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RESEARCH ARTICLE

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Respirable coal mine dust in underground mines, United States, 1982-2017

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Abstract

Background: This study summarized the mass concentration and quartz mass percent of respirable coal mine dust samples (annually, by district, and by occupation) from underground coal mines during 1982-2017.

Methods: Respirable dust and quartz data collected and analyzed by Mine Safety and Health Administration (MSHA) were summarized by year, coal mining occupation, and geographical area. The older (before August 2016) 2.0 mg/m^3 respirable dust MSHA permissible exposure limit (PEL) was used across all years for comparative purposes. For respirable dust and quartz, geometric mean and percent of samples exceeding the respirable dust PEL (2.0 mg/m^3 or a reduced standard for samples with >5% quartz content) were calculated. For quartz samples, the average percent quartz content was also calculated.

Results: The overall geometric mean concentration for 681 497 respirable dust samples was 0.55 mg/m^3 and 5.5% of the samples exceeded the 2.0 mg/m^3 PEL. The overall respirable quartz geometric mean concentration for 210 944 samples was 0.038 mg/m^3 and 18.7% of these samples exceeded the applicable standard. There was a decline over time in the percent of respirable dust samples exceeding 2.0 mg/m^3. The respirable dust geometric mean concentration was lower in central Appalachia compared to the rest of the United States. However, the respirable quartz geometric mean concentration and the mean percent quartz content were higher in central Appalachia.

Conclusion: This study summarizes respirable dust and quartz concentrations from coal mine inspector samples and may provide an insight into differences in the prevalence of pneumoconiosis by region and occupation.

KEYWORDS
coal mine dust, MSHA, MSHA Districts, occupational groups, quartz

1 | INTRODUCTION

The Federal Coal Mine Health and Safety Act of 1969 (Coal Act) was enacted to improve "the working conditions and practices in the

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Nation's coal mines to prevent death and serious physical harm and to prevent occupational diseases", particularly coal workers' pneumoconiosis (CWP) or "black lung." The Coal Act mandated regular inspections of coal mines and established the federal permissible exposure limit (PEL) for respirable coal mine dust (respirable dust), with a reduced dust limit if the sample contains more than 5% quartz.[1] Subsequently, the Federal Mine Safety and Health Act (Mine Act) of 1977 created the Mine Safety and Health Administration (MSHA), which enforces health and safety standards in the mines, including compliance sampling for respirable dust.[2] From the mid-1970s through the late 1990s, the prevalence of CWP among long-tenured coal miners decreased from more than 30% to 5%, and the most severe form of CWP, called progressive massive fibrosis, was nearly eradicated.[3] Since that time, there has been a resurgence of CWP, and the prevalence of progressive massive fibrosis in the central Appalachian region has surpassed any historical precedent. The persistence of pneumoconiosis-related illness and deaths among coal miners prompted MSHA in 2014 to revise its standards for occupational exposure to respirable dust, with the goal "to end black lung" in the United States.[4] The new standards included a reduced PEL for respirable dust, increased sampling frequency, introduction of continuous personal dust monitoring technology, and expansion of medical surveillance services for coal miners. Pneumoconiosis in coal miners is only caused by exposure to respirable dust. Although there is a sizable literature describing morbidity and mortality from coal worker's pneumoconiosis in the United States, we are not aware of any contemporary scientific study summarizing the results of air sampling data collected during coal mine inspections. The purpose of this study is to summarize 36 years of compliance sampling data for respirable dust, and for respirable dust containing quartz (quartz), as collected by MSHA coal mine inspectors in US underground mines, which can inform our understanding of observed patterns of pneumoconiosis in the United States.

2 | METHODS

2.1 | Permissible exposure limits

In 1972, the PEL for respirable dust in coal mines was reduced to 2.0 mg/m^3 concentration, unless the quartz content of the respirable dust sample exceeded 5%.[5] When the quartz content exceeded 5% in an average of multiple samples, the PEL for respirable dust was reduced for that area of the mine based on the following formula:

$$\text{PEL} = \frac{\frac{10\text{mg}}{\text{m}^3}}{\%\ \text{Quartz}}$$

The PELs were based on time-weighted average concentrations sampled over an 8-hour work-shift. Sampling devices must be worn by a specified miner and remain operational throughout the entire shift or for 8 hours, whichever time was less. Each sample was compared to the historic PEL of 2.0 mg/m^3 for the respirable dust analysis (MSHA reduced the PEL to 1.5 mg/m^3 on August 1, 2016, and required sampling for the full duration of the miner's shift, even if longer than 8 hours). For the quartz analysis, a PEL of 2.0 mg/m^3 was used if the percent quartz in the sample was less than or equal to 5%. A reduced PEL, calculated using the formula above, was used if the percent quartz in the sample exceeded 5%.

2.2 | Respirable coal mine dust and respirable quartz data

Respirable dust data were derived from air sampling of coal mining occupations performed by MSHA mine inspectors during 1982-2017 to assess compliance with dust regulations. They include the date of sample collection, the concentration of respirable dust, the occupation code, and the mine identification number. The National Institute for Occupational Safety and Health (NIOSH) received the respirable dust data from MSHA's Laboratory Information Management System database for samples collected during 1982-1999, and accessed publicly available data for samples collected during 2000-2017.[6] A subset of the respirable dust samples was analyzed for quartz. Quartz data were received from MSHA's Pittsburgh Quartz Database; these data include the concentration of the respirable quartz and the percentage of quartz (by weight) in the sample. Samples were included if they met the following criteria: (1) collected underground; (2) obtained in the United States or one of its territories; (3) designated by MSHA as valid (not voided); and (4) occupational "full-shift" (ie, at least 8-hours). In addition, for quartz data, the quartz content must have been greater than or equal to zero. Concentrations were imputed for samples with a value of less than the minimum quantifiable concentration (MQC) based upon the distribution of quantifiable samples (MQC/$\sqrt{2}$).[7] The data were summarized by calendar year, job category, and MSHA coal mine district. For respirable dust data, geometric means for respirable dust concentrations were calculated. For quartz data, geometric means for respirable quartz concentrations, and the percentage of quartz in each sample, were calculated. Although coal mine operators collected samples for respirable dust, only MSHA inspector samples were included in the analysis because relatively few operator samples were analyzed for quartz.

2.2.1 | Occupations

The overall and occupation-specific geometric mean concentrations for respirable dust and quartz were calculated, as well as the percent of samples exceeding the PEL during 1982-2017. Occupations with fewer than 1000 samples were combined. The samples were collected for enforcement purposes and the majority were from high-risk occupations. For example, continuous miner operators and helper (designated occupations), roof bolter (designated area), and shuttle car operator (nondesignated occupation) are occupations mandated by MSHA to be sampled.

2.2.2 | Geographical areas

There are currently nine MSHA coal mining districts. MSHA districts changed over time so all samples from a given mine were assigned to the current MSHA district corresponding to the county where the mine is located, as indicated in Figure 1. To compare respirable dust and quartz findings in central Appalachia to the rest of the United States, data from MSHA Districts 4, 5, and 12 were combined, and compared with combined data from MSHA Districts 2 to 3 and 7 to 10.

2.3 | Data analysis

The number of samples, geometric mean, and percent of samples over the PEL for the respirable dust data and the mean quartz percent for the quartz data were calculated. All analyses were conducted using SAS software version 9.4 (SAS Institute, Cary, NC). Maps were created using MapInfo Professional 15.24 (Pitney Bowes Software, New York, NY), SigmaPlot 12.5 (Systat Software, San Jose, CA) and other figures were created using SigmaPlot software.

3 | RESULTS

3.1 | Respirable coal mine dust

A total of 681 497 respirable coal mine dust samples collected during 1982-2017 were included in the analysis; 1212 samples (0.2%) were lower than the MQC and were imputed. A total of 37 783 (5.5%) samples exceeded the PEL (Table 1). The overall geometric mean for respirable dust was 0.55 mg/m^3, while the geometric mean for samples over the PEL was 2.95 mg/m^3. The geometric means and medians (shown respectively) of occupational groups with more than 5% of the respirable dust samples exceeding the PEL included longwall worker (1.02; 1.07 mg/m^3), continuous miner operator and helper (0.73; 0.76 mg/m^3), cutting machine operator and helper (0.67; 0.70 mg/m^3), auger (0.65; 0.70 mg/m^3), roof bolter (0.59; 0.61 mg/m^3), stopping builder/ventilation man/mason (0.57; 0.58 mg/m^3), blaster and helper (0.50; 0.52 mg/m^3), coal drill operator and helper (0.48; 0.50 mg/m^3), beltman/conveyor man/belt cleaner (0.46; 0.50 mg/m^3), and loading machine operator (0.44; 0.40 mg/m^3; Table 1).

3.2 | Quartz dust

The overall respirable quartz geometric mean for 210 944 quartz samples was 0.038 mg/m^3; 39 519 (18.7%) samples exceeded the applicable PEL (Table 1) and 5650 (2.7%) samples were lower than the MQC and were imputed. Occupational groups with the highest geometric means were roof bolter (0.046 mg/m^3), continuous miner operator and helper (0.043 mg/m^3), longwall worker (0.036 mg/m^3), auger (0.036 mg/m^3), and cutting machine operator and helper (0.027 mg/m^3; Table 1). Medians were calculated and approximately equivalent to the geometric means. The continuous miner operator and helper and the roof bolter occupation groups had 21.9% and 19.1%, respectively, of samples exceeding the PEL, and represented 82% of samples exceeding the PEL. Thirty-one percent of the underground mines, at some time during 1982-2015, had at least one section on a reduced standard due to quartz content in samples.

3.3 | Respirable coal mine dust and respirable quartz dust by MSHA district

Figure 2 displays the geometric means for respirable dust concentrations in mg/m^3, and the mean percent quartz, by year and by MSHA district. Each district has had long-term declines in mean respirable dust levels. During the analysis period, mean percent quartz content of airborne respirable dust samples was consistently above 5% in central Appalachia (Districts 4, 5, and 12).

Figure 3 displays the respirable dust geometric mean concentration by year and region (panel A) and the percent of respirable dust samples containing quartz exceeding the PEL, by year and region (panel B). Overall, the geometric mean concentration for respirable dust was significantly lower ($P < .0001$) in central Appalachia (0.486 mg/m^3) than the rest of the United States (0.647 mg/m^3), and since approximately 1990, there has been a steady decline in mean respirable dust concentrations for both areas (panel A). However, the geometric mean concentration for respirable quartz was significantly higher ($P < .0001$) in central Appalachia (0.05 mg/m^3) than the rest of the United States (0.028 mg/m^3). Medians were calculated and approximately equivalent to the geometric means. The respirable quartz 95th percentile was also higher in central Appalachia (0.225 mg/m^3 vs 0.126 mg/m^3). The mean percent quartz was also significantly higher ($P < .0001$) in central Appalachia (6.724%) compared to the rest of the United States (3.886%; Figure 4). The 95th percentile for mean percent quartz was also higher in central Appalachia (15.2% vs 9.2%).

4 | DISCUSSION

During 1982-2017, geometric mean respirable coal mine dust concentrations in samples collected by coal mine inspectors were consistently below the PEL and concentrations have been consistently lower in central Appalachia compared to the rest of the country. There has also been a precipitous decline in the percent of respirable dust samples exceeding the PEL, with a 17-fold decrease in central Appalachia since 1990. In contrast to the respirable dust findings, mean percent quartz content in samples analyzed from central Appalachian coal mines has consistently exceeded 5%, while mostly remaining below 5% in the rest of the country. Miners are at an increased risk of silica-related disease, therefore the respirable dust PEL is reduced when more than 5% silica is detected, to help protect miners from respiratory impairment. Not all respirable dust samples are analyzed for quartz, however in this time period, 31% were analyzed for quartz. At some point during 1982-2015, 31% of underground US coal mines had at least one mining section placed on a reduced standard due to an enforced violation related to excessive

TABLE 1 Inspector samples of respirable dust and respirable quartz by underground miner occupation group, 1982-2017

	Inspector samples respirable dust					Inspector samples respirable quartz							
	All samples		Over PEL 2 mg/m^3 MRE			All samples		Over PEL			Quartz %	Quartz % >5	
Occupation groups	n	GM	n	GM	% >PEL	n	GM	n	GM	% >PEL	Mean	n	Mean
Longwall workers	37 543	1.023	5360	2.897	14.3	9413	0.036	2138	0.090	22.7	3.716	2186	7.613
Designated area: miscellaneous	2043	0.885	243	3.191	11.9	1123	0.032	246	0.093	21.9	3.598	299	7.892
Continuous miner operator & helper	127 069	0.725	11 307	2.963	8.9	67 341	0.043	14 763	0.138	21.9	5.372	28 613	8.674
Cutting machine operator & helper	7632	0.666	1033	3.311	13.5	3213	0.027	871	0.062	27.1	2.796	357	8.419
Auger	3710	0.647	594	4.593	16.0	716	0.036	250	0.106	34.9	3.289	133	8.237
Roof bolter	171 438	0.587	9229	2.898	5.4	91 593	0.046	17 523	0.147	19.1	6.346	50 352	8.935
Stopping builder/ Ventilation man/mason	1468	0.571	81	2.783	5.5	79	0.045	25	0.130	31.6	5.077	32	7.794
Mobile bridge operator	17 764	0.562	741	2.785	4.2	1652	0.028	183	0.114	11.1	4.353	504	7.561
Section foreman	8852	0.503	297	2.962	3.4	626	0.030	85	0.110	13.6	3.997	140	8.463
Blaster & helper	1721	0.501	128	3.023	7.4	82	0.024	16	0.053	19.5	2.837	10	7.510
Utility man	11 830	0.492	418	2.995	3.5	802	0.020	83	0.086	10.3	3.801	193	7.861
Shuttle car operator	153 194	0.481	4258	2.800	2.8	10 133	0.021	819	0.117	8.1	4.223	2909	7.783
Coal drill operator & helper	7239	0.477	386	3.367	5.3	850	0.025	140	0.072	16.5	3.047	130	7.632
Beltman/conveyor man/ Belt cleaner	1083	0.464	60	3.224	5.5	83	0.026	14	0.099	16.9	3.605	18	7.956
Scoop car operator	48 400	0.450	1458	2.856	3.0	3013	0.021	258	0.113	8.6	4.006	743	7.610
Loading machine operator	5755	0.439	344	3.312	6.0	502	0.015	72	0.060	14.3	3.131	62	8.668
Mechanic & helper	7042	0.396	144	3.055	2.0	618	0.016	37	0.093	6.0	3.328	98	7.379
Jobs with <1000 samples	3332	0.365	144	2.925	4.3	6551	0.037	938	0.109	14.3	5.924	3266	9.402
Tractor operator/ Motorman	5472	0.357	124	3.104	2.3	155	0.034	21	0.135	13.5	5.153	47	10.787
Designated area: Belt area	40 954	0.314	1164	3.054	2.8	11 176	0.014	934	0.038	8.4	2.631	1132	8.203
Designated area: section dumping points	1575	0.313	27	3.435	1.7	274	0.016	20	0.068	7.3	3.350	48	8.365
Electrician & helper	10 447	0.301	92	2.704	0.9	469	0.014	14	0.105	3.0	4.445	152	7.349
Laborer	3314	0.249	105	3.429	3.2	180	0.017	19	0.074	10.6	3.269	26	7.362
Hand loaders	2620	0.173	46	3.066	1.8	300	0.014	50	0.059	16.7	3.592	41	16.563
Total	681 497	0.547	37 783	2.953	5.5	210 944	0.038	39 519	0.129	18.7	5.413	91 491	8.761

Note: For the same occupations worked at the face and nonface or for jobs worked in the same area of the mine, occupation groups were created by combining MSHA occupation codes: (1) Roof bolter (012, 014, 019, 046, 047, 048, 146); (2) Longwall (040, 041, 044, 051, 052, 060, 061, 064); (3) Rock duster (006, 106); (4) Shuttle car operator (050, 073, 250); (5) Motorman (074, 269); (6) Beltman/Conveyor man;/Belt cleaner (001, 101, 201, 154); (7) Auger (010, 017, 018, 055, 070, 071); (8) Electrician & helper (002, 003, 102, 103); (9) Mechanic & helper (004, 005, 104, 105); (10) Blaster/Shotfirer (007, 031); (11) Stopping builder/Brattice man (008, 032, 108); (12) Supply man (009, 109); (13) Fan attendant (015, 115); (14) Laborer (016, 116); (15) Coal driller operator & helper (033, 034); (16) Continuous miner operator & helper (035, 036); and (17) Cutting machine operator & helper (037, 038). Abbreviations: GM, Geometric mean; PEL, permissible exposure limit

quartz. In addition, of all the US coal mines on a reduced standard at some point during 2006-2015, nearly half (49%) were in central Appalachia. The occupation groups with the highest mean respirable dust concentrations included longwall worker, continuous miner operator and helper, cutting machine operator and helper, auger, and roof bolter. These jobs involve active mining at the face in areas of higher dust concentrations.

Pneumoconioses in coal miners, such as CWP, silicosis, and mixed dust pneumoconiosis, are caused only by coal mine dust exposure. In 1995, NIOSH published a respirable coal mine dust

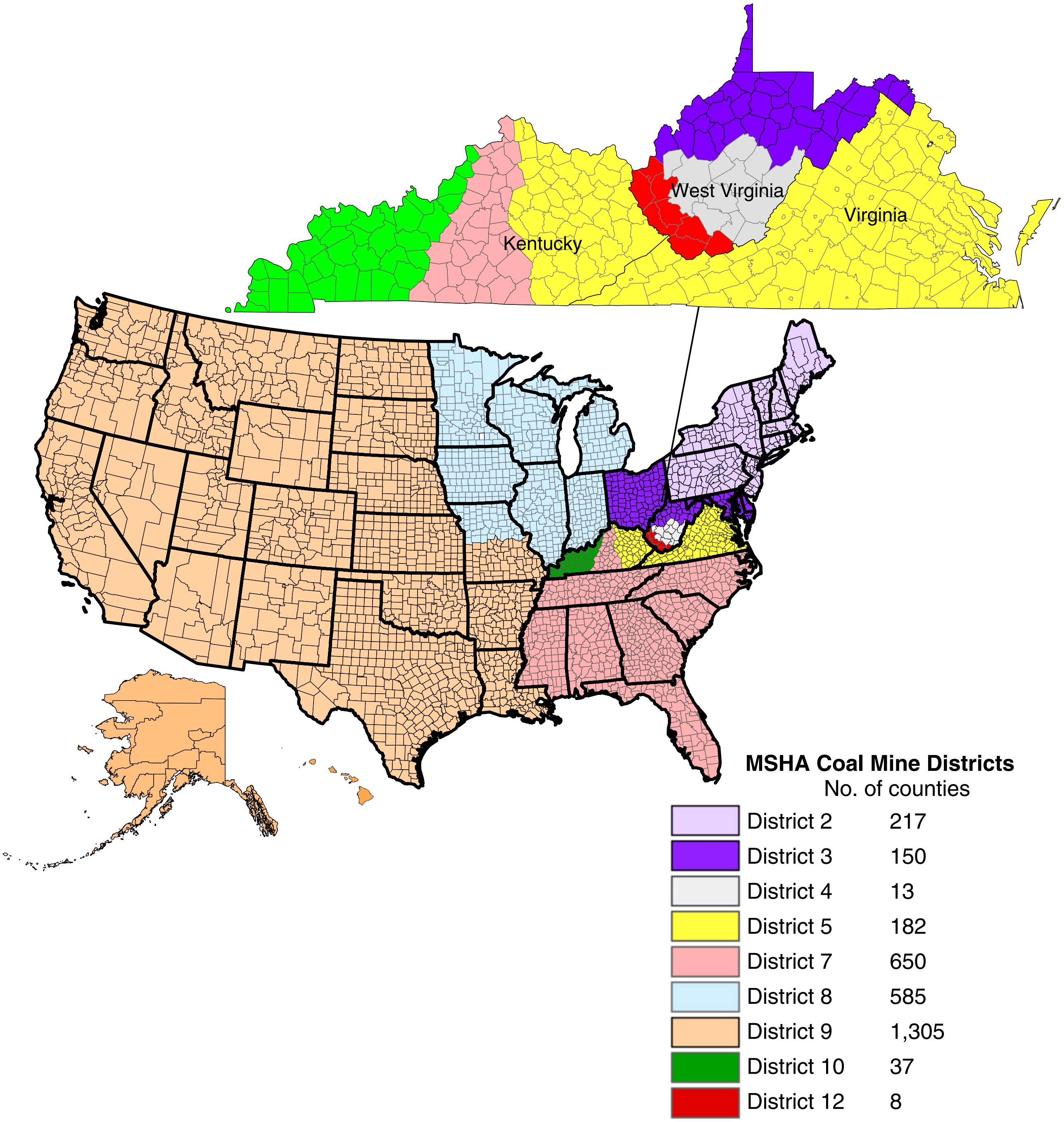

FIGURE 1 Mine Safety and Health Administration (MSHA) Coal Mine Districts—United States and inset central Appalachia (Districts 4, 5, and 12 combined)

recommended exposure limit (REL) of 1 mg/m^3 and recommended that to "minimize the risk of adverse health effects, exposure shall be kept as far below the REL as feasible using engineering controls and work practices."[5] Cumulative dust exposure and dust content (eg, coal rank or silica content) are important determinants of disease onset and progression. Reports have demonstrated a sharp increase since the late 1990s in the prevalence of CWP and progressive massive fibrosis in the central Appalachian states of Kentucky, Virginia, and West Virginia.[3,8] Silica (or quartz) exposure has been implicated as a possible explanation for this resurgence.[9] From the 1980s through the early 2000s, there was an eight-fold increase in the proportion of central Appalachian coal miners with radiographic patterns consistent with silica exposure; during the same period, this measure did not change for the rest of the country.[9] A recent pathology study examined lung tissue from central Appalachian coal miners with rapidly progressive CWP.[10] Most cases had features of accelerated silicosis and mixed dust pneumoconiosis rather than the classic lesions associated with CWP. Yorio et al[11] investigated lung disease and pneumoconiosis patterns by MSHA

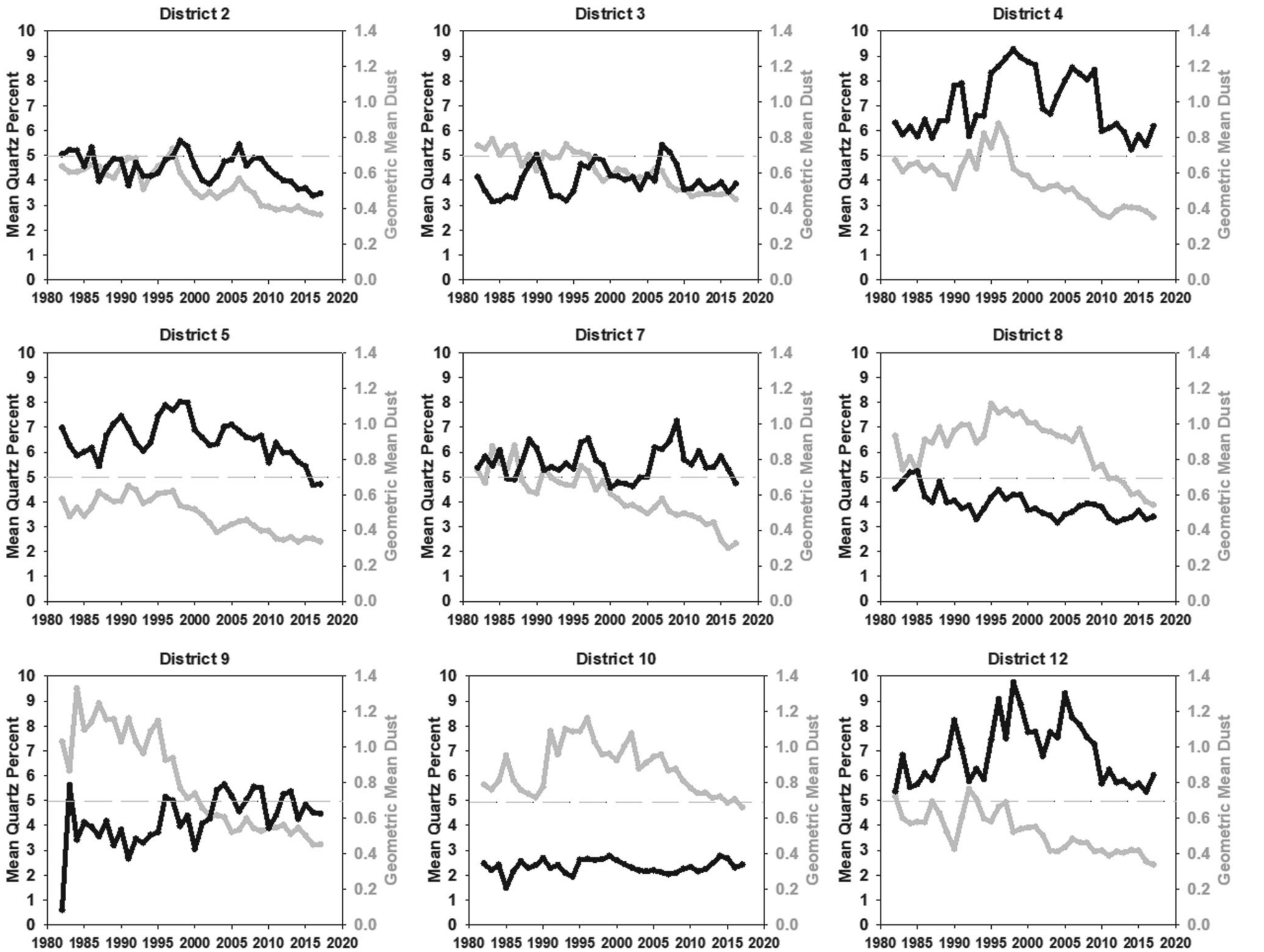

FIGURE 2 Geometric mean respirable dust (gray line) and mean quartz percent (black line) by MSHA Coal Mine District. MSHA, Mine Safety and Health Administration

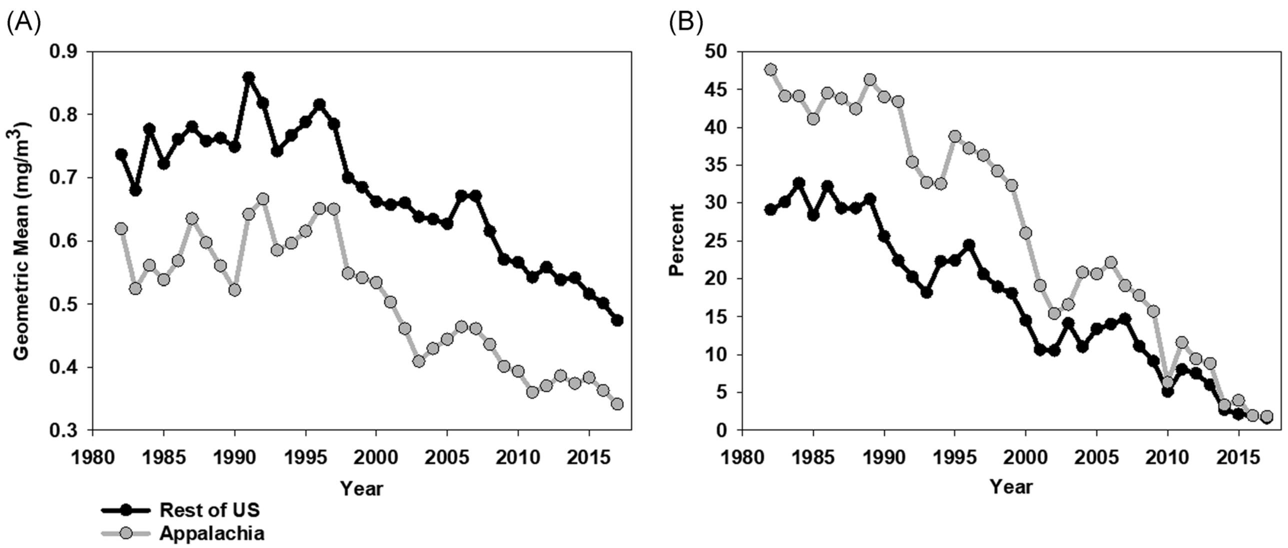

FIGURE 3 Comparison of annual geometric mean (A) respirable dust and (B) percent respirable dust samples containing quartz exceeding the permissible exposure limit for central Appalachia (MSHA Districts 4, 5, and 12 combined; gray line) and the rest of the United States (MSHA Districts 2-3, 7-10 combined; black line) by year. MSHA, Mine Safety and Health Administration

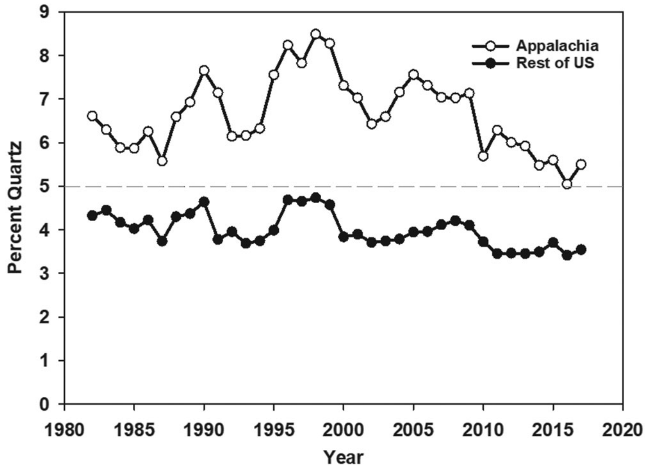

FIGURE 4 Mean percent quartz in samples for central Appalachia (MSHA Districts 4, 5, and 12 combined) and the rest of the United States (MSHA Districts 2-3, 7-10 combined) by year. MSHA, Mine Safety and Health Administration

district from 2006 to 2015. Districts 4, 5, and 12 (central Appalachia) contained 75% of all reported US CWP cases.

In the central Appalachian districts, mean percent quartz was consistently above 5%, with a peak of 8.5% in 1998. The rock layers bordering coal seams can contain substantial amounts of quartz, and research has indicated that respirable quartz in underground coal mines is primarily from rock adjacent to the mined coal seam.[12] Coal mining in central Appalachia, where seams tend to be thinner than in other coal mining regions, frequently involves cutting large amount of rock along with coal to maintain clearances for modern mining equipment.[13,14] Suarthana et al[15] presented the median coal seam height by MSHA district and central Appalachia had some of the lowest seam heights. A recent study found that dust samples from central Appalachian mines had relatively higher percentages of quartz and aluminosilicates, consistent with the practice of cutting rock along with the coal.[16]

Improving the timeliness of reporting for monitoring respirable silica exposures in coal mines has become a priority in the field of occupational safety and health. Currently, samples collected during compliance sampling are shipped to a lab for analysis, and it can take days or weeks until analysis results are available. NIOSH is developing a method to generate end-of-shift silica exposure data at the mine site. This method is currently being piloted and is available for coal mines,[17] and could provide more timely information to workers and operators to inform evaluation of engineering controls and work practices to reduce silica exposure.

The data analyzed in this study have well-recognized limitations. The dust samples were collected for compliance purposes rather than for surveillance of worker exposures, and might not represent exposures typically experienced by coal miners. Also, before the new MSHA rule, full-shift sampling for shifts longer than 8 hours was not required. However, these data provide the best available exposure proxy for the US coal mining industry, are internally consistent, and are informative for assessing trends in inspector-reported dust levels over time, and for comparing regions or groups of interest. We used geometric means as the primary measure to summarize these data. This is a common approach to present industrial hygiene sampling data as the geometric mean is one way to manage skewed sampling data, and decrease the effect of outliers. However, there are well-known limitations to using this summary measure (as with any single measure). Therefore we calculated additional summary measures, the medians for occupational data, and 95% percentiles for the outliers for the central Appalachian and rest of the US regions. The findings were consistent irrespective of the specific summary measures used.

5 | CONCLUSION

Among more than 680 000 inspector samples analyzed over the last 36 years, respirable dust concentrations have steadily declined in underground coal mines, and have been consistently lower in central Appalachia. However, the mean percent quartz in these samples has consistently been above 5% in central Appalachia, and consistently below 5% in the rest of the country. These findings suggest an important role for silica exposure in the resurgence of severe and rapidly progressive CWP in central Appalachia, and underscore the continued need for effective dust exposure monitoring and control for all miners.

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CONFLICT OF INTERESTS

The authors declare that there are no conflict of interests.

DISCLOSURE BY AJIM EDITOR OF RECORD

John Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

AUTHOR CONTRIBUTIONS

Doney, Blackley, Hale, Halldin, Kurth, and Laney participated in the conception or design of the work. Doney, Blackley, Hale, Halldin, Kurth, and Laney participated in the acquisition, analysis, or interpretation of data for the work. Doney, Blackley, and Laney drafted the work and revised it critically for important intellectual content. All authors provided final approval of this article to be published and agreement to be accountable for all aspects of the work.

ETHICS APPROVAL AND INFORMED CONSENT

Data was collected for compliance purposes and is de-identified and publically available. No reviews and approvals needed.

DISCLAIMER

The findings and conclusions of this report are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health. Mention of a specific product or company does not constitute endorsement by the Centers for Disease Control and Prevention.

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REFERENCES

1. Federal Coal Mine Health and Safety Act of 1969, in Pub. L. No. 91-173, S. 2917. 1969. http://www.msha.gov/SOLICITOR/COALACT/69act.htm, Accessed August 6, 2018.
2. Federal Mine Safety and Health Act of 1977, in Pub. L. No. 91-173, as amended by Pub. L. 95-164. 1977. https://arlweb.msha.gov/REGS/ACT/ACTTC.HTM, Accessed November 26, 2018.
3. Blackley DJ, Halldin CN, Laney AS. Continued increase in prevalence of coal workers' pneumoconiosis in central Appalachia. *Am J Public Health*. 2018;108(9):1220-1222.
4. MSHA fact sheet. https://arlweb.msha.gov/endblacklung/docs/factsheet.pdf, Accessed September 24, 2018.
5. National Institute for Occupational Safety and Health (NIOSH). Criteria for a recommended standard: Occupational exposure to respirable coal mine dust, DHHS (NIOSH) Pub. No. 95–106. Cincinnati, OH: NIOSH, 1995. https://www.cdc.gov/niosh/docs/95-106/pdfs/95-106.pdf, Accessed April 4, 2018.
6. MSHA web site. https://www.msha.gov, Accessed September 20, 2018.
7. Hornung RW, Reed L. Estimation of average concentration in the presence of nondetectable values. *Appl Occup Environ Hyg*. 1990;5(1):46-51.
8. Blackley DJ, Crum JB, Halldin CN, Storey E, Laney AS. Resurgence of progressive massive fibrosis in coal miners—eastern Kentucky, 2016. *MMWR Morb Mortal Wkly Rep*. 2016;65(49):1385-1389.
9. Laney AS, Petsonk EL, Attfield MD. Pneumoconiosis among underground bituminous coal miners in the United States: is silicosis becoming more frequent? *Occup Environ Med*. 2010;67(10):652-656.
10. Cohen RA, Petsonk EL, Rose C, et al. Lung pathology in US coal workers with rapidly progressive pneumoconiosis implicates silica and silicates. *Am J Respir Crit Care Med*. 2016;193(6):673-680.
11. Yorio PL, Laney AS, Halldin CN, et al. Interstitial lung diseases in the US mining industry: using MSHA data to examine trends and the prevention effects of compliance with health regulations, 1996-2015. *Risk Anal*. 2018;38:1962-1971. https://doi.org/10.1111/risa.13000
12. Schatzel SJ. Identifying sources of respirable quartz and silica dust in underground coal mines in southern West Virginia, western Virginia, and eastern Kentucky. *Int J Coal Geol*. 2009;78:110-118.
13. Reynolds LE, Blackley DL, Colinet JF, et al. Work practices and respiratory health status of Appalachian coal miners with progressive massive fibrosis. *J Occup Environ Med*. 2018;60(11):e575-e581.
14. Pollock DE, Potts JD, Joy GJ. Investigation into dust exposures and mining practices in the southern Appalachian region. *Min Eng*. 2010;62(2):44-49.
15. Suarthana E, Laney AS, Storey E, Hale JM, Attfield MD. Coal workers' pneumoconiosis in the United States: regional differences 40 years after implementation of the 1969 Federal Coal Mine Health and Safety Act. *Occup Environ Med*. 2011;68:908-913.
16. Johann-Essex V, Keles C, Rezaee M, Scaggs-Witte M, Sarver E. Respirable coal mine dust characteristics in samples collected in central and northern Appalachia. *Int J Coal Geol*. 2017;182:85-93.
17. National Institute for Occupational Safety and Health. Mining product: FAST—Field Analysis of Silica Tool. https://www.cdc.gov/niosh/mining/works/coversheet2056.html, Accessed February 13, 2019.

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