Exposures of Underground Miners to Diesel Particulate Matter in the United States

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Monitoring personal exposures to diesel particulate matter (DPM) plays an important role in efforts to reduce exposure of workers to diesel aerosols.

- Compliance monitoring of personal exposure levels (PELs) for DPM is done in several countries:
  - In the U.S.A. [30 CFR 57.5061] and Ontario [OHSA 2017] monitoring is done primary in underground metal, nonmetal, and stone mines.
  - In Australia, monitoring is done also in underground coal mines [Noll et al. 2015]…
- Regular monitoring personal exposures to total carbon (TC) and elemental carbon (EC) by operators is a major pillar of a performance or risk based approaches toward reducing exposures of underground miners to diesel aerosols.

2

In the U.S.A., compliance sampling is done by Mine Safety and Health Administration (MSHA) inspectors [MSHA 2017].

- The NIOSH 5040 method [NIOSH 2016] has been adopted for compliance monitoring [MSHA 2016]:
- The DPM sampling strategy is executed on discretion of the MSHA inspectors:
  - On site assessment is used to determine "…which occupations are "high risk" and need to be sampled." [MSHA 2006];
  - Therefore, sampling is not random;
  - Compliance sampling is not exposure assessment sampling.
- MSHA establish compliance based on the results of the thermal optical transmittance (TOT) [NIOSH 2016] analysis performed on:
  - the personal exposure DPM samples:
    - elemental carbon (EC) - contaminant code (CD) 560;
    - total carbon (TC) directly measured or calculated using EC data and mine specific TC/EC ratio established on a number of ambient samples - CD 561.
  - the ambient samples used to establish mine specific TC/EC ratio – CD 562.

3

In order to assure that a personal exposure results are more than likely to represent an overexposure at the MSHA PEL, MSHA developed method specific error factors [MSHA 2008].

- The error factors (EF) for EC and TC were calculated to account for potential systematic errors and ensure noncompliance with at least 95-percentile confidence.
- The EFs accounts errors in quantification of sample volume, deposited surface area, and analytical procedure.
- Taking in account EFs the citations for personal overexposure to DPM are issued for 8-hour shift when:
  - EC * EF(1.095) ≥ 160 $\mu g/m^3$ (EC ≥ 176 $\mu g/m^3$), and
  - EC * EF (1.095) < 160 $\mu g/m^3$, but TC*EF (1.192) ≥ 160 $\mu g/m^3$ (191 $\mu g_{TC}/m^3$) or EC*TC/EC*EF (1.259-1.121) ≥ 180 - 202 $\mu g/m^3$ (depending on the number of ambient samples).
- Often, for the rough calculations, the assumption is introduce that TC/EC ratio in underground mines is 1.3 and that exposure to 123 $\mu g_{EC}/m^3$ is equivalent to exposure to 160 $\mu g_{TC}/m^3$.

4

The results of DPM compliance sampling in the United States [MSHA 2018] were used to assess the general trends in DPM exposures and need for development of novel control technologies and strategies.

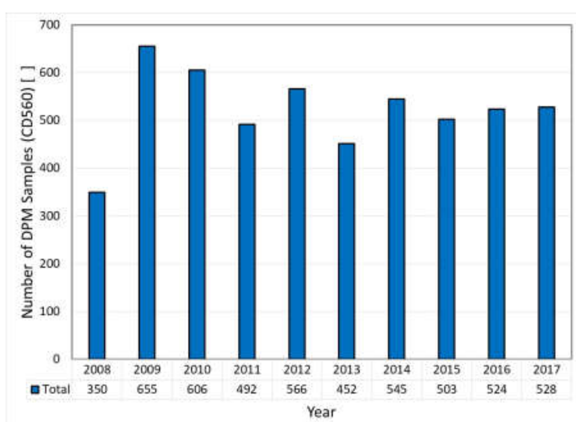
- The DPM samples were collected in various underground metal, nonmetal, and stone mines:
  - Metal mines included those that produce gold, lead, molybdenum, nickel, platinum group, silver, uranium, and zinc.
  - Nonmetal mines included those that produce potash, salt, and trona.
  - Stone mines included those that produce crushed, broken limestone, cement, dimensional marble, lime, and sand.

Statistics for Metal and Nonmetal Mines in the U.S. for CY2015	Total Number of Mines	Total Number of Underground Mines	Total Number of Employees	Total Number of Employees in Underground Mines
Metal	315	92	41,459	6,391
Nonmetal	924	44	26,089	2,652
Stone	4,303	116	67,070	1,958
Sand	6,292	0	34,781	0
Total	11,834	252	169,399	11,001

5

The analysis was performed for the DPM compliance samples collected between 2008, the first year when 160 µg/m³ PEL became effective [73 Fed. Reg. 29058], and 2017 [MSHA 2018].

- In period between 2008 and 2017, 350 to 655 of personal EC exposure compliance samples (CD560) were collected per year.
- In those years, the similar numbers of TC and EC area samples (CD562) were collected.



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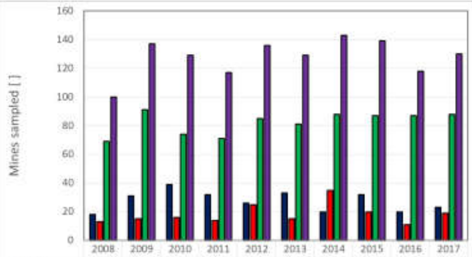
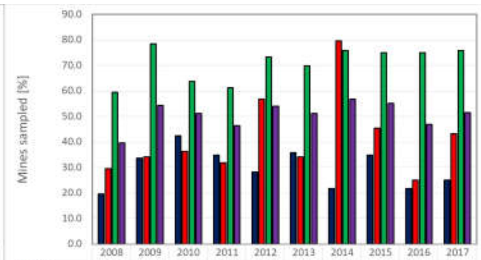
The DPM sampling did not occur uniformly across the sectors.

- Sampling took place in:
  - 40 to 52 percent of all mines.
  - 60 to 78 percent of stone mines.
  - 19 to 36 percent of metal mines.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Metal	18	31	39	32	26	33	20	32	20	23
Nonmetal	13	15	16	14	25	15	35	20	11	19
Stone & Sand	69	91	74	71	85	81	88	87	87	88
COMBINED	100	137	129	117	136	129	143	139	118	130

Year

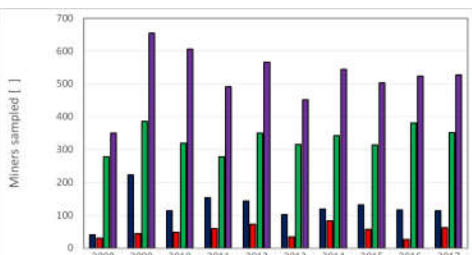


	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Metal	19.6	33.7	42.4	34.8	28.3	35.9	21.7	34.8	21.7	25.0
Nonmetal	29.5	34.1	36.4	31.8	56.8	34.1	79.5	45.5	25.0	43.2
Stone & Sand	59.5	78.4	63.8	61.2	73.3	69.8	75.9	75.0	75.0	75.9
COMBINED	39.7	54.4	51.2	46.4	54.0	51.2	56.7	55.2	46.8	51.6

Year

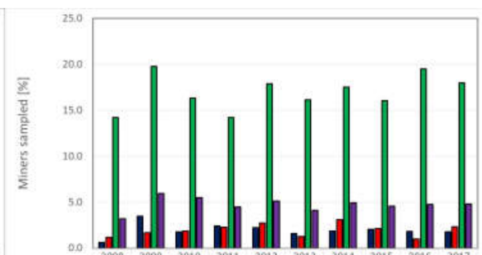
The DPM sampling did not occur uniformly across the occupations.

- 14 to 20 percent of stone miners were sampled for one shift, and
- 1 to 4 percent of metal miners were sampled for one shift.
- Overall, the set of the data is rather limited.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Metal	41	223	114	154	143	102	119	132	116	114
Nonmetal	31	45	49	60	73	34	83	57	26	62
Stone & Sand	278	387	320	278	350	316	343	314	382	352
COMBINED	350	655	606	492	566	452	545	503	524	528

Year

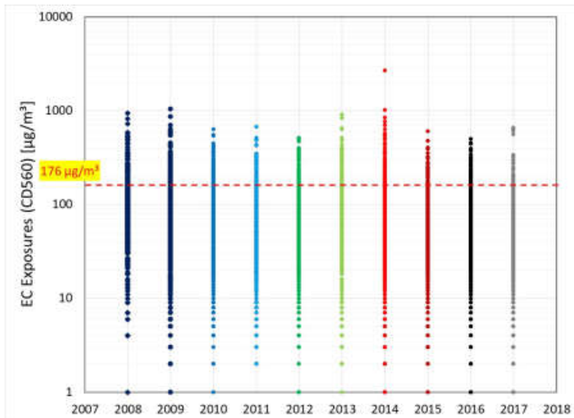


	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Metal	0.6	3.5	1.8	2.4	2.2	1.6	1.9	2.1	1.8	1.8
Nonmetal	1.2	1.7	1.8	2.3	2.8	1.3	3.1	2.1	1.0	2.3
Stone & Sand	14.2	19.8	16.3	14.2	17.9	16.1	17.5	16.0	19.5	18.0
COMBINED	3.2	6.0	5.5	4.5	5.1	4.1	5.0	4.6	4.8	4.8

Year

The data showed that EC exposures varied widely among underground occupations.

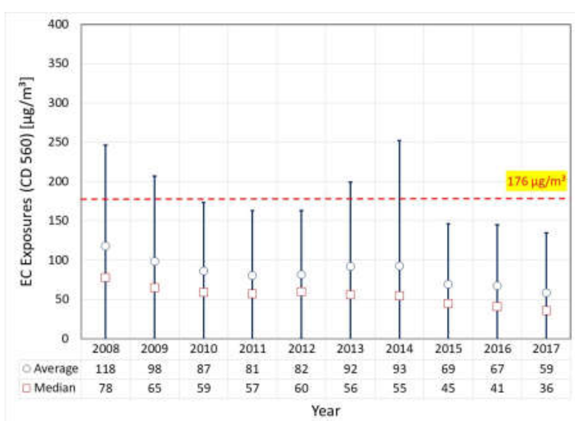
- The lowest observed EC exposures were between 0 µg/m³ (all but 2015) and 1 µg/m³ (2015).
- The highest observed EC exposures were between 498 µg/m³ (2016) and 2665 µg/m³ (2014).



9

The average and median EC exposures were bellow 176 µg/m³ for all observed years.

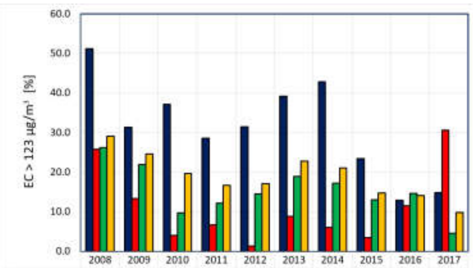
- The industry-average EC exposures gradually dropped from 118 µg/m³ to 59 µg/m³.
- The error bars, that represent standard deviations of EC means, indicate wide distribution of EC exposures across the sampled occupations.



10

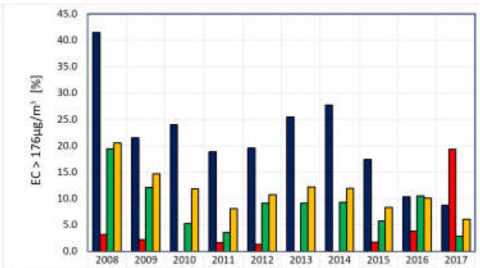
However, a number of the miners were exposed to EC concentrations in excess of 123 μg/m³ and 176 μg/m³.

- For the majority of the observed years, the fractions of the miners exposed to EC concentrations in excess of 123 and 176 μg/m³ were higher for the metal than for the stone operations.
- In general, the fraction of EC samples collected in metal and stone mines that exceeded 123 and 176 μg/m³ decreased over the whole studied period.
- The trends for nonmetal miners are not clear.



Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Metal	51.2	31.4	37.1	28.6	31.5	39.2	42.9	23.5	12.9	14.9
Nonmetal	25.8	13.3	4.1	6.7	1.4	8.8	6.0	3.5	11.5	30.6
Stone & Sand	26.3	22.0	9.7	12.2	14.6	19.0	17.2	13.1	14.7	4.5
Combined	29.1	24.6	19.6	16.7	17.1	22.8	21.1	14.7	14.1	9.8

Year



Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Metal	41.5	21.5	24.1	18.8	19.6	25.5	27.7	17.4	10.3	8.8
Nonmetal	3.2	2.2	0.0	1.7	1.4	0.0	0.0	1.8	3.8	19.4
Stone & Sand	19.4	12.1	5.3	3.6	9.1	9.2	9.3	5.7	10.5	2.8
Combined	20.6	14.7	11.9	8.1	10.8	12.2	11.9	8.3	10.1	6.1

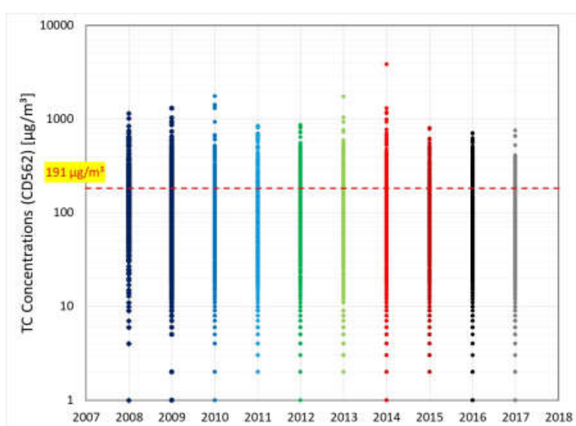
Year

CDC NIOSH

11

The TC concentrations (CD 562) also varied widely.

- The lowest observed TC concentrations were between 0 μg/m³ (2009-2014, 2017) and 2 μg/m³ (2015).
- The highest observed TC concentrations were between 705 μg/m³ (2016) and 3831 μg/m³ (2014).

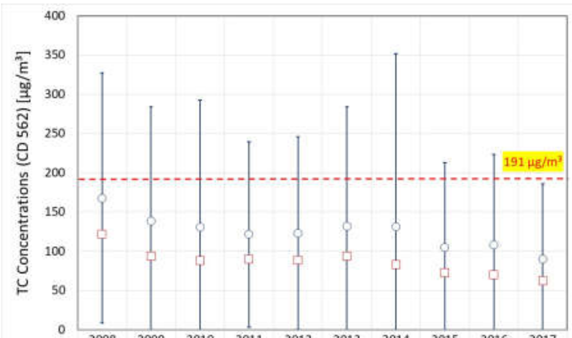


CDC NIOSH

12

The average and median TC concentrations were bellow 191 μg/m³ for all observed years.

- Over the studied period average TC concentrations gradually dropped from 168 μg/m³ to 90 μg/m³.
- However, the error bars, that represent standard deviations of TC means, indicate wide distribution of TC concentrations across the industry.



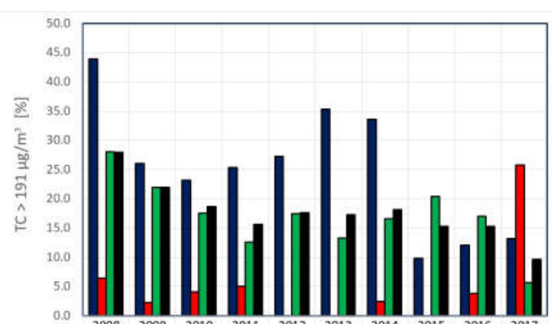
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
○ Average	168	138	131	122	123	132	132	105	109	90
□ Median	122	94	88	90	89	94	83	73	71	63

Year

13

TC concentrations in some metal and stone mines exceeded 191 μg/m³.

- For the majority of observed years, the fractions of the samples that showed TC concentrations in excess of 191 μg/m³ were higher for the metal than for the stone operations.
- The fraction of TC samples collected in the metal and stone mines that exceeded 191 μg/m³ gradually decreased over the studied period.



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Metal	43.9	26.0	23.2	25.3	27.3	35.3	33.6	9.8	12.1	13.2
Nonmetal	6.5	2.2	4.1	5.0	0.0	0.0	2.4	0.0	3.8	25.8
Stone & Sand	28.1	22.0	17.5	12.6	17.4	13.3	16.6	20.4	17.0	5.7
Combined	28.0	22.0	18.6	15.7	17.7	17.3	18.2	15.3	15.3	9.7

Year

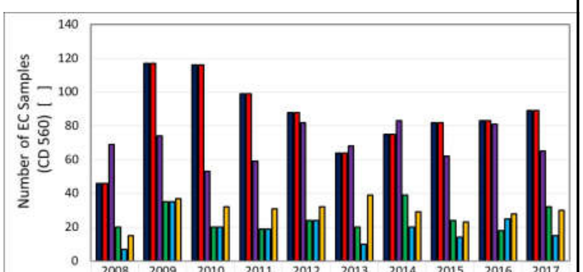
14

The job-specific exposures were examined for 6 out of 120 specific jobs MSHA recognizes in metal, nonmetal, and stone industry in the United States.

#	Job Occupation Code	Job	#	Job Occupation Code	Job	#	Job Occupation Code	Job	#	Job Occupation Code	Job
1	28	Scoop tram operator	31	344	Car shake-out operator/car dumper	61	588	Sizing/washing operations worker	91	716	Cement man/concrete worker
2	29	Mucking machine operator	32	352	Iron worker/metal worker	62	601	Conveyor belt crew	92	726	Grizzly man/grizzly tender
3	30	Slusher operator	33	367	Shovel operator	63	602	Electrician/wireman	93	728	Load-Haul-Dump - complete cycle
4	32	Brattice man (ventilation man)	34	368	Bulldozer operator	64	603	Electrician helper dredge operator	94	734	Rotary pneumatic drill operator
5	34	Diamond drill operator (surface/UG)	35	372	Barge attendant/boat operator	65	604	Mechanic	95	739	Hand trammer (load & dump)
6	35	Continuous miner helper	36	375	Road grader operator	66	607	Jackhammer operator/chipping hammer operator	96	747	Scaler (hand)
7	36	Continuous miner operator	37	376	Truck driver	67	608	Mason/bricklayer	97	750	Shuttle car operator (diesel)
8	37	Cutting machine helper	38	378	Mobile crane operator	68	609	Supply man/nipper	98	759	Raise borer operator
9	38	Cutting machine operator	39	379	Dryer operator/kiln operator	69	612	Belt vulcanizer	99	763	Shaft miner/shaft repairer
10	39	Hand loader (load only)	40	385	Lampman	70	613	Cleanup man	100	765	Sand filler (dry)
11	41	Jacksetter	41	387	Rotary bucker excavator operator	71	614	Sampler/lab technician	101	766	Sand filler (wet)
12	43	Gathering arm loader operator	42	388	Scalper-screen operator	72	616	Laborer/utility man	102	778	Backhoe operator
13	45	Chute blaster	43	389	Forklift operator	73	618	Greaser/oiler	103	779	Pelletizing operations worker
14	46	Rock bolter/roof bolter	44	392	Toplander/skip dumper/tipple operator	74	619	Welder	104	782	Front-end loader operator
15	48	Roof bolter mounted	45	393	Weighman/scale man	75	622	Dump operator	105	804	Plumber/pipefitter/millwright
16	53	Utility man/laborer	46	394	Carpenter/plumber/painter	76	623	Surveyor/transit man	106	807	Powder man/shotfirer/shooter/blaster
17	57	Stope miner	47	397	Yard engine operator/fireman	77	634	Rotary electric/hydraulic drill operator	107	825	Bobcat operator
18	58	Drift miner	48	399	Dimension stone cutter/sawyer/splitter/trimmer/finisher	78	649	Administration/supervisory personnel	108	833	Drill helper/chuck tender
19	59	Raise miner	49	413	Janitor	79	660	Machinist	109	847	Scaler (mechanical)
20	79	Crusher operator/pan-feeder operator	50	416	Salvage worker	80	663	Shaft miner/shaft repairer	110	850	Ramcar operator
21	134	Jet piercing channeler operator	51	420	Aerial tram operator	81	668	Tractor operator	111	878	Overhead crane operator
22	154	Belt cleaner/beltpicker/conveyor crew	52	434	Churn drill operator	82	669	Bin puller/truck loader	112	879	Bagger/bagging operations worker
23	179	Mill operator (rod/ball/pebble)	53	456	Engineer (ventilation/electric/mining)	83	673	Leaching operations worker	113	894	Painter
24	216	Track man/track gang	54	479	Hydrating plant operator	84	674	Warehouseman/supply handler	114	921	Hoist operator/hoistman-engineer
25	234	Jet piercing drill operator	55	488	Dry screening-plant operator	85	678	Dragline operator	115	930	Skip tender/cager/station attendant
26	261	Battery station operator	56	513	Building repair & maintenance	86	679	Flotation/concentrator operator	116	934	Jumbo percussion drill operator
27	279	Hammer mill operator	57	514	Laboratory technician/Refiner	87	682	Pan scraper operator	117	950	Shuttle (elec.) car operator
28	331	Clamshell operator	58	516	Tamping machine operator	88	706	Shotcrete man/gunite man	118	962	Trip rider/swamper
29	334	Wagon drill operator	59	534	Jackleg operator/stoper drill operator	89	708	Ventilation crew	119	969	Motorman
30	342	Bit grinder/bit sharpener/machinist	60	579	Slurry operator/mixing operator/pumping operator/pumper	90	710	Ground control/timberman	120	979	Packaging operations worker

The occupation-specific EC exposures were examined only for occupations that were sampled at least seven or more times per year.

- Truck driver (376)
- Front-end loader operator (782)
- Powder man/shotfirer/shooter/blaster (807)
- Rotary electric/hydraulic drill operator (634)
- Rotary pneumatic drill operator (734)
- Jumbo percussion drill operator (934)



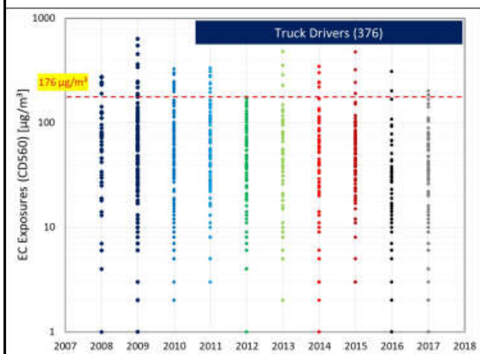
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
376	46	117	116	99	88	64	75	82	83	89
782	46	117	116	99	88	64	75	82	83	89
807	69	74	53	59	82	68	83	62	81	65
634	20	35	20	19	24	20	39	24	18	32
734	7	35	20	19	24	10	20	14	25	15
934	15	37	32	31	32	39	29	23	28	30

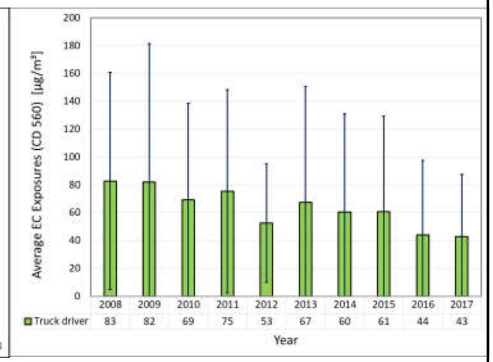
Year

16

Truck Drivers (376)

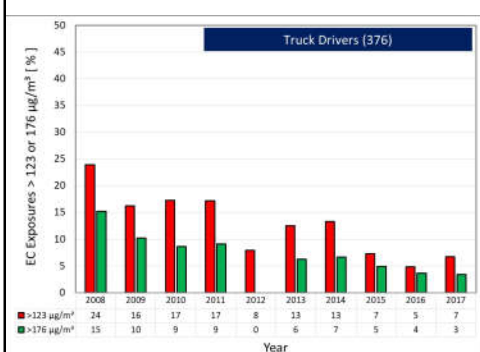
- Over the examined period, the average EC exposures of truck drivers gradually dropped from 83 μg/m³ to 43 μg/m³.

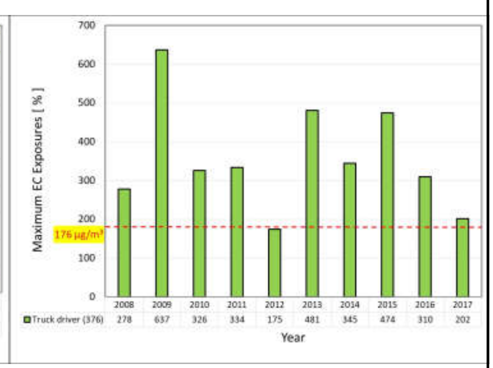




Truck Drivers (376)- Continuation

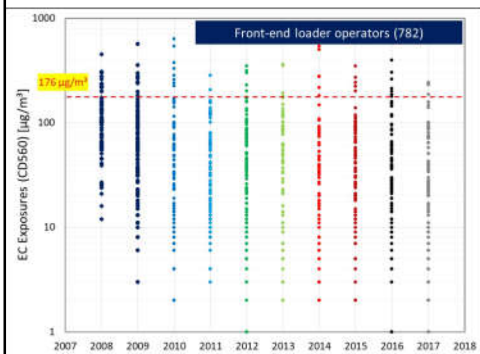
- The percentages of EC samples collected for the truck drivers that exceeded 123 μg/m³ gradually dropped from 24 to 7 and the percentage of those that exceeded 176 μg/m³ gradually dropped from 15 to 3.
- The EC exposures as high as 673 μg/m³ were recorded.

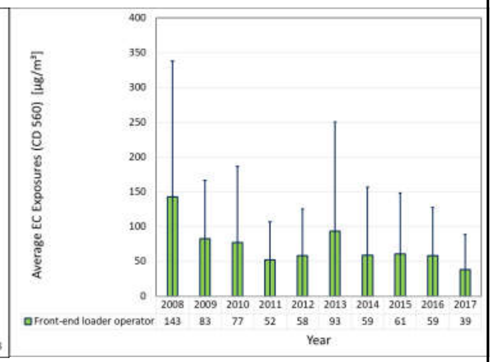




Front-end loader operator (782)

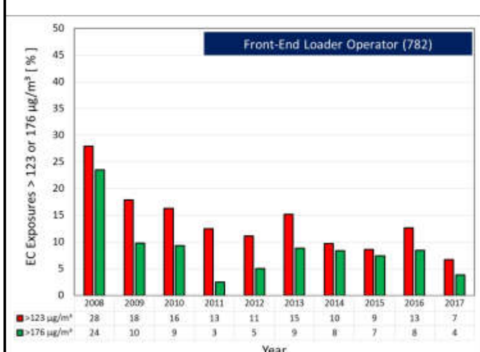
- The average EC exposures of front-end loader operators dropped from 143 µg/m³ to 39 µg/m³.

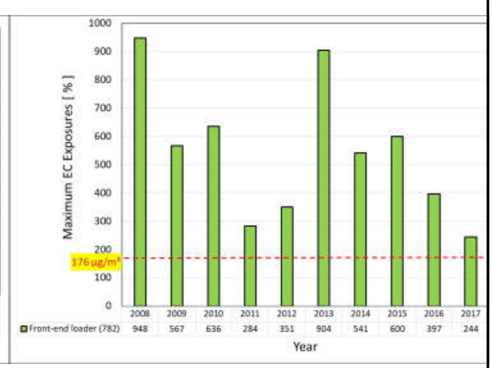




Front-end loader operator (782) - Continuation

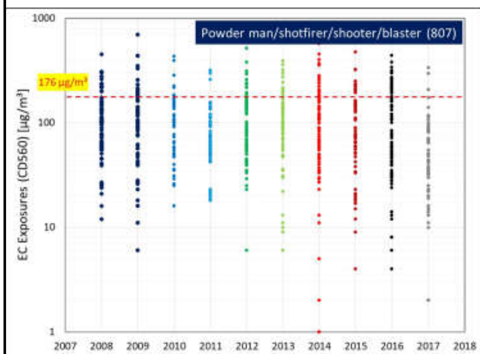
- The percentages of EC samples collected for the front-end loader operators that exceeded 123 µg/m³ gradually dropped from 28 to 7, and percentage of those that exceeded 176 µg/m³ dropped from 24 to 4.
- The highest observed EC exposures were 948 µg/m³.

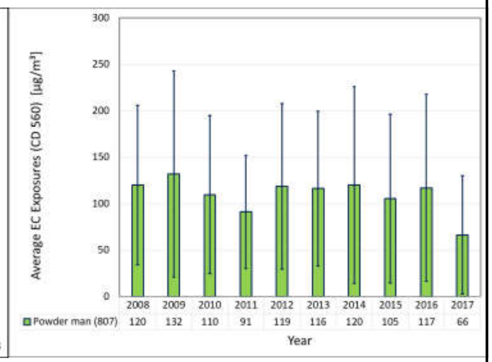




Powder man/shotfirer/shooter/blaster (807)

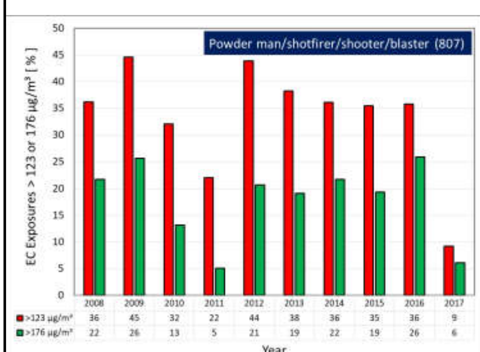
- The average EC exposures of the powder men/shotfirers/shooters/blasters were the highest of the observed occupations and did not exhibit noticeable decline.

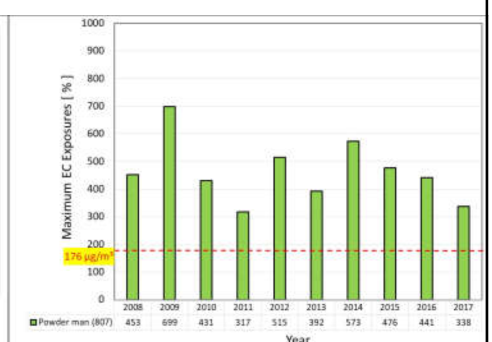




Powder man/shotfirer/shooter/blaster (807) - Continuation

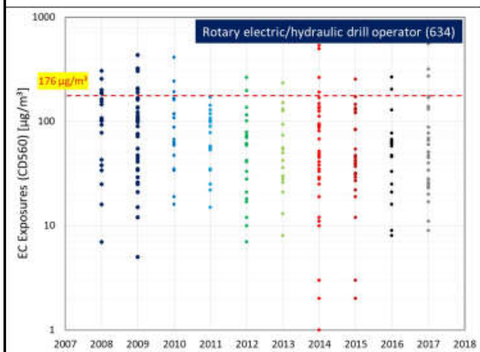
- The percentages of EC samples for the powder men/shotfirers/shooters/blasters that exceeded 123 and 176 µg/m³ did not show clear trend and were the highest of six examined occupations.
- The EC exposures of the powder men/shotfirers/shooters/blasters were as high as 699 µg/m³.

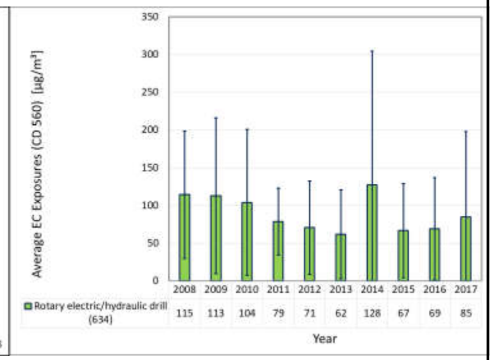




Rotary electric/hydraulic drill operator (634)

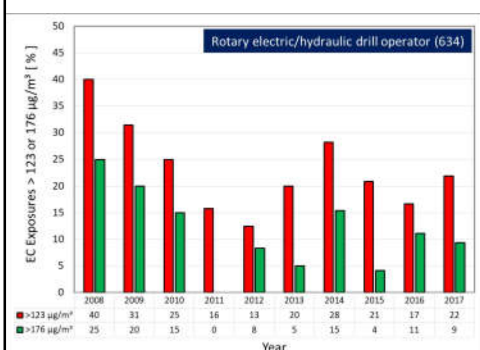
- The average EC exposures of the rotary electric/hydraulic drill operator did not show defined trend.

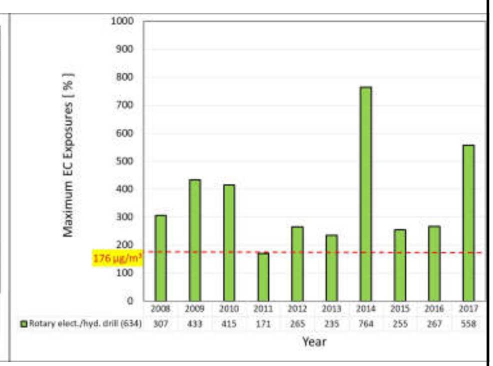




Rotary electric/hydraulic drill operator (634) - Continuation

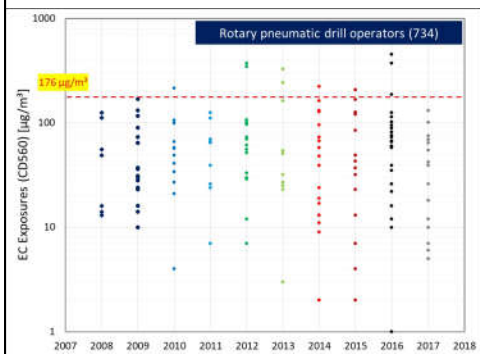
- The percentages of the EC samples collected for the rotary electric/hydraulic drill operators that exceeded 123 and 176 µg/m³ fluctuated over examined period.
- The EC exposures for the rotary electric/hydraulic drill operators were as high as 764 µg/m³.

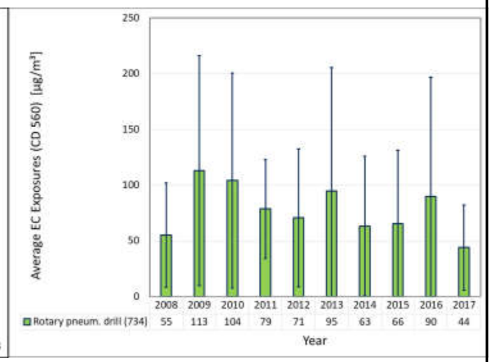




Rotary pneumatic drill operators (734)

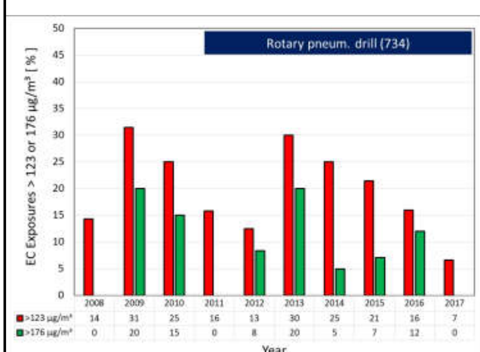
- The average EC exposures of the rotary pneumatic drill operators did not show definitive trend.

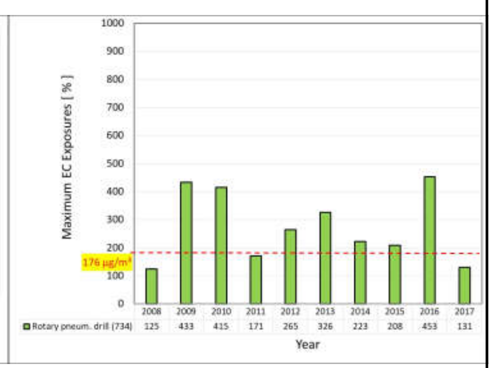




Rotary pneumatic drill operator (734)

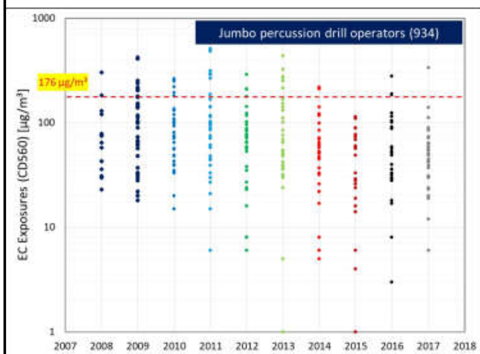
- The percentages of the EC exposures for the rotary electric/hydraulic drill operators that exceeded 123 and 176 µg/m³ were fluctuating over examined period.
- The EC exposures of the rotary electric/hydraulic drill operators were as high as 453 µg/m³.

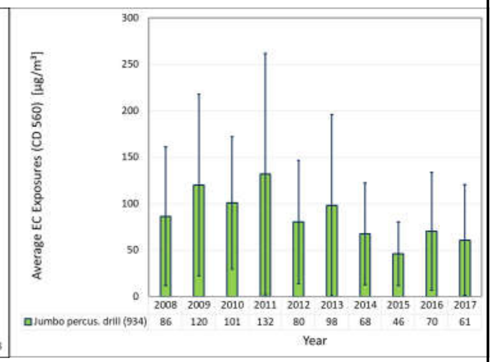




Jumbo percussion drill operators (934)

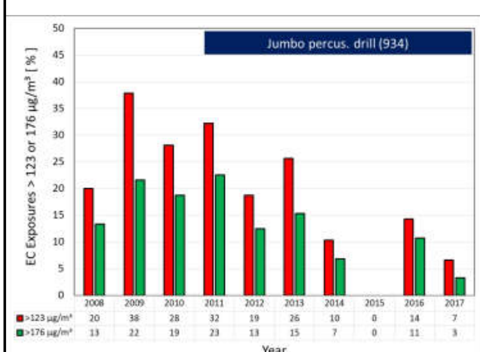
- The average EC exposures of the jumbo percussion drill operator did not exhibit clear trends.

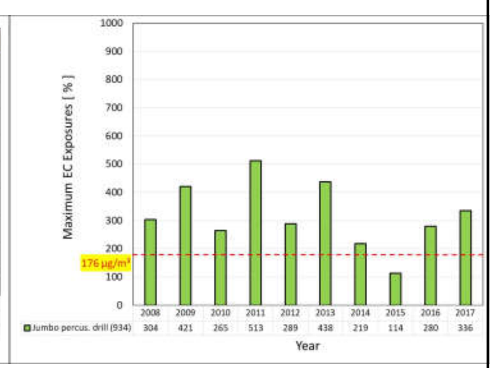




Jumbo percussion drill operator (934)

- The percentages of the EC exposures of the jumbo percussion drill operators that exceeded 123 and 176 µg/m³ generally declined over the 2009-2017 period.
- The EC exposures of the rotary electric/hydraulic drill operators were as high as 513 µg/m³ (2011).





The Highest Observed Individual EC Exposure

- In 2008, 2009, 2010, 2011, 2013, 2014, 2015, and 2016, the highest EC exposures were observed for the occupations associated with mucking in metal mines (28, 29, 782) .
- In 2012, the highest EC exposures were observed for powder man/shotfirer/shooter/blaster in stone mine.
- In 2017, the highest EC exposures were observed for the churn drill operator in metal mine.

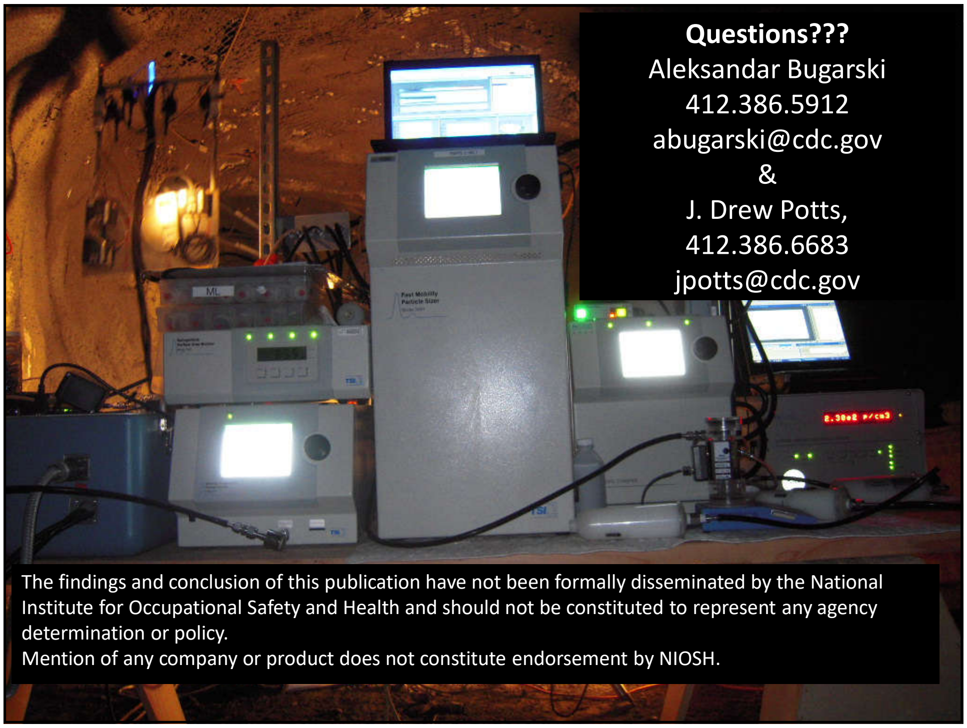
YEAR	Job	Comodity	EC [µg/m³]
2008	Front-end loader operator (782)	Gold	948
2009	Scoop tram operator (28)	Gold	1041
2010	Front-end loader operator (782)	Gold	636
2011	Load-Haul-Dump - complete cycle (728)	Gold	678
2012	Powder man/shotfirer/shooter/blaster (807)	Crushed, broken limestone	515
2013	Front-end loader operator (782)	Gold	904
2014	Mucking machine operator (29)	Gold	2665
2015	Front-end loader operator (782)	Zinc	600
2016	Mucking machine operator (29)	Gold	498
2017	Churn drill operator (434)	Platinum Group	658

29

In Conclusion

- Due to sampling design limitations, the MSHA DPM compliance data set was not sufficiently comprehensive to allow for true assessment of exposures of underground miners to DPM.
- However, in absence of more comprehensive data set, the existing data was used to assess the general trends and need for development of novel control technologies and strategies.
- The results of our analysis corroborated finding of MSHA analysis [MSHA 2017] that suggested gradual reduction in the industry-wide average exposures of underground miner to EC and TC concentrations in the mines for the studied period between 2008 and 2017.
- However, the analysis also showed that on during the studied period 10 to 30 percent of the miners across the industry were exposed to EC concentrations in excess of 123 µg/m³ and 6 to 21 percent were exposed to EC concentrations in excess of 176 µg/m³.
- The fraction of the industry-averaged EC samples that exceeded 123 and 176 µg/m³ decreased over the studied period.
- The occupation-specific analysis showed that those industry-wide average trends were not observed universally across the examined occupations.
- Therefore, in order to provide equal protection to all underground mining occupations, the existing efforts on the general reductions of contribution of diesel-powered vehicles to the DPM burden might need to be bolstered with solutions targeted to specific operations and occupations.

30



References

- 30 CFR 57.5061. Compliance determinations. Safety and Health Standards. Underground metal and nonmetal mines. Mine Safety and Health Administration, Department of Labor, Code of Federal Regulations. Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- 73 Fed. Reg. 29058 [2008]. Mine Safety and Health Administration: 30 CFR 57.5060, Diesel particulate matter exposure of underground metal and nonmetal miners. Mine Safety and Health Administration. Code of Federal Regulations, Washington, DC: U.S. Government Printing Office, Office of the Federal Register.
- MSHA [2006]. Metal/nonmetal health inspection procedures handbook number PH06-IV-1(1). In: MSHA handbook series. U.S. Department of Labor, Mine Safety and Health Administration, Metal and Nonmetal Mine Safety and Health.
- MSHA [2008]. Enforcement of diesel particulate matter final limit at metal and nonmetal underground mines. U.S. Department of Labor, Mine Safety and Health Administration, Program policy letter No. P08-IV-01. [http://www.msha.gov/regs/complian/ppls/2008/PPL08-IV-1.pdf].
- MSHA [2016]. Carbon (Diesel Particulate Matter) by Thermal/Optical Analysis. MSHA P-13. Revision #003. Mine Safety and Health Administration, Department of Labor.
- MSHA [2017]. Underground Metal/Nonmetal Mines Average DPM Concentration FY12-15 by Quarter [https://arlweb.msha.gov/01-995/dpm-compliance-sample-summary.pdf].
- MSHA [2018]. The DPM personal sampling compliance data. [https://arlweb.msha.gov/OpenGovernmentData/OGIMSHA.asp].
- NIOSH [2016]. Diesel Particulate Matter (as Elemental Carbon). In: NIOSH Manual of Analytical Methods (NMAM), 5th Edition, Cincinnati, OH: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health https://www.cdc.gov/niosh/nmam/pdfs/NMAM_5thEd_EBook.pdf
- Noll J, Gilles S, Wu HW, Rubinstein E [2015]. The relationship between elemental carbon and diesel particulate matter in underground metal/nonmetal mines in the United States and coal mines in Australia. Journal of Occupational and Environmental Hygiene, 12(3): 205-211.
- OHSA [2017]. Occupational Health and Safety Act (OHSA), Regulation 854. Mines and Mining Plants.. Ontario Ministry of Labor.

32

Abstract

The general and occupation-specific trends in exposures of underground miners in the U.S.A. to elemental carbon (EC) were studied using the results of MSHA compliance sampling in underground metal, nonmetal, and stone mines for period between 2008 and 2017. During studied years, MSHA inspectors collected per year between 350 and 655 samples in 40 to 52 percent of the active underground mines. The exposures were assessed for least one shift per year for 14 and 20 percent of all miners working in underground stone mines and 1 to 4 percent of all miners working in underground metal mines in the U.S.A. It is important to note that from statistics perspective the data set was relatively limited in the extent and that, by design, the compliance sampling was not executed randomly. The exposures to EC were found to vary widely among operations and occupations. The analysis showed positive trends in industry-wide average and median exposures to EC. Although, for the past decade the average and median exposures to EC have been well below 160 $\mu g_{TC}/m^3$ PEL, fraction of the collected samples exceeded error factor corrected personal exposure standard (176 $\mu g_{EC}/m^3$). Overexposures were found to occur more frequently in metal mines. The exposures were found to be the highest for front-end loader operators, blasters, and drill operators. Data suggests that industry efforts, supported by advancements in diesel emissions control strategies and technologies, resulted in gradual reductions in industry-wide exposures of underground miner to EC. However, in order to provide equal protection to all underground mining occupations those efforts might need to be bolstered with solutions targeted to specific operations and occupations.