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Helmet-CAM: Strategically Minimizing Exposures to Respirable Dust Through Video Exposure Monitoring

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Abstract

Exposure to respirable crystalline silica (RCS) remains a serious health hazard to the US mining workforce who are potentially exposed as various ore bodies are drilled, blasted, hauled by truck, crushed, screened, and transported to their destinations. The current Mine Safety and Health Administration (MSHA) permissible exposure limit (PEL) for RCS remains at approximately 100 μg/m^3, but it is noteworthy that the Occupational Safety and Health Administration (OSHA) has lowered its PEL to 50 μg/ m^3 (with enforcement dates staggered through 2022 for various sectors), and the National Institute for Occupational Safety and Health (NIOSH) has held a 50 μg/m^3 recommended standard since 1976. To examine a method for reducing RCS exposure using a NIOSH-developed video exposure monitoring (VEM) technology (referred to as Helmet-CAM), video and respirable dust concentration data were collected on eighty miners across seven unique mining sites. The data was then collated and partitioned using a thresholding scheme to determine exposures that were in excess of ten times the mean exposure for that worker. Focusing on these short duration, high magnitude exposures can provide insight to implement controls and interventions that can dramatically lower the employee's overall average exposure. In 19 of the 80 cases analyzed, it was found that exposure could be significantly lowered by 20% or more by reducing exposures that occur during just 10 min of work per 8-hour shift. This approach provides a method to quickly analyze and determine which activities are creating the greatest health concerns. In most cases, once identified, focused control technologies or behavioral modifications can be applied to those tasks.

Keywords

Video; Exposure; Monitoring; Silica; Exposure; Respirable

1 Introduction

Between 2000 and 2017, the Mine Safety and Health Administration (MSHA) collected 518,195 personal health compliance samples in metal/nonmetal (M/NM) operations [1]. Of

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Conflict of Interest The authors declare that they have no conflict of interest.

Compliance with Ethical Standards

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these, 56,465 samples were tested for quartz, with 19,295 samples (34%) in excess of the action limit—50% of the permissible exposure limit (PEL), or 50 μg/m^3. With a total of 168,123 M/NM miners employed in 2017 and 6060 samples for respirable dust or quartz, just 3.6% of the workforce had been sampled in that year. Given this low frequency of compliance sampling, mines could benefit from additional methods and strategies to sample and identify dust sources for their workforce.

Mines with proactive safety cultures know that they cannot rely only on compliance sampling but must also have a well-planned internal effort to sample and identify elevated dust exposures within their sites. Many operations conduct routine personal sampling with gravimetric sampling methods. While full-shift gravimetric sampling does give an accurate time-weighted average (TWA) exposure, it is not able to pinpoint elevated exposure sources. Personal dust monitors that record continuous readings via optical light scattering technologies are able to measure respirable dust levels on a second-by-second basis and therefore add additional discernment of dust profiles. New technologies are also able to be coupled with personal dust monitors to enhance this information. To identify the worker's specific task or activity during peak exposures, NIOSH developed a video exposure monitoring system (Helmet-CAM, Fig. 1) with accompanying software package called EVADE (Enhanced Video Analysis of Dust Exposure, Fig. 2). EVADE allows users to combine logged dust monitor data with recorded video from wearable body cameras to determine the specific task, situation, or activity at times of elevated dust exposures [2]. This method [3] hasbeen used by NIOSH on more than 250 mine workers and has provided knowledge of the source of dust exposures. From those assessments, possible interventions have resulted in a number of "quick fixes" that can be used in many instances to reduce exposures with only minimal effort and cost [4]. Brand-specific hardware is not needed with EVADE, and NIOSH researchers have successfully used multiple wearable video camera systems combined with a Thermo Scientific pDR-1500 real-time dust monitor [5]. After both datasets have been logged, the video and dust data are uploaded into EVADE for synchronization and analysis.

The EVADE software has many useful features that allow health and safety (H&S) professionals to quickly load the collected data from employees, conduct a brief analysis, and then review that information with workers. Workers who have seen this pairing of their task identification and dust exposure have become more aware of the dust hazard and asked questions such as "How much [respirable silica] is too much before it affects you?" or "If you're exposed to the exposure limit your whole life, will you get silicosis?" [6]. And while the process of collecting, reviewing, and discussing the data is convenient for a limited number of workers (for example, via a 1-day study at a single mine), it could become unmanageable and impractical for gathering larger datasets (for example, collecting data once per month across a dozen operations). However, it would stand to reason that the more complete information gained about a worker's true dust exposure, the more confidence H&S professionals would have in ensuring that they efficiently target those dust sources that demand the most immediate correction. For that purpose, a unique methodology is provided in this paper for possible industry adoption.

NIOSH researchers used the EVADE software in a series of behavioral/engineering cooperative interventions. Workers were fitted with a person-wearable video camera and a real-time data-logging respirable dust monitor during part of their work shift while performing routine tasks. After they wore the units for approximately 2 hours, results were downloaded and subsequently reviewed by researchers with workers and managers to identify sources of respirable dust and provide an impetus to mitigate these risks. These activities occurred during two separate field site visits, approximately 8 weeks apart. The time period and risk mitigation discussions between visits allowed workers and managers a chance to implement new administrative controls or to better utilize current (or implement new) engineering controls and then evaluate any differences in exposure levels.

Throughout the duration of the site-specific interventions, feedback was provided to the participating managers about elevated exposure areas and work tasks and considerations to possibly reduce exposures. Between field visits, site-level management explored engineering controls and communicated with workers about possible methods to reduce exposure, which were reassessed on the second visit. The longitudinal assessments revealed trends in respirable dust sources and, in many cases, simple, quick-fix strategies to reduce exposure [4, 7–9]. Engineering and administrative controls were identified by the researchers after a brief review of the video and dust data using the EVADE software. This software package and data presentation provided compelling and persuasive support towards implementing solutions with management.

Mines participating in this study were selected on the basis largely of convenience sampling depending on their product classification, availability, and willingness to participate. Typically, researchers quickly reviewed the data at the mine site and then again in greater detail after the visit, which resulted in a concise report provided to the mining operation highlighting the areas of concern based on evidence of elevated exposures. Utilizing extensive experience with the application of engineering controls and interventions for respirable dust [10], suggestions were also included for the key problem areas. For the key problem areas identified, NIOSH researchers decided to conduct a more comprehensive analysis, aggregating the data with data from the other studies collected over a span of 5 years (between August 2011 and October 2016). Results from this analysis were also shared with study participants where relevant.

The objective of the analysis methodology described herein is to offer a technique for quickly determining if the exposures are coming from distinct events (where improved work practices or targeted engineering controls may lower exposures) or overall high dust levels (where changes in total ventilation may be needed). In this way, resources can be spent most efficiently on addressing those situations that create the highest potential for short-duration overexposures.

2 Methodology

Respirable dust data (time histories) used for the analysis was processed in several high-level steps. First, the dust data files were processed using the procedures described below (collation, thresholding, peak identification, and evaluation of potential to substantially decrease mean exposures). The result of those procedures was a list of datasets (one dataset per miner) classified as having the possibility of significant exposure reduction with the removal of limited peaks. This refined dataset was then evaluated with EVADE, to identify the work task, location, and work practices at the time of the exposure.

Importantly, the dust data collected with the personal dust monitor, which uses optical light scattering technology, is a relative number. While these instruments are factory-calibrated against a test aerosol, it is known that certain factors influence the instrument's response, including the wavelength of the source light, the angle between the incident and the detected light, particle index of refraction, and particle size [11]. Because of the influences due to particle specifics, the manufacturer recommends correction with respect to the internal gravimetric filter for the most accurate results, and indeed this approach has proven to be reliable [12]. However, for this study, the data was purposely not gravimetrically corrected —keeping the measurements relative ensured that the workers would be encouraged to perform their normal job functions, including those tasks with expected high exposures. This approach was in keeping with the primary purpose of NIOSH's Helmet-CAM studies, which is to identify target areas for application of engineering and administrative controls without the need for compliance sampling, which is handled by MSHA. For reference, a recent NIOSH study [13] found that the pDR-1500 had equivalency factors of 1.564 on average across (6) specific dusts and (2) humidity levels. A 10 mm respirable dust cyclone (Dorr-Oliver, Zefon International, Ocala, FL) was used as a size selector on the pDR-1500 real-time aerosol monitor.

The collected dust files are in ASCII format and contain the time stamp and dust readings (in μg/m^3), recorded every 2 s. Scripts written in Matlab (Mathworks of Natick, MA) were developed that read the "*.txt" files and process the data. Each dataset is individually analyzed to determine if short duration exposures exist to an extent that the average exposure is significantly influenced by them. Metrics are calculated such as the mean, maximum, and length of each dataset. A threshold of 10 × the mean was chosen to determine which points in the file are greater than that limit. Those points greater than the threshold limit are flagged, and a new mean is calculated with those points having been removed (Fig. 3). To determine if a dataset should be set aside for further analysis, the mean dust exposures are compared with and without point removal. If the mean exposure level is decreased by 20% or more, the dataset is flagged and studied further. Computationally, this is a simple task, and the entire process takes less than 7 s for over 225,000 data points collected (in total for all eighty datasets).

3 Results and Discussion

The data gathered during the Helmet-CAM studies represent more than 144 h of workers engaged in various unscripted tasks (Fig. 4), including maintenance personnel, bagging operators, skid steer drivers, and general laborers. The mean dataset length was 108 min with a mean exposure of 159 μg/m^3. The standard error is then 2.17 μg/m^3, which with 95% confidence intervals would estimate the mean to fall between 155 and 163 μg/m^3.

When the data was processed with the thresholding scheme described previously, 19 of the 80 datasets met the thresholding criteria (i.e., the mean exposure would drop by 20% or greater if peaks greater than 10 × the original mean exposure were removed). Five of those 19 criteria-matching datasets would have their exposure reduced by greater than 50% with this analysis (Fig. 5, bottom chart). The average “over threshold” time was just 112 s per mine worker, which means that the peaks identified occupy just 1.7% of the time sampled, or roughly 10 min in an 8-hour shift. To highlight the types of activities occurring during the peak exposures, two datasets are discussed below.

In the first dataset of interest (number 022), a haul truck driver is delivering screened sand between a load-out station and a stockpile. The algorithm found 11 peaks that are in excess of the threshold criteria (greater than 10 × the mean). Using EVADE to analyze the data, it was found that these peaks correlate to when the truck was backing up to the stockpile through an open area. Because the truck was older and lacked an effective filtration and pressurization system with air conditioning, the truck driver relies on natural ventilation (windows down), which allowed the dust cloud stirred up by the truck to flow into the truck cab. The original mean exposure was 116 μg/m^3, and the removal of these peaks would reduce his exposure by 59.1%. Further, analysis with EVADE revealed that about 83 min into the recording, the reversing through dust cloud levels dropped by about 54%, with the video showing the presence of a water truck when the reductions suddenly began, and thus pointing to the effectiveness of watering haul roads and heavily trafficked areas.

In the second example, the algorithm found twelve peaks on a mobile bagger responsible for the filling, tying (Fig. 6), and stacking of flexible intermediate bulk containers (bulk bags). By removing this short-duration exposure that occurred in just 110 s (just 1.6% of the measurement session), the worker’s exposure would have been reduced by over 65%. This example demonstrates that short-duration exposures can occur during specific work tasks such as bagging, which operators can address by such practices as exploring local exhaust ventilation options for bagging stations, training employees on best practices of tying bag collars away from their breathing zone, and encouraging the use of respirators where appropriate.

4 Conclusions

The Helmet-CAM assessment technology and EVADE software have proven to be a useful combination in quickly identifying the sources of significant respirable dust exposures at mine sites. This combination can be part of a larger multi-level intervention effort to systematically reduce worker exposure through increased awareness and control of dust exposures. In an effort to further reduce dust exposures, mine operators may wish to generate a more complete dust exposure profile, and this would necessarily happen through more frequent and longer duration sampling.

This paper has described a method of data post-processing accomplished with computer algorithms which could be used to “screen” the data and identify those exposure hazards that are short in duration yet substantial enough that their correction would lead to significant reductions in worker exposure. After an appreciation for the use of the technology has been developed, this or a similar technique could be used to identify, track, and ultimately reduce the personal exposure to health hazards by mobile workers.

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Fig. 1.
Photo of video exposure monitoring equipment worn by a miner with mobile camera (right shoulder) and cyclone inlet (left lapel)

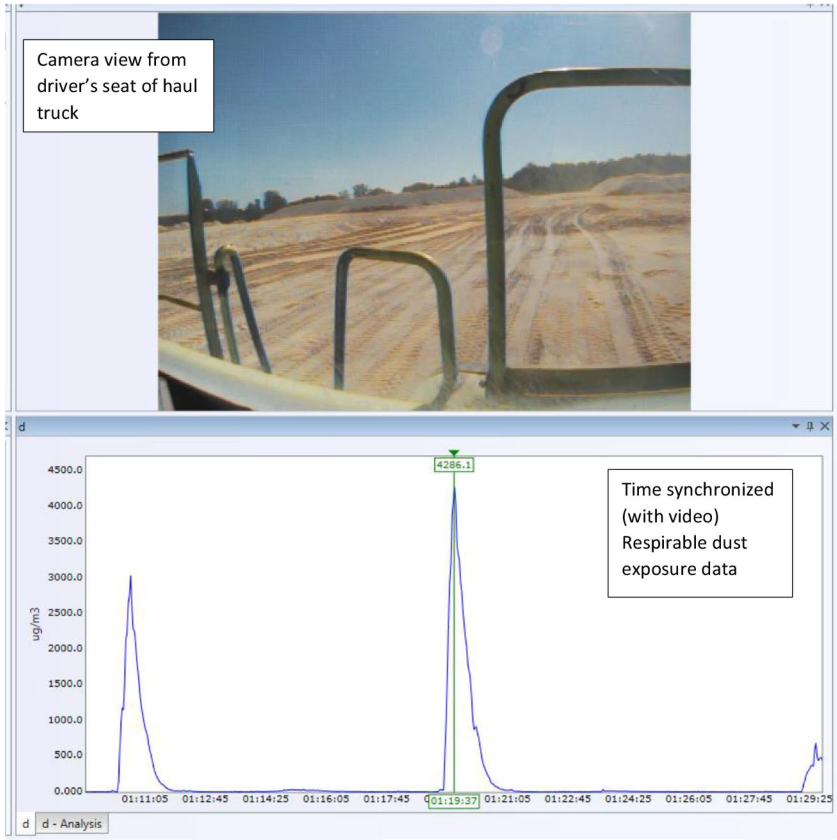

Fig. 2.
Use of EVADE software screenshots (haul truck)

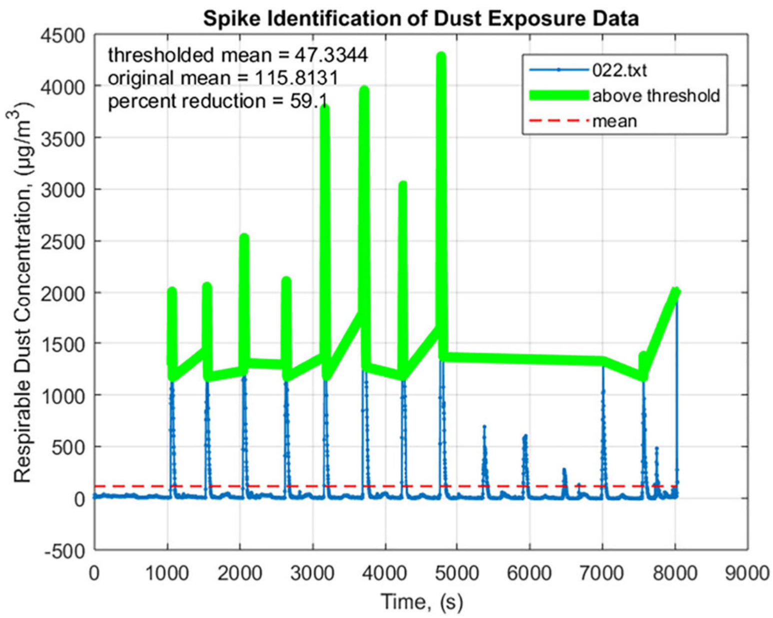

Fig. 3.

Example of spike identification of dust exposure levels

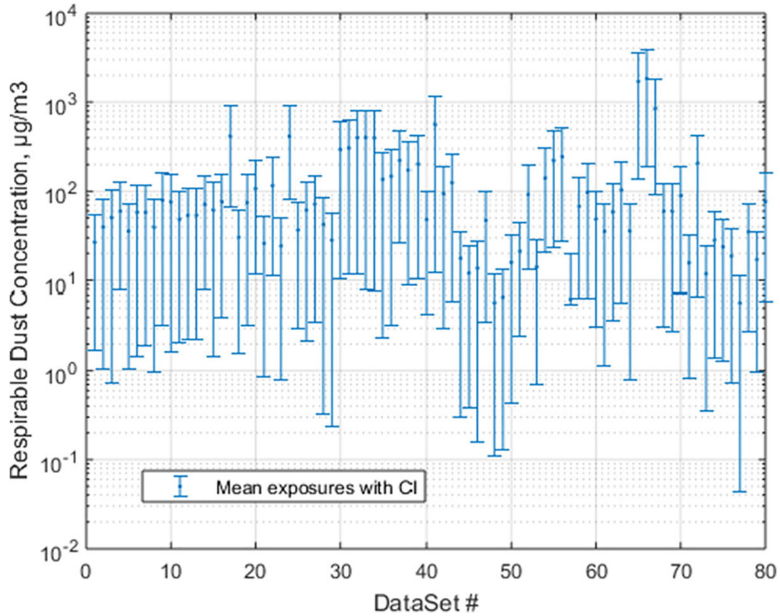

Fig. 4.

Respirable dust concentration of all eighty datasets with 95% confidence intervals

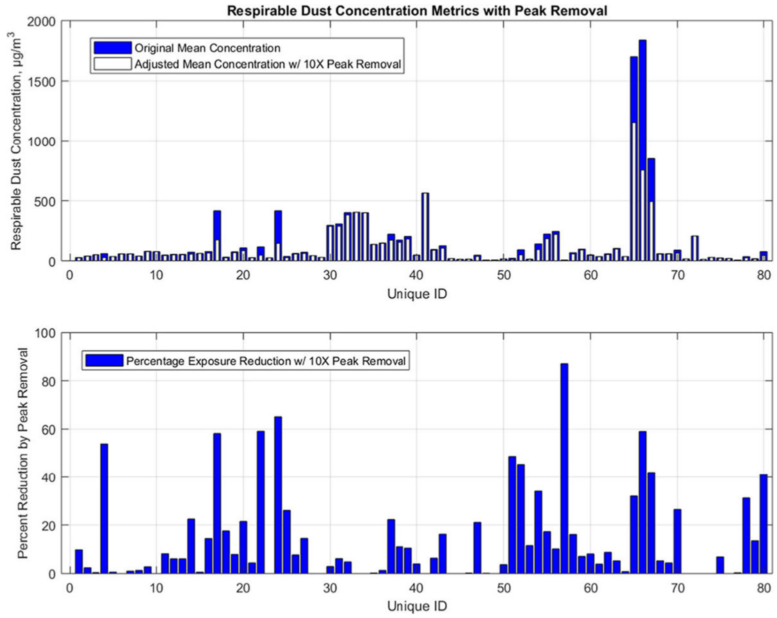

Fig. 5.

Original mean dust concentration (top chart, blue) and mean concentration if peaks greater than 10 × mean are removed (top chart, white). Percentage dust exposure reduction realized by peak removal (bottom chart, blue)

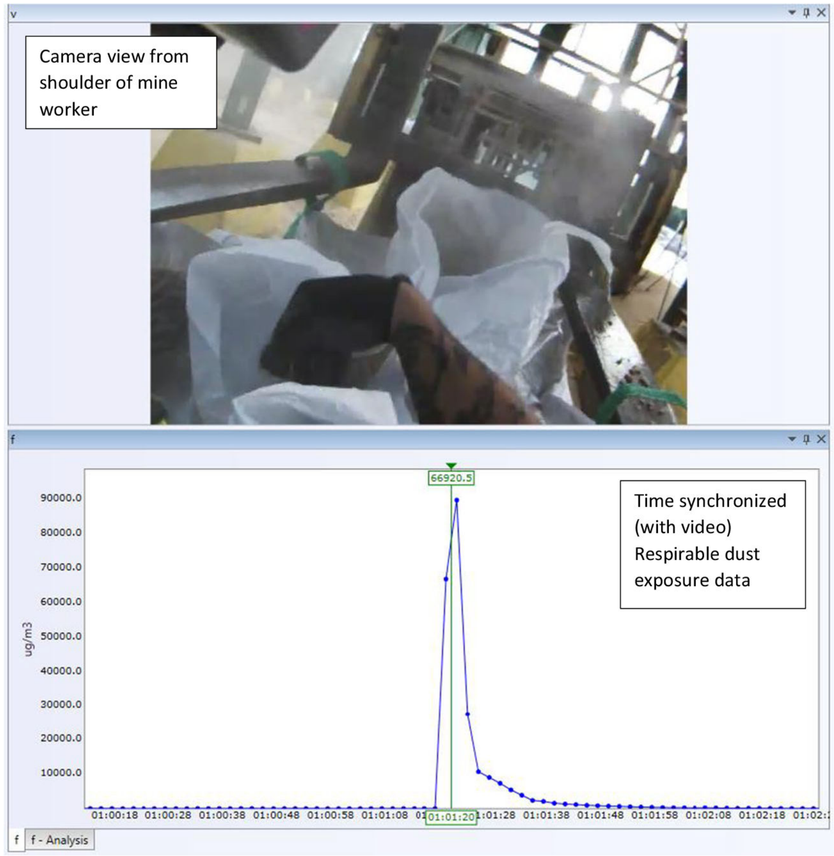

Fig. 6.
Use of EVADE software (bulk bagger) linking the activity (worker approaching bulk bag after filling to begin tying the bag) to the dust exposure peak