responsible for ventilation and dust control), company health specialists (particularly those individuals responsible for dust sampling), and labor representatives can do things or fail to do things that affect miners' exposure to respirable dust. As experience with PDMs increases, the nature of their influence will become more apparent.

In the case of mining companies adopting PDMs, different actors may play leading roles at different innovation stages. Senior-level corporate managers, engineers, and union leaders may be most important at the problem definition and early adoption stages. Mine-level managers and union leaders may be important actors at the adoption and early implementation stages. Mine health and safety staff members may be instrumental at the implementation stage. Higher-level managers and union leaders may once again play a key role at the institutionalization stage.

Steckler et al. [2002] argue that organizational climate is an important determinant of whether new programs are successfully implemented. In an organization in which staff feels unsupported and apathetic, it is unlikely that they will put in the extra effort required to adapt, implement, and maintain new innovations or programs [O'Keefe 1999]. This suggests that the information available from PDMs will be used most effectively at mines where management-labor relations are positive, where there is trust, and where there are open lines of communication.

McLeroy et al. [1988] assert that organizations are layered: "Their strata range from the surrounding environment at the broadest level to the overall organization structure to the management within to work groups to each individual member. Change may be influenced at each of these strata, and health promotion strategies that are directed at several levels simultaneously may be most durable in producing the desired results."

In conclusion, the extent to which it will be possible to use PDMs to reduce miners' exposure to high respirable dust levels depends on factors at the individual, interpersonal, and organizational levels. Health promotion researchers seem to agree that the likelihood of success is usually much better when efforts to bring about change are directed at multiple levels rather than a single level [Janz et al. 2002].

METHODS

In this NIOSH study, PDMs and training materials were delivered to the mine's safety director well before miners began wearing PDMs. After becoming familiar with the devices and instructional materials, the safety director trained a crew of miners to use the PDMs. NIOSH researchers observed the training class and rated various aspects of the instruction. Miners were asked to complete a short questionnaire to evaluation their understanding of the information about PDMs. Miners wore the PDMs for 4 weeks. Researchers returned at the end of the fourth week to interview the miners and the persons in the safety department who had maintained the PDM equipment and kept records of the dust exposure data.

Appendix A lists miner interview questions, and Appendix B lists the questions asked of mine safety staff members. The interview questions were intended to yield the following types of information:

- Descriptions of incidents in which miners tried to use their PDMs to reduce their dust exposure
- Problems or difficulties encountered by miners while wearing the PDMs
- Problems or difficulties encountered with maintaining the PDMs and the data they provide
- Evidence regarding the validity of a conceptual model proposed to explain how PDM feedback leads to changes in miners' behavior and to reduced dust exposure

All miners who wore a PDM during the preceding month, and who were present on the day that the NIOSH interviewers visited the mine, were asked to participate in an interview. All interviews were conducted in private, usually at a dinner area near the miner's worksite. All participants were assured that their responses would be held in confidence and were told that their participation was completely voluntary. No one refused to participate in the interviews. Each interview lasted approximately 20–30 min. All interview questions had been reviewed and approved by the NIOSH Human Subjects Review Board and the Office of Management and Budget (OMB).

Data were collected from October 2006 to May 2007. A total of 30 miners from 4 underground coal mines participated in the interviews. Table 1 presents information about each of the four mines, including the number of miners interviewed, number of underground employees, location, seam height, and whether or not the miners were represented by a union. The sample is composed primarily of large mines operating in relatively high seams. The mines were located in Utah and West Virginia.

Table 1.—Sample mine characteristics

Mine	No. of miners interviewed	No. of underground employees	Location	Seam height, in	Union representation?
A	5	255	Utah	102	Yes.
B	6	439	Northern West Virginia	72–84	Yes.
C	10	81	Southern West Virginia	66–76	No.
D	9	125	Southern West Virginia	54	No.

Half of the mines were represented by a union, and half were nonunion. Mine C used only continuous mining machinery to extract the coal. The other mines used longwall mining equipment in addition to continuous mining machines. The crews in mines C and D were operating a "supersection," i.e., two continuous mining machines (rather than one) were being used in the section where miners were wearing the PDMs.

FINDINGS

Miners were asked what job they currently performed and how much mining experience they had. Table 2 lists their jobs.

Table 2.—Breakdown of mine employees interviewed, by job title

Job title	No.
Shuttle car operator	5
Continuous miner operator	5
Longwall shearer operator	2
Longwall jacksetter	3
Roof bolter operator	8
Mechanic	2
Electrician	1
Scoop operator	1
Section foreman	2
Faceman	1
Total	30

Most miners had substantial experience working as a coal miner. Nineteen had more than 10 years of experience. Only one had less than 2 years of experience. All but three miners had worked in their present job category for more than a year. Miners' ages were distributed as follows:

Age (years)	*N*
Less than 30	6
30–39	6
40–49	12
50 and over	6

The sample consists of miners with considerable mining experience representing all of the major job categories performed in the face areas of U.S. underground coal mines.

Miners' Interpretation and Response to PDM Feedback

Hopefully, the feedback that miners get from their PDMs about dust concentrations will be a major stimulus to take action. Figure 2 proposes a four-stage conceptual model of miners' decision processes with respect to how they interpret and respond to the dust exposure numbers from their PDMs. The model is based on a few different lines of psychological research, including the Health Belief Model, self-efficacy, and studies on feedback interventions. The four stages of the model are: diagnosis, action planning and intervention, evaluation, and institutionalization. Each stage is described below, and miners' responses to interview questions relating to stages 1, 2, and 3 are summarized.

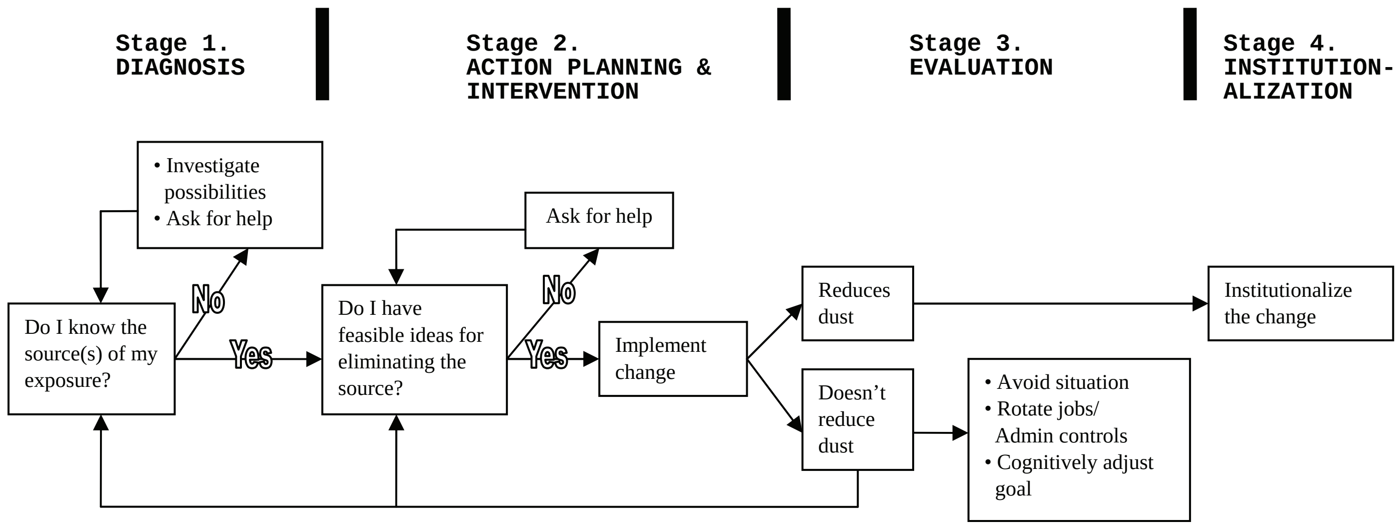

Figure 2.—Conceptual model of how miners use PDM information.

Stage 1: Diagnosis

The model starts with the assumption that the person wearing the PDM notices a number that is high enough to cause concern. Given that they have focused attention on the high level of respirable dust in their work environment, some miners are apt to start thinking about what is causing it. If they do not know what is causing the high respirable dust levels, they may investigate. For example, they might check to see if the necessary ventilation controls are working properly. Perhaps water sprays on coal-cutting machinery are not working or ventilation curtains are not properly installed. If they cannot find a plausible explanation, they may ask others if they know why the respirable dust level is so high.

Miners' responses to interview questions pertaining to "Diagnosis." Miners were asked, "During a typical shift, how many times do you look at the numbers on your PDM?" Twenty-five miners gave numerical estimates ranging from 1 to 20. The median numerical estimate was six (6) times. Five miners said that they looked at the PDM numbers "frequently" or "several times."

Miners were given a response card and asked to select one of four options to answer the question: "Which option best describes how often you looked at your dust exposure number before you turned in your PDM at the end of the day?" Most miners said they looked at this number every day. The distribution of responses is as follows:

Response Distribution

Every day	20
Most days	8
A few days	1
Never	1

Miners were reminded that their PDM has a few different screens with information about dust concentrations. The initial screen has values for MC0, CUM0, and PROJ. MC0 is the miner's average respirable dust exposure during the past 30 min (expressed as number of milligrams per cubic meter). CUM0 is the miner's cumulative respirable dust exposure since the shift began. Mathematically, CUM0 is the mass divided by volume sampled to the present point in time. PROJ is the miner's projected exposure for the whole shift. Mathematically, PROJ is the mass divided by the volume to be sampled for the entire shift. PROJ starts out as a very low number and steadily progresses to the true end-of-shift concentration. If CUM0 exceeds the permissible exposure limit (PEL), steps can be taken to reduce the miner's exposure to stay within the PEL before the end of the shift. However, once the limit (PROJ) is exceeded, it becomes impossible to meet the PEL.

Miners were given a response card and asked to select one of four options to answer the question: "How often did you look at this initial screen?" The distribution of responses is as follows:

Response Distribution

More than 3 times per day	20
At least once per day	9
A few times per week	0
Less than once per week	0

Miners were next reminded that another screen on their PDM shows a bar chart. Each bar represents the average dust concentration for 30-min intervals since the beginning of the shift. Miners were given a response card and asked to select one of four options to answer the question: "How often did you look at the bar chart screen?" The distribution of responses is as follows:

Response Distribution

More than 3 times per day	20
At least once per day	6
A few times per week	3
Less than once per week	1

Miners were asked, "Did you notice whether your numbers tended to fluctuate throughout the day?" Twenty-seven of thirty miners replied "yes." Those who said "yes" were next asked if it was usually clear to them what was making the numbers go up and down. All replied "yes." Miners were asked, "Were you ever surprised or concerned by what the numbers on the PDM display were telling you?" Seventeen of thirty replied "yes." Those who said "yes" were asked to recall the most recent time this happened and to explain what they were doing when they noticed the unusual reading. The types of activities they mentioned were: returning from tailgate on longwall, cutting coal with continuous miner, cutting rock with continuous miner, operating shields on longwall, riding the mantrip, operating scoop in the return, and roof bolting. All but 1 of these 17 miners said that they were surprised by how high the numbers on their PDM were. One miner who was cutting rock with a continuous mining machine said he was surprised because the numbers were not as high as he thought they would be.

Stage 2: Action Planning and Intervention

Once miners think they have a plausible explanation for the high levels of respirable dust, some are apt to start thinking about how to eliminate exposure to the source. If they think they can correct the problem on their own, they will hopefully take care of it. If they do not know how to eliminate the source, they may ask for help. If they do not have the time or resources needed to fix the problem, they may inform their supervisor.

Miners' responses to interview questions pertaining to "Action Planning and Intervention." Miners were asked if they had tried to do anything to reduce their dust exposure. The following 27 actions were reported: 15 miners stated that they changed position, 3 changed ventilation, 4 changed both position and ventilation, and 1 wore his respirator more often.

Position. Continuous miner and longwall operators said they stood a few feet farther away from the dust. Roof bolter operators said they waited for the continuous miner to finish cutting before bolting. Shuttle car operators reported that they stayed behind the ventilation curtain in intake air longer.

Ventilation. Miners reported keeping the ventilation curtains up closer to the face and keeping them tighter.

Respirators. One of the miners on the longwall said he began wearing a respirator during certain phases of his job. At a supersection, the crew was told to wear respirators until airflow could be increased to the section.

Stage 3: Evaluation

The next stage of the conceptual model is evaluation. After making a change to try to reduce their exposure, miners will hopefully try to evaluate whether the change helped. One good way to do this is to check the numbers on their PDMs to see if they went down.

If the change does not initially reduce respirable dust, they may try the same approach but more vigorously, or they may conclude that they really did not know the true source of the dust or that a different type of countermeasure is needed. They may try to investigate other possible sources or countermeasures or may seek help or advice from others.

Miners may not always be able to maintain acceptable levels of respirable dust. Changes that are beyond their control may be needed, i.e., mine-wide ventilation system changes. At one mine, several changes were attempted during the first 2 weeks of the field test, but dust levels were still too high. The safety director said the PDM data helped him convince mine managers that they must increase the volume of air flowing to this section of the mine. Thus, PDM data can be a very useful decision tool for mine safety directors, managers, and engineers, as well as for the miners themselves.

When high dust levels persist, miners may simply learn to avoid being in certain locations at certain times when they know respirable dust levels will be high. In addition, it may be possible to reduce an individual's daily exposure through administrative controls, such as having miners perform a different job for part of the day, i.e., one that does not expose them to as much dust as their primary job.

Miners are entitled to have chest x-rays performed at prescribed intervals. Those whose x-rays indicate they are developing CWP may slow or stop its progression by choosing to exercise their rights under 30 CFR[4] 90 to be reassigned to work in an area of the mine where the respirable dust concentration in the mine atmosphere does not exceed 1.0 mg/m^3.

[4]*Code of Federal Regulations.* See CFR in references.

Another way miners might respond to feedback about high respirable dust exposure is to cognitively adjust (upward) the perceived level of respirable dust they think they need to be concerned about. This will be discussed in greater detail below. After repeated failures, some miners may experience “learned helplessness” and give up trying. Learned helplessness is “the experience of uncontrollable failure to solve a problem originally perceived as solvable” [Mikulincer 1994, p. 13].

Taylor’s [1983] Cognitive Adaptation Theory maintains that disconfirmation of efforts to control one’s health often does not produce the emotional upset or inactivity that one might expect based on reactance or learned helplessness theories. Rather, there are many things that can potentially be controlled, and if one’s need to control a situation is great, one will control what one can and give up attempting to control what one cannot. When a particular plan is thwarted, some alternative plan is often substituted to try to accomplish the same goal. This suggests that if a miner is truly concerned about contracting CWP, he or she is apt to try *several* different approaches to reducing respirable dust exposure before giving up.

Until now, miners have never had quick access to information about their personal dust exposure. Therefore, it might have been easier for them to assume that the amount of respirable dust they were breathing was nothing to worry about. Because PDMs provide miners with relatively quick and objective evidence about their respirable dust exposure, miners may be less likely to harbor false illusions, i.e., that the air they are breathing is harmless when in fact it contains high levels of respirable dust.

Miners’ responses to interview questions pertaining to “Evaluation.” Whenever miners reported making changes to reduce their dust exposure, they were asked, “Did you look at the numbers on your PDM to see if they went down after you made this change?” In 22 cases, miners replied “yes.” In all but two of these cases, the miner reported seeing the numbers go down following the change. In one case, the miner said that the change caused his numbers to stop rising. In another case, the miner said that change did not seem to affect his numbers, but he thought that the change had helped reduce his coworker’s exposure, i.e., the continuous miner operator.

For miners to be motivated to take precautionary measures to protect their health, the Health Belief Model suggests that they must believe the preventive actions will be effective in reducing their exposure to the hazard. To assess miners’ perceptions of the magnitude of the effect of their changes, they were asked to choose one of four options on a response card to answer the question, “Which option best describes how much you think this change will reduce your overall exposure to dust?” The distribution of responses is as follows:

Response Distribution

None	0
Small	4
Moderate	16
Large	4

This suggests that most of the miners believed that the changes they made were efficacious in reducing their dust exposure.

There is also some limited objective evidence that dust exposures declined following the introduction of PDMs. One of the mines that participated in the study allowed NIOSH access to the dust exposure data collected during the 4 weeks that the miners wore the PDMs. Analysis of the data confirmed that this mining crew’s exposure steadily declined throughout the month during which they wore PDMs. By the end of the test, the miners' exposure had declined by 60%. Due to the many factors that may influence miners' dust exposure, the results from this one field test should not necessarily be viewed as indicative of what might result if PDMs were used at other mines. Clearly, further tests are needed to make good predictions about the impact that PDMs will have on reducing miners' dust exposures. While the present study was not designed to provide such estimates, the results from this one mining crew seem to support the notion that providing feedback on exposure levels empowers miners to reduce their dust exposure.

Second samples. PDMs are designed to allow miners to quickly determine whether changes are effective in reducing respirable dust. By pressing two buttons on the PDM, miners can initiate a new "second sample" at any point in their workday. They will start to receive feedback within 15 min regarding whether or not the change they just made is reducing respirable dust. Miners can start/stop a second sample as often as they want. Starting a second sample does not affect the initially programmed sampling for the entire shift.

During the interviews, miners were reminded that their PDM allows them to start taking a new "second sample" at any point during their shift. They were asked, "Did you ever try out the 'second sample' feature on your PDM?" Relatively few miners (11 of 30) reported trying to use this feature. Of the 11 who tried, most said they used it only once or twice. Miners may need additional instruction or encouragement to take advantage of the second sample capability.

Stage 4: Institutionalization

The final stage in the model is institutionalization. When interventions seem to be effective in reducing respirable dust, miners and mine managers will hopefully tell others about their experience so that those who work in similar circumstances can benefit. Some further testing and refinements of successful interventions may occur. Once it is verified as an effective and feasible means of reducing an important source of respirable dust, the intervention will hopefully become institutionalized, i.e., become part of the mine's routine operations. It may be especially helpful if someone is designated to champion successful approaches to dust reduction. This person would hopefully seek out good approaches, provide positive recognition to those who identify them, and ensure that the ideas get disseminated throughout the company. The period of the field tests for this study (4 weeks) was too short to assess the extent to which changes would become institutionalized at the companies that tried using the PDMs. Hopefully, PDMs will someday become used on a widespread basis, and further research can be performed on the extent to which this new technology brings about lasting changes and the extent to which these changes become adopted throughout the coal industry.

How Much Dust Is Viewed as Too Much?

How will miners judge the acceptability of respirable dust concentrations? Hundreds of studies have been conducted by social scientists on the effects of feedback on human performance. Kluger and DeNisi [1996] provide an excellent review of the considerable body of research on the effects of feedback interventions on human performance. They have tried to synthesize these findings into a theory containing several propositions about how people react to feedback that tells them where their performance lies relative to a standard. If a miner's perceived standard or goal for acceptable dust exposure is known, it should become easier to predict how he or she will react to PDM feedback.

Kluger and DeNisi's theory suggests that, when people know they are failing to achieve their standard, they will usually be motivated to try to improve. They argue that people may first simply try to put more effort into doing the same things they are already doing in order to achieve their standard, i.e., working harder. However, if they still find that they are failing to meet their standard, they may try to think of new and different strategies. Kluger and DeNisi argue that if, after trying new strategies they still fail to achieve their standard, people may cognitively adjust their view of what constitutes an acceptable standard. People may adjust their perceived standard to one that is more easily achievable. For example, miners might start out disliking the idea of ever working in higher concentrations of respirable dust, but later on conclude that these levels are acceptable for short periods of time or when doing certain nonroutine tasks. Miners might try to spend less time doing tasks that involve exposure to high respirable dust levels. If that is not feasible, they might try asking others for help or ideas, or they might decide that it is an impossible situation and give up, i.e., learned helplessness.

On the other hand, if miners find that they are exceeding their goals for keeping their respirable dust exposure below a standard value, and it takes extra time or effort to avoid dust, Kluger and DeNisi's theory suggests that some miners may relax their efforts to avoid dust. This is an interesting scenario that bears careful watch. If some miners' respirable dust exposures *increase* following the introduction of PDMs, it may be necessary to remind them of the harmful effects of respirable dust on their lungs.

Understanding how miners select standards for judging their dust exposure may help us understand how they will react to PDM feedback on their dust exposure. There are several possible standards they might adopt.

(1) *Government standards.* Miners could adopt the government's mandated upper exposure limit. MSHA has established 2.0 mg/m^3 as the upper limit for each miner's average exposure during an 8-hr shift. (When silica is present, the permissible exposure value is lowered.) In order for miners to be able to put the numbers they see on their PDMs into proper perspective, it is important that they have a benchmark or frame of reference. As part of an assessment of miners' retention of information presented to them in a training video, the miners in our sample were asked, "According to MSHA, what is the maximum average number of milligrams of coal dust per cubic meter that miners should be exposed to during an 8-hr shift, assuming no silica is present?" Only 20 of 30 miners could recall that MSHA's limit for respirable coal dust exposure is 2 mg. This suggests that several of the miners may not have had a good frame of reference for evaluating the numbers they saw on their PDMs. Additional efforts may be needed to ensure that miners remember this fact from the training they are given. Perhaps the number "2" could be associated with the number of lungs a person has. Since the maximum exposure value for each section of the mine can vary depending on the amount of silica that may also be present in the air, the best approach to reminding miners of their upper exposure limit might be to print out the number and tape it on each miner's PDM. Posters or stickers might also serve as effective reminders.

(2) *Comparisons to coworkers.* Miners could base their judgments on how their dust exposure level compares with that of coworkers doing the same job.

(3) *Comparisons to past levels.* Miners could base their judgments on how their current dust exposure level compares with their own prior levels (while doing the same particular task).

Since PDMs provide feedback on a variety of different dust concentration measures (CUM0, MC0, PROJ, bar chart), miners may tend to focus on some more than others. Data were collected on this issue by asking miners, “Of all the different types of information the PDM gives you, which type did you tend to look at the most?” The distribution of responses is as follows:

Response Distribution

Dust exposure for past 30 min (MC0)	4
Cumulative exposure since shift began (CUM0)	8
Projected exposure for the whole shift (PROJ)	8
Bar chart	7

One miner said he paid equal attention to MC0 and PROJ. One miner said he looked mainly at the numbers on the first screen rather than the bar chart, but did not recall paying more attention to any one value in particular. One miner said he looked at both MC0 and the bar chart equally. Based on the responses from this relatively small sample, it seems that there is no single preferred indicator of dust exposure. As mentioned previously, almost all miners reported looking at their end-of-shift average respirable dust exposure before turning in their PDMs at the end of the day.

There are many unanswered questions about how miners will interpret and respond to information from their PDMs. Will miners focus on their exposure during relatively short time intervals when their exposures seem to be unusually high? Will they focus on such events only when they seem to occur with some regularity? Will they ignore occasional or random spikes in respirable dust concentrations? Once PDMs have been introduced on a more widespread basis, it should become clearer which types of information miners attend to and what standards miners are adopting.

Limitations of the conceptual model. It is important to note that the model presented in Figure 2 is mainly intended to help explain the behavior of miners as they *first* begin using PDMs and/or those who work in high levels of respirable dust on an *occasional* basis. It is likely that if miners have formed a strong habit of avoiding high respirable dust levels in all circumstances, they never even stop to consider any of the factors shown in the model. Similarly, once miners have formed a strong habit of going in high respirable dust levels to perform certain tasks, they may seldom take into consideration any of the factors shown in the model. They may not even take notice of their PDM readings.

Over time, miners using PDMs will hopefully learn what they can and cannot do to lessen their exposures to respirable dust, and they may subsequently pay less attention to the PDM feedback. Only when they happen to notice numbers that are different from what they have come to expect will they stop to think about what might have caused the unusual reading.

Miners’ Receptivity to Wearing PDMs

Worker resistance to change is common. It was anticipated that at least some miners would have reservations about wearing the new PDM. In order to understand what miners might find objectionable about wearing PDMs, they were asked to describe any problems they might have had. They were also asked to name any reasons why miners would *not* want to wear a PDM. The following issues were cited most frequently by miners:

- Size and weight
- Light cord / sample hose
- Cap lamp
- Attachment to miner's belt

Size and weight. Several miners noted that the PDM felt heavier and seemed bulkier than the cap lamp battery they normally wear on their belt. The PDM weighs 6.6 lb. It is 8 oz heavier than lead-acid battery cap lamp systems, but 1.5 lb lighter than the combined weight of wearing a lead-acid battery cap lamp and dust sampler. As a result of recent improvements in cap lamp battery technologies, the lead-acid battery cap lamp systems are gradually being replaced by cap lamp systems that do not weigh as much. Some mobile equipment operators said that, due to the PDM's size and the limited space in their operator's compartment, it was difficult to sit down with the PDM attached to their belt. Some noted that their PDM got "banged around" when they had to work in close quarters.

Light cord / sample hose. The length of the cord running from the PDM on the miner's belt to the sample inlet on the cap lamp was designed to accommodate relatively tall people for the purposes of field testing the manufacturer's prototype units. Some miners complained that the cord was too long and got caught on things as they worked. The cord is wrapped in a durable but rather rough material that some miners complained was uncomfortable when it rubbed against their neck. Those who maintained the PDMs noted that it would have been easier to clean mud off the cord if it had a smoother surface. Some miners thought that the sample hose sometimes got pinched off when they sat down. When the flow of air gets cut off, an error message appears on the display screen. These error messages (flow error) sometimes caused miners to doubt whether their PDM was working properly.

Cap lamp. A few miners complained that there were dark areas in the center of their spot, making it more difficult to see in the dark underground environment. Unlike the cap lamps these miners normally use, the light on the PDM cannot be focused with a knob. Its focus can only be changed by adding and removing shims from the base of the light bulb. This procedure is rather time-consuming. It requires removing three screws, taking the cover off the light, changing the number of shims, and reinstalling the cover. If the spot is still not focused to the miner's liking, this procedure must be repeated until the right number of shims is determined. A few of the PDM maintainers noted that the bulbs burned out and had to be replaced rather often. They also noted that the lights would sometimes go out before the shift was over. The batteries should be capable of providing at least 12 hr of light when fully charged. The manufacturer believes that the reason the lights sometimes failed before the end of the shift was because of poor connections between the PDM and recharging unit. The manufacturer plans to redesign this connection to ensure that the batteries always get fully charged before miners begin their shift. Miners also noted that, unlike their cap lamps, the PDM light does not provide any advance warning before the light actually goes out.

Attachment to miner's belt. Miners at the first mine were using a significantly smaller lithium battery for their cap lamps. This battery fit into a small pouch permanently attached to their belts. This prevented the miners from attaching the larger pouches provided by NIOSH to hold the PDM onto their belt. The miners at this mine were especially bothered by the larger size and weight of the PDM compared to the small lithium battery they had been used to wearing. Miners at this mine used a metal clamp to attach the PDM to their belt. A few miners noted that PDMs held on by clamps (as opposed to the pouches) tended to fall off their belt. To minimize inconveniences and discomfort, it is suggested that miners who wear PDMs should be given belts that allow attachment via either pouches or clamps and that the belts have suspenders to help support the load more comfortably.

Members of the mine safety staff who helped maintain the PDMs were also asked to identify problems and offer suggestions for improving the PDMs. Many of their observations paralleled those of the miners who wore the PDMs. However, two additional observations are worth noting. Maintainers suggested changing the software such that when programming a PDM for the next sample, the default values should reflect whatever value was entered the previous time that the PDM was programmed. They said that this would save time and reduce the chances of entering erroneus values during the daily programming process. At one mine, the safety staff strongly suggested adding some type of noticeable signal to let miners know when they are in an area of relatively high levels of respirable dust and/or when they are approaching the maximum exposure limit for a shift. For example, a flashing light might be used to get the miner's attention. They were concerned that miners will become complacent after wearing their PDMs for a while and will stop paying attention to the display information.

Miners were asked if they had had experience wearing other types of dust monitors besides the PDM. All but one replied "yes." Interviewers said to those who had experience wearing both the old and new type of monitor, "I'd like you to think about how the old dust sampling system compares to the new. Which do you prefer?" Eighteen (62%) preferred the new PDM, seven (24%) preferred existing monitors, and four (14%) had no preference.

Seven miners stated that 4 weeks was too long to wear the PDM. Some said they would have preferred the new PDM or would have been willing to wear it longer if design improvements are made.

Miners were asked to explain the reasons for their preference. Those who said they prefer the new PDM perceived the following advantages:

- Provides quicker feedback
- Does not fall off your coveralls like cassettes
- Combination light/sampler is more compact
- Does not get in the way as much
- Provides a truer sample of actual exposure because (1) the PDM cannot be removed and left in fresh air while miners go elsewhere and (2) the location of the sample inlet (brim of hard hat) is closer to one's nose, i.e., the miner's breathing zone.

Those who said they prefer using traditional dust monitors cited the following reasons:

- Lighter and less bulky
- The cord does not irritate the neck
- Does not get in the way as much
- Could not focus the PDM's cap light

All of these concerns have been conveyed to the manufacturer. Hopefully, the PDM can be redesigned to further enhance acceptance by those who will be using it.

CONCLUSIONS

The information presented in this report helps delineate the important role of PDMs as a tool for reducing coal miners' exposure to respirable dust. A major strength of the NIOSH study is that the information was obtained from people who regularly work underground and who will actually be using this new technology. Their assessment of the potential for using PDMs to protect their lungs should most definitely be considered as an informative and insightful source of information.

Results from the interviews with miners tend to support the propositions in the first three stages of the conceptual model. Most miners paid attention to PDM feedback and made efforts to reduce their dust exposure. The PDMs were not used long enough at the four mines in the study to provide evidence about the final stage in the model—institutionalization. The empirical evidence concerning the validity of the model is rather limited. It is hoped that the findings from this study will serve to stimulate additional research and will raise more questions about the role of feedback as a determinant of self-protective worker behavior.

One should not conclude that the results of this study are representative of the entire industry. The sample of mines that participated in the study was small, and it was not randomly selected. It is possible that the sample of companies participating in this study is more committed to ensuring their employees' health and safety than the remainder of the industry.

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APPENDIX A.—MINE INTERVIEW GUIDE

Form Approved
OMB No. 0920-0698
Exp. Date 11/30/2007

INTERVIEW GUIDE FOR MINERS REGARDING PDMs

DATE:______________________________________

INTERVIEWER:________________________________

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1. INTRODUCTION

Hello, my name is ________________. I work for NIOSH. NIOSH is doing a research study to get information on what coal miners think about the Personal Dust Monitor and how it might be used to reduce their exposure to respirable dust. Since you have experience using the PDM, we would like to interview you. The interview takes about 20-30 minutes. Your participation is completely voluntary. You don't need to answer any questions you don't want to. Your responses to interview questions will be treated in a confidential manner, unless otherwise compelled by law. We do not record the names of the people we interview. The information you provide will be analyzed and reported along with the information provided by miners at other mines. In any public release of survey results, no data will be disclosed that could be used to identify specific individuals. Only NIOSH staff who are involved in collecting or preparing the information for analysis will have access to your answers.

If you do not object to being interviewed, I need you to review and sign this consent form. [*Give form to miner and explain*].

Do you have any questions before I begin the interview?

2. MINER'S BACKGROUND

To begin, I need to get some information about you and your experience in mining.

2.1 How many years have you worked as a coal miner?

- ☐ < 2
- ☐ 2 - 5
- ☐ 6 - 10
- ☐ 11 - 20
- ☐ > 20

2.2 What is your present job?

☐ Shuttle car	☐ Longwall shearer
☐ Continuous miner	☐ Longwall jack setter
☐ Roof bolter	☐ Longwall utility
☐ Electrician	☐ Stage loader
☐ Mechanic	☐ Other______________________________
☐ Foreman	

2.3 How many years have you been on that job?___________________________

- ☐ < 1 year
- ☐ 1- 3
- ☐ > 3

2.4 How old are you?

- ☐ < 30
- ☐ 30 - 39
- ☐ 40 - 49
- ☐ 50 and over

3. COMPREHENSION AND USE OF PDM INFORMATION

The next few questions are about the personal dust monitors and the information they provide.

3.1 Including today, about how many shifts have you worn the PDM?

- ☐ More than 15 (3+ weeks)
- ☐ 11 – 15 (2-3 weeks)
- ☐ 6 – 10 (1-2 week)
- ☐ 1 – 5 (a week or less)

3.2 During a typical shift, how many times do you look at the numbers on your PDM?

- ☐ ZERO
- ☐ > 0 (*write number*) ______________ ⟶ **SKIP** to 3.4

3.3 (If looked ZERO times), Did you ever look at it?

- ☐ No ⟶ **SKIP** to *** Section 5. "Problems with the PDM"
- ☐ Yes

3.4 Were there certain times that you were more likely to look at it than others?

- ☐ No ⟶ **SKIP** to *** 3.6
- ☐ Yes

3.5 (If YES) When did you tend to look at it?_________________________________

[PROBES] During breaks, certain times of the day, or phases of your job or mining cycle

*** 3.6 I'd like you to answer the next question using one of the options on the response card. Which option best describes how often you looked at your dust exposure number before you turned in your PDM at the end of the day?

RESPONSE CARD A

☐ every day

☐ most days

☐ a few days

☐ never

3.7 Your PDM has a few different screens with information about dust concentrations. The initial screen has values for MC0, CUM0 and PROJ. Using the options on this card, please tell me how often you look at this initial screen?

RESPONSE CARD B

☐ more than 3 times per day

☐ at least once per day

☐ a few times per week

☐ less than once per week

3.8 Another screen on your PDM shows a bar chart. Each bar represents the average dust concentration for 30 minutes. Using the options on this card, please tell me how often you looked at the bar chart screen?

RESPONSE CARD B

☐ more than 3 times per day

☐ at least once per day

☐ a few times per week

☐ less than once per week

3.9 Of all the different types of information the PDM gives you, which type did you tend to look at the most?

- ☐ 1 dust exposure for past 30 minutes (MC0)
- ☐ 2 cumulative exposure since shift began (CUM0)
- ☐ 3 projected exposure for the whole shift (PROJ)
- ☐ 4 bar chart (on screen 2)
- ☐ Other________________________________

*** 3.10 The PDM allows you to start taking a new "second sample" at any point during your shift. Did you ever try out the "second sample" feature on your PDM?

- ☐ No
- ☐ Yes ⟶ **SKIP** to 3.13

3.11 (If NO) Are there any reasons why you did not try out this feature?

[PROBES]

Didn't realize it was possible to start a new sample ⟶ **SKIP** to *** 3.16

Didn't remember how to start a new sample ⟶ **SKIP** to *** 3.16
Didn't want to interfere with the sample data being collected for the whole shift
Too busy with my work to think about it
Not worried about my dust exposure

3.12 Do you remember which button or buttons you push to start a second sample? Please explain.

- ☐ CORRECT
- ☐ INCORRECT

SKIP to *** 3.16

*** 3.13 (If YES) How many times did you use this feature?_____________________

3.14 I'd like you to recall the most recent time you used this feature. What were you trying to find out?

3.15 Were you able to find out what you wanted to know?

☐ No

☐ Yes

*** 3.16 Dust concentration numbers may go up and down throughout the course of a shift. Did you notice whether your numbers tended to fluctuate throughout the day?

☐ No ⟶ **SKIP** to *** 3.18

☐ Yes

3.17 (If YES) Was it usually clear to you what was making the numbers go up and down?

☐ No Please explain why____

☐ Yes

3.18 Were you ever surprised or concerned by what the numbers on the PDM display were telling you?

☐ No ⟶ **SKIP** to *** 3.21

☐ Yes

3.19 (If YES), I'd like you to recall the most recent time this happened. What were you doing when you noticed the unusual reading?

3.20 Did you do anything to try to reduce your dust exposure?

☐ No

☐ Yes Please describe___________________________________

*** 3.21 According to MSHA, what is the maximum average number of mg of coal dust per cubic meter that miners should be exposed to during an 8 hour shift? (Assuming no silica is present)

☐ CORRECT

☐ INCORRECT

4. ATTEMPTS TO REDUCE DUST EXPOSURE

The next few questions are about any attempts you may have made to reduce your dust exposure since you began using the PDM.

4.1 Since you began using the PDM, have you tried to make any changes to see if you could reduce your dust exposure?

- ☐ No ⟶ **SKIP** to *** 4.13
- ☐ Yes

4.2 (If YES) Please describe the types of changes you made.

Change 1:____

Change 2:____

4.3 Did [*Insert Change 1*] make any difference in your dust concentration level?

- ☐ No ⟶ **Go to *** 4.8 (Change 2)** **OR if there are no other changes, SKIP** to *** 4.13
- ☐ Don’t know ⟶ (same as above)
- ☐ Yes

4.4 (If YES--miner reports he/she was successful in reducing exposure) Did you look at the numbers on your PDM to see if they went down after you made this change?

- ☐ No ⟶ **SKIP** to 4.6
- ☐ Yes

4.5 (If YES) What did you see?

*** 4.6 I'd like you to answer the next question using one of the options on the response card. Which option best describes how much you think this change will reduce your overall exposure to dust?

RESPONSE CARD C

- ☐ none
- ☐ a small reduction
- ☐ a moderate reduction
- ☐ a large reduction

4.7 Have there been any drawbacks or disadvantages to [*insert Change 1*]?

CHANGE 2____

*** 4.8 Did [*Insert Change 2*] make any difference in your dust concentration level?

- ☐ No ⟶ **SKIP** to *** 4.13
- ☐ Don't know ↗ (**SKIP** to *** 4.13)
- ☐ Yes

4.9 (If YES--miner reports he/she was successful in reducing exposure) Did you look at the numbers on your PDM to see if they went down after you made this change?

- ☐ No ⟶ **SKIP** to 4.11
- ☐ Yes

4.10 (If YES) What did you see?

4.11 I'd like you to answer the next question using one of the options on the response card. Which option best describes how much you think this change will reduce your overall exposure to dust?

RESPONSE CARD C

- ☐ none
- ☐ a small reduction
- ☐ a moderate reduction
- ☐ a large reduction

4.12 Have there been any drawbacks or disadvantages to [*insert Change 2*]?

*** 4.13 Since the PDMs were introduced, has anyone (else) at this mine changed the way they are doing their job in order to reduce their exposure to dust?

- ☐ No or Don't Know ⟶ **SKIP** to 4.15
- ☐ Yes

4.14 (If Yes) Please describe.____

4.15 Can you think of any (other) ways the PDM information might be useful for reducing miners' exposure to dust?

- ☐ No ⟶ **SKIP** to *** Section 5
- ☐ Yes

4.16 (If Yes) Please describe.____

5. PROBLEMS WITH THE PDM

The next few questions are about any problems you may have had using the PDM.

5.1 Did you have any problems using the new PDM?

- ☐ No ⟶ **SKIP** to 5.3
- ☐ Yes

5.2 (If YES) Please describe.____

5.3 Could anything be changed to improve the PDM?

- ☐ No ⟶ **SKIP** to 5.5
- ☐ Yes

5.4 (If YES) Please describe.____

5.5 Can you think of any reasons why miners would NOT want to wear the new PDM?

- ☐ No ⟶ **SKIP** to 5.7
- ☐ Yes

5.6 (If YES) Please describe.____

5.7 Did you ever wear one of the old types of dust sampling monitors?

- ☐ No ⟶ **SKIP** to *** Section 6
- ☐ Yes

5.8 (If YES) I'd like you to think about how the old dust sampling system compares to the new. Which do you prefer?

- ☐ No preference ⟶ **SKIP** to *** Section 6
- ☐ OLD Please explain why ____
- ☐ NEW Please explain why ____

[PROBES] Less hindrance/more comfortable to wear, Quicker feedback, More accurate

6. TRAINING

The next few questions are about the training you received on your PDM.

6.1 Thinking about the training you were given before you started using the PDM, is there anything that could be changed to improve it?

- ☐ No
- ☐ Yes

6.2 (If YES) Please describe.____

6.3 Using this card, please tell me how confident you are that you know how to do each of the following with your PDM:

RESPONSE CARD D

1 very confident
2 confident
3 not completely sure
4 no idea

How confident are you that you could…

____ 6.3.1 Find your average dust concentration for the past 30 minutes.

____ 6.3.2 Find your average dust concentration since the beginning of the shift.

____ 6.3.3 Find your average dust concentration for the whole shift after the unit has automatically shut itself off at the end of the day

____ 6.3.4 Start collecting a second sample of dust concentration values at any time you want to during a shift

____ 6.3.5 Find out if you have already exceeded the legal limit for dust exposure during a single shift

6.4 If the MC0 number goes above 2.0, does that mean you have exceeded the dust standard?

- ☐ CORRECT
- ☐ INCORRECT

6.5 If the PROJ number goes above 2.0, does that mean you have exceeded the dust standard?

- ☐ CORRECT
- ☐ INCORRECT

That is all the questions I have. Is there anything you would like to ask or tell me?

Thank you for helping us with this study.

APPENDIX B.—MINE SAFETY STAFF INTERVIEW GUIDE

INTERVIEW GUIDE
MAINTENANCE PERSONS

INTERVIEWER:

Mine:

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1. INTRODUCTION

Hello, my name is ________________. I work for NIOSH. I would like to ask you a few questions about the care and maintenance of the Personal Dust Monitors by people at mining operations. Since you have experience doing this type of work, we would like to interview you. The interview takes about 20 minutes. Your participation is completely voluntary. You don't need to answer any questions you don't want to. Your responses to interview questions will be treated in a confidential manner. We keep no records of the names of people we interview.

Do you have any questions before I begin the interview?

2. MAINTENANCE PERSON's BACKGROUND

To begin, I need to get some information about you and your experience in the mining industry.

2.1 What is your present job?

2.2 How many years have you been on that job?

2.3 How many PDM units did you maintain on a daily basis?

2.4 How many shifts did you work with them?
PROBES: Over 20?

2.5 On average, how many minutes did it usually take you to download the data and prepare them for the next shift?

2.6 What jobs were the people performing who regularly wore the PDMs?

- ☐ Shuttle car
- ☐ Continuous miner
- ☐ Roof bolter
- ☐ Electrician
- ☐ Mechanic
- ☐ Foreman
- ☐ Longwall shearer
- ☐ Longwall jack setter
- ☐ Longwall utility
- ☐ Stage loader
- ☐ Other______________________________

3. PROBLEMS WITH THE PDM

[Whenever they say they had a problem, ask them to describe it and what might be done to solve the problem]

The next few questions are about any problems you may have had maintaining the PDM.

Did you have any problems with …

	If yes--DESCRIPTION OF PROBLEM	POTENTIAL SOLUTION
3.1 Cap lamp		
3.2 Air supply hose/Cord connecting air inlet to PDM unit on belt		
3.3 Pouches or clamps for holding PDM onto miner's belt		
3.4 Battery		
3.5 Laptop		
3.6 Software		
3.7 Downloading/saving data from prior shift		
3.8 Printing out hard copies of the data		
3.9 Programming the PDM for the next shift		

3.10 Connecting to recharging rack		
3.11 Replacing filters		
3.12 Removing TE module		
3.13 Using filter exchange tool		
3.14 Cleaning the grit pot (removal, cleaning, replacement		
3.14a PTO for powering remote control		

3.15 What is the most difficult aspect of maintaining the PDMs?

3.16 Can you think of anything that could be done to make this less difficult?

3.17 How many units did NOT perform as they should have during the entire time you have been using them at this mine?

____ out of ____ total units

3.18 What is the most common type of mechanical problem with the PDM units?

3.19 Were there any types of mechanical problems that you were able to fix?

3.20 How did you fix it?

3.21 How long did it take?

3.22 Did the problem reoccur?

3.23 What is the most common complaint you heard from miners about the PDMs?

4. COMPARISON TO OLD DUST SAMPLING METHOD

4.1 Are you the person who is primarily responsible for carrying out the dust sampling program at this mine?

- ☐ No
- ☐ Yes

I'd like you to think about how the old dust sampling system compares to the new PDM. Compared to the old system of dust sampling, what are the advantages and disadvantages of sampling with the new PDMs?

4.2 ADVANTAGES:

4.3 DISADVANTAGES:

4.4 Overall, which of the two dust sampling systems do you prefer?

- ☐ No preference
- ☐ OLD Please explain why
- ☐ NEW Please explain why

5. USING PDMs TO MAKE CHANGES

5.1 Since this mine began using the new PDMs, have any new situations been identified as causing miners to receive significant exposure to respirable dust?

5.2 [IF YES], please describe:

5.3 Have any changes been made to reduce miners' exposure to respirable dust?

5.4 [If YES], please describe

5.5 Do you think they were effective?

5.6 Were there any drawbacks to these changes?

5.7 Have any new procedures or policies been implemented that would affect miners' dust exposure?

5.8 Can you think of any new procedures or policies that might help to reduce miners' dust exposure?

5.9 Have miners asked for any changes to be made in light of the feedback they now get from their PDM?

5.10 [If YES] What did they request?

5.11 Was the change implemented?

5.12 [If YES] Was it beneficial in reducing miners' dust exposure?

5.13 Any costs or drawbacks?

5.14 Have you looked at the data that has been collected from the PDMs?

5.15 If yes, does anything about it surprise you?

5.16 Does it seem like useful information?

5.17 [If YES], please explain how it is useful.

5.18 Is there anything about the data that is hard to understand, confusing or misleading?

6. TRAINING

The next few questions are about the training you received for maintaining the PDMs.

6.1 Thinking about the training you were given about maintaining the PDMs, is there anything that could be changed to improve it?

- ☐ No
- ☐ Yes

6.2 (If YES) Please describe.

6.3 Did you read the mini-manual instruction book?

6.4 Was anything unclear in this manual?

6.5 Did you watch the video on how to maintain the PDMs?

6.6 Was anything unclear in the video?

6.7 Do you think that most people will be able to learn what they need to know about maintaining PDMs from these instructional materials?

- ☐ No
- ☐ Yes

6.8 [If NO] What additional information or help is needed?

That is all the questions I have. Is there anything you would like to ask or tell me?

Other comments

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