NIOSH PMRD Project: Advance Strategies for Controlling Exposures to Diesel Aerosols FY18 – FY22

Presented by
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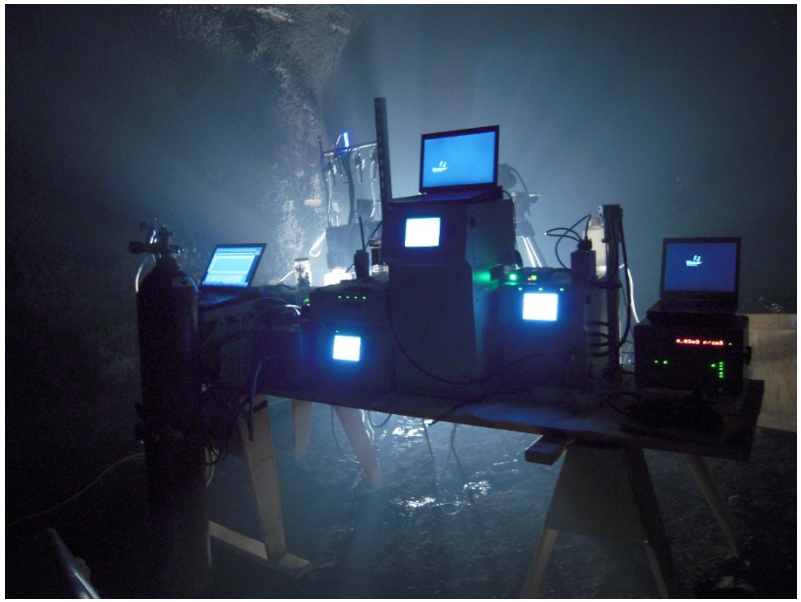
Project has five specific aims (SA).

- SA1: Develop and evaluate technologies and strategies to prevent overexposures to DPM of critically affected occupations in underground metal and nonmetal mining operations.
- SA2: Evaluate, in the laboratory and field, and implement novel and emerging advanced engine technologies for heavy- and light-duty underground mining applications
- SA3: Develop and evaluate canopy air curtains for mobile underground mining equipment as a control strategy for diesel aerosols.
- SA4: Develop and evaluate filtration and pressurization systems for environmental enclosures for mobile underground mining equipment as a control strategy for diesel aerosols.
- SA5: Develop and evaluate, in the laboratory and field, advanced disposable filter elements for use in filtration systems for permissible diesel-powered equipment.

NIOSH PMRD has relatively long history of conducting diesel research.

- For almost two decades, the Diesel Team at NIOSH PMRD assisted industry, labor, and government in the efforts to reduce exposure of underground miners to aerosols and gases emitted by diesel powered equipment.

- Research conducted at NIOSH PMRD primarily focused on:
  - development, evaluation, and implementation of advance control strategies and technologies for underground mining applications;
  - improvements in monitoring exposures to diesel aerosols;
  - characterization of aerosols emitted by diesel-powered equipment…

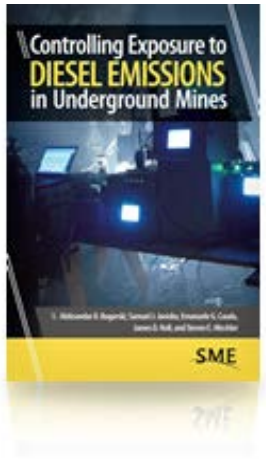


NIOSH PMRD Diesel Team research produced wealth of findings on the various aspects of integrated approach toward reducing exposure of underground miners to diesel aerosols and gases.

- Control technologies for underground mining industry:
  - diesel particulate filter systems [Bugarski et al. 2016a, Bugarski et al. 2015b, Bugarski et al. 2013, Bugarski et al. 2009];
  - diesel oxidation catalytic converters [Bugarski et al. 2015a, Bugarski et al. 2009];
  - disposable filter elements [Bugarski et al. 2011, Bugarski et al. 2009];
  - environmental enclosures [Noll et al. 2014];
  - Fe-based fuel additives and emissions from diesel engine retrofitted with the sintered metal filtration system [Bugarski et al. 2016a, Bugarski et al. 2013];
  - corn- and soy-based FAME biodiesel fuels as a control strategy [Bugarski et al. 2017, Bugarski et al. 2014, Bugarski et al. 2010];
  - hydrotreated vegetable oil (Neste Oil NexBTL) renewable diesel as a control strategy [Bugarski et al. 2016b].
- Characterization of aerosols emitted by diesel-powered equipment [Bugarski et al. 2011, Bugarski et al. 2009, Noll et al. 2007].
- Evaluation of health effects of exposure to diesel and biodiesel aerosols [Kisin et al. 2015, Yanamala et al. 2013, Kisin et al. 2013, Shi et al. 2010].
- Development of DPM monitoring methodology [Noll et al. 2015, Noll et al. 2008].

The findings were disseminated in direct interactions with industry, at one day workshops, and in peer-reviewed journals, NIOSH RIs, and book.

- Major field studies conducted in several mines in the U.S. and Canada (EnergyWest Deer Creek Mine, Inco Stobie Mine, Stillwater Nye Mine, Newmont Leeville, Vale Creighton, Vale Copper Cliff…)
- NIOSH PMRD held over 40 one-day diesel workshops at various events in the U.S., South Africa, and Australia.
- NIOSH PMRD published over 100 articles on various topics in peer-reviewed journals
- The recommendations to industry were published as NIOSH RI [Bugarski et al. 2011] and SME-published book [Bugarski et al. 2012].



Why we need more research on DPM?

Diesel-powered equipment is extensively used in the underground mining industry.

- Over 5,000 diesel engines provide power to various equipment in 185 underground coalmines [Bugarski and Barone 2016], and approximately 7,700 diesel-powered units are deployed in 252 underground metal, nonmetal, and stone mines.
- Approximately 15,000 underground coal miners and 11,000 underground metal/nonmetal (M/NM) miners in the U.S. are exposed to aerosols and gases emitted by diesel engines.
- Exposure to diesel exhaust has been linked to various adverse health outcomes [Mills et al. 2005, Power et al. 2011, Attfield et al. 2012, Peters et al. 2016].
- In 2012, the International Agency on Research on Cancer (IARC) categorized diesel engine exhaust as a carcinogen to humans (Group 1) [IARC 2012].
- Diesel engine and exhaust aftertreatment technologies dramatically advanced in past few years.
- Current M/NM diesel regulations [30 CFR Part 57] are founded on feasibility of implementation of control strategies.

SA1: Develop and evaluate technologies and strategies to prevent overexposures to DPM of critically affected occupations in underground metal and nonmetal mining operations.

It is hard to come by reliable data on the exposures of underground miner or concentrations of diesel particulate matter in underground mines.

- Data on MSHA compliance and noncompliance DPM sampling performed in underground metal and nonmetal mines in the U.S. is publically available [MSHA 2017a].

- MSHA collects two types of samples:
  - Compliance samples:
    - Contaminant code (CD) 560 - elemental carbon (EC)
    - CD 561 - total carbon (TC) directly measured or calculated using EC data and mine specific TC/EC ratio established on a number of ambient samples.
  - Noncompliance samples:
    - CD 562 – used to establish mine specific TC/EC ratio.

- The sampling strategy is executed on discretion of the inspectors and could not be considered as random.

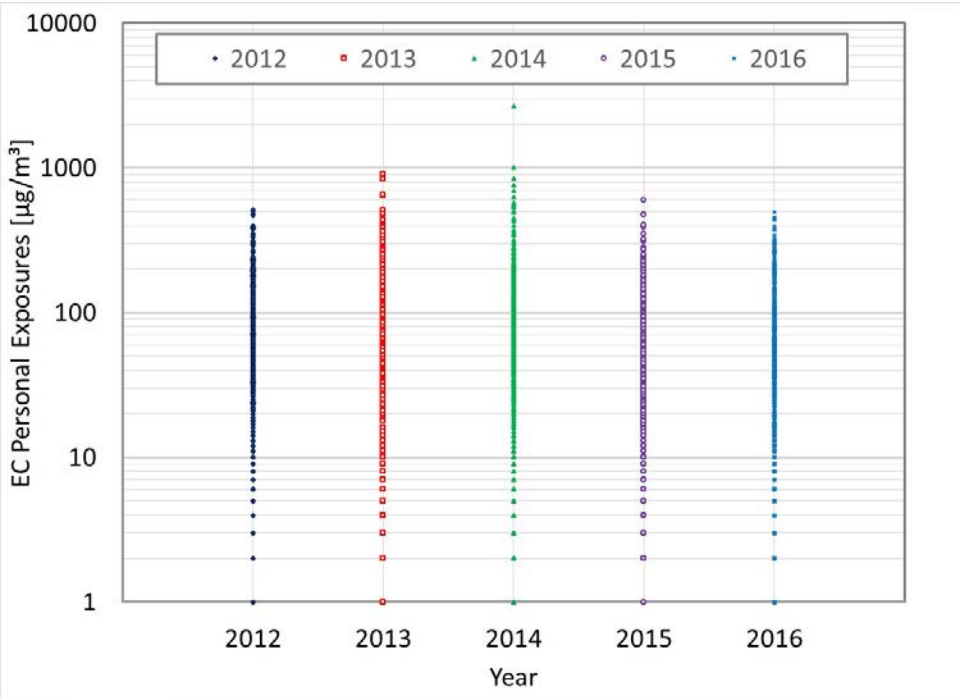
- No data is available for underground coal mining sector.

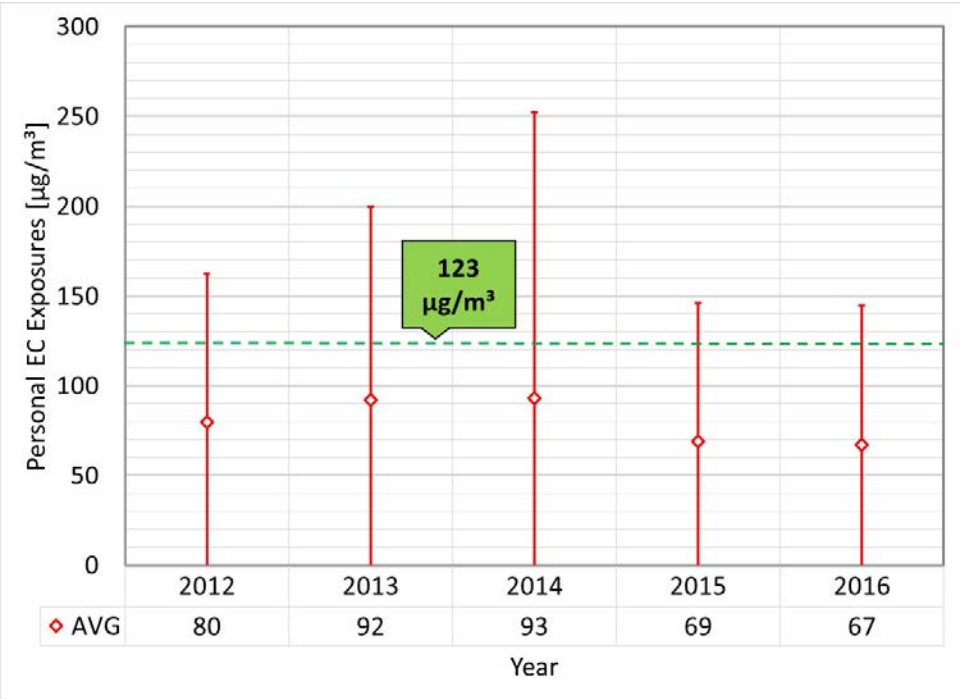
- Some limited data from Australia is available in literature [Peters et al. 2017].

Analysis of MSHA DPM compliance and noncompliance data provided us with some insight in the trends.

- The MSHA analysis of compliance data for period between 2003 and 2015 [MSHA 2017b] showed positive trends in industry average EC exposures and TC ambient concentrations.

- Internally performed analysis of CD 560 data for 2012-2016 period showed that the average exposures to elemental carbon (EC) of the sampled miners were substantially bellow 123 $\mu g_{EC}/m^3$ (160 $\mu g_{EC}/m^3$ / typical TC/EC ratio of 1.3).

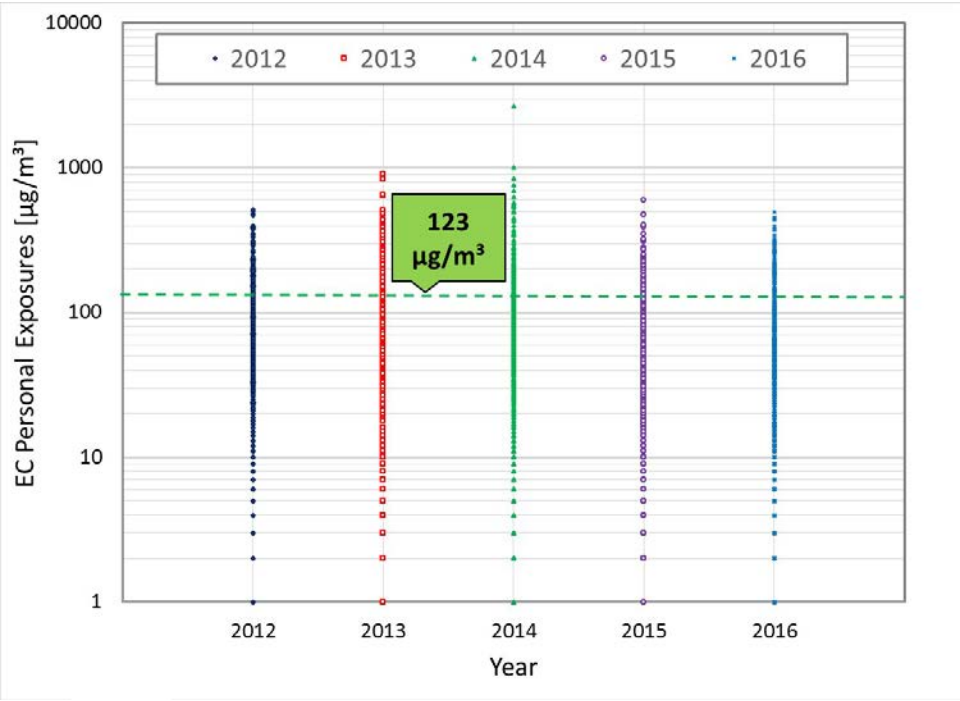


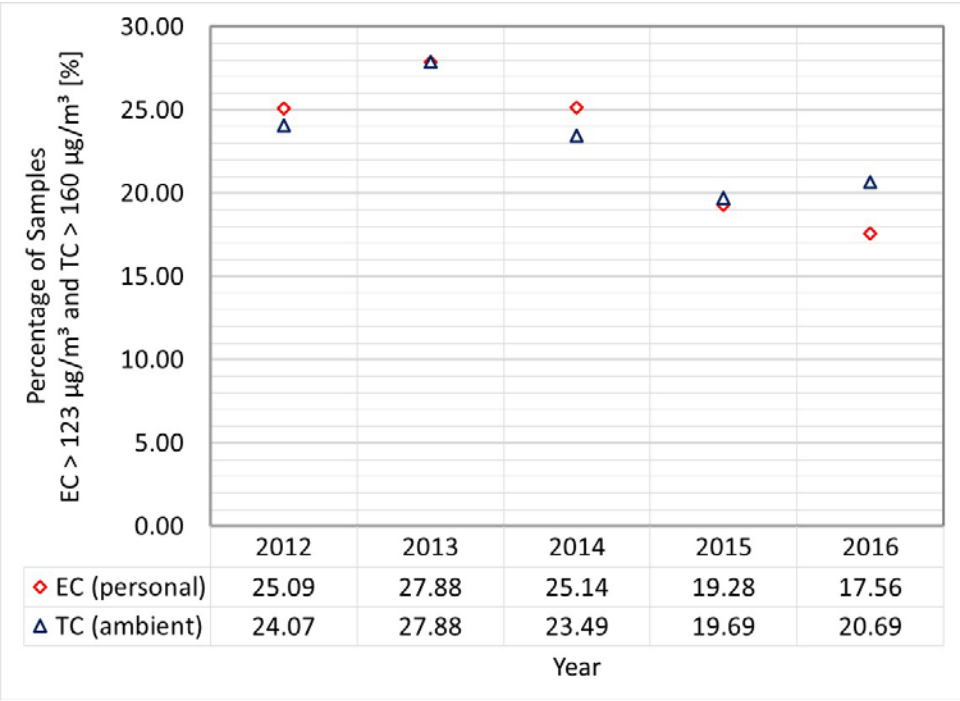


However, substantial number of individual samples collected for 2012-2016 period showed high EC exposures and TC concentrations.

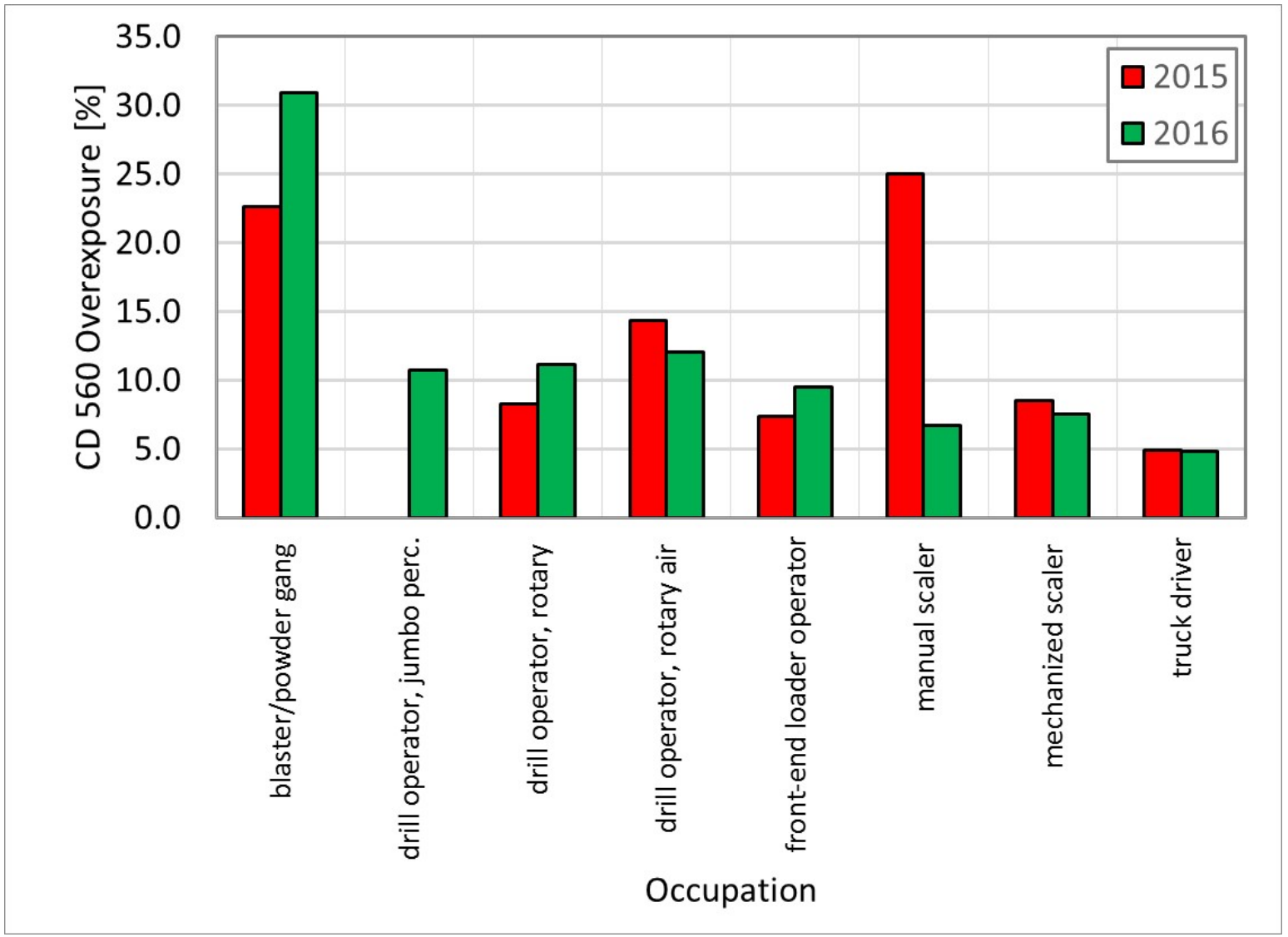
- Between 18 and 28 percent of CD 560 samples collected in 2012-2016 period showed EC exposures in excess of 123 $\mu g_{EC}/m^3$.

- Between 20 and 28 percent of CD 562 samples collected in 2012-2016 period showed TC concentrations in excess of 160 $\mu g_{TC}/m^3$.





It appears that overexposures are more frequent for some occupations than for the others.



In summary:

- Therefore, the data indicate that industry and government efforts, including NIOSH PMRD diesel research, resulted in general reduction of DPM levels in the mines.

- Although, on average, exposures have been well below PEL, relatively large fraction of the observed samples still indicate overexposures.

- Overexposures are more frequent for some occupations than for the others.

- Therefore, it transpires that additional solutions specific to operations and occupations are needed to protect all occupations.

The objective of this specific aim is to study technologies and strategies that can help industry to reduce DPM exposures for critically affected occupations in underground metal and nonmetal mining operations.

- NIOSH PMRD will solicit cooperation with one or more underground metal or nonmetal operations that are interested in reducing current exposures levels of the general and critical occupations to DPM.
  - MSHA/NIOSH Diesel Partnership,
  - MSHRAC,
  - mining associations (NMA, NSSGA, IMA-NA), or
  - directs contacts with companies/operations…

- At the selected site(s), NIOSH and partners will monitor exposures and ambient concentrations for selected occupations over extended period of time.

- Physical and chemical properties of diesel aerosols for the specific workplaces and scenarios will be characterized for several shifts.

Based on the preliminary surveys and characterizations, NIOSH PMRD and partners will developed multifaceted engineering and administrative workplace solutions [Bugarski et al. 2012].

- The selected solutions will be implemented and evaluated in the isolated zone.
- In the follow up study, the effectiveness of the selected solutions will be assessed using periodic monitoring of selected occupations over extended period of time.
- Industry should benefit from novel technologies and workplace strategies that should help to further reduce general levels of diesel aerosols and eliminate instances of overexposures for specific occupations such as drill operator, front-end loader and scaler .
- The findings will be disseminated to the partners and wider mining community.

SA2: Evaluate, in the laboratory and field, and implement novel and emerging advanced engine technologies for heavy- and light-duty underground mining applications.

Underground mining industry needs engine technologies that would provide means for dramatically reduction in particulate and gaseous emissions from diesel-powered equipment.

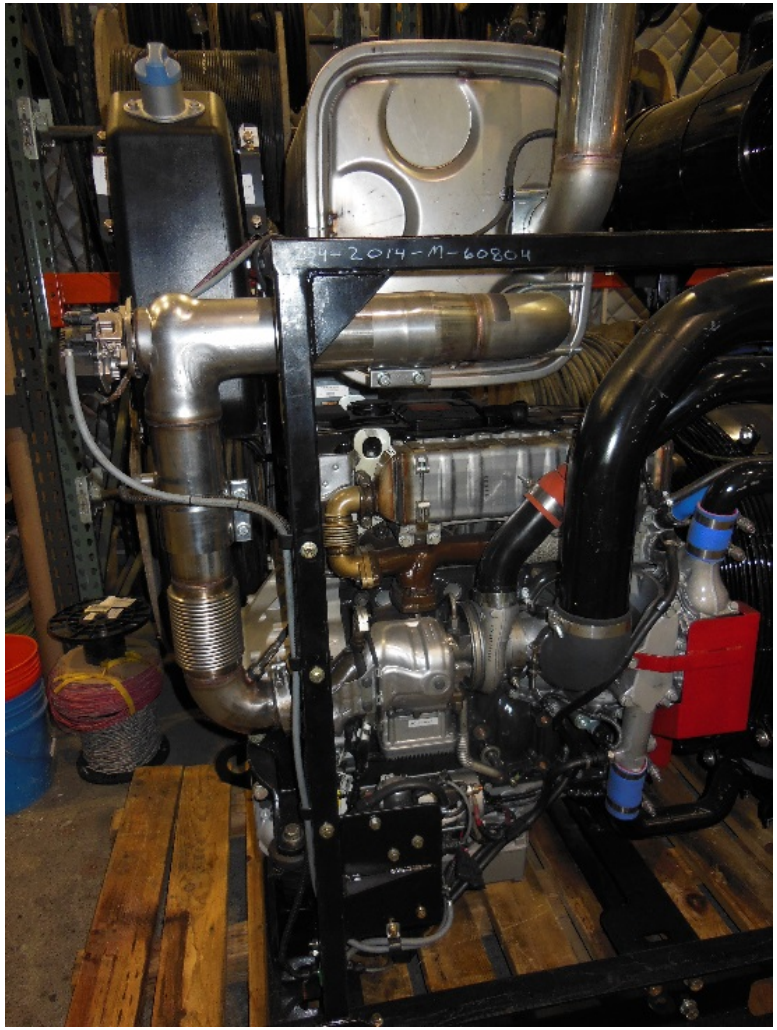
- Analysis of underground coal mining diesel inventory [Bugarski and Barone 2016]:
  - The majority of the permissible diesel-powered vehicles are powered by engines that do not meet EPA Tier 2/Tier 3 PM standard.
  - The fleet of non-permissible HD vehicles is powered predominantly by EPA Tier 2 engines from mid-2000s.
  - Only 54 of 1253 non-permissible HD vehicles are powered by engines approved after 2010.
  - Approximately 0.5% of non-permissible LD vehicles are currently powered by engines that meet EPA Tier 4 standards.

- It appears that due to the excellent durability of diesel engines, rebuild availability, and specifics of underground mining industry economics, replacement of older high emitting engines with advanced low emitting engines might take several decades.

- Slow penetration of advanced engines with extremely low particulate emissions [Khalek et al. 2011, Khalek et al. 2015, McDonald et al. 2015] into the underground mines adversely affect efforts on reducing exposures to diesel aerosols and gases.

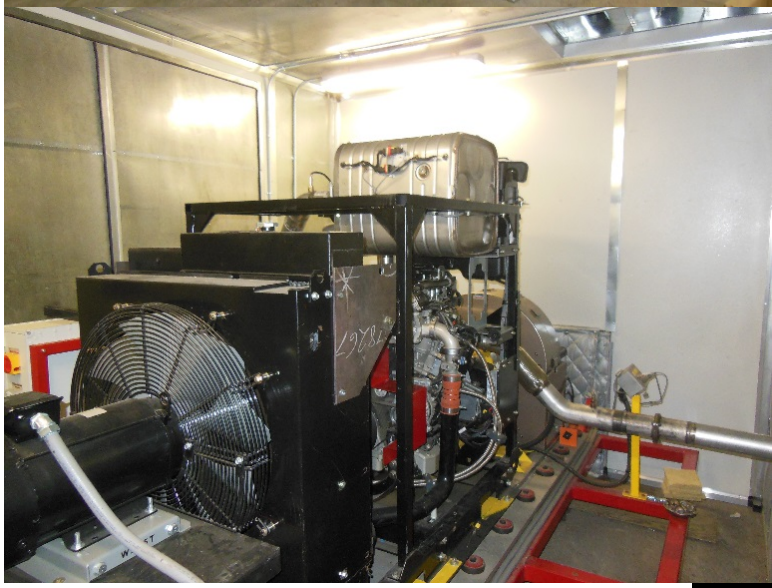
Objective of this project would be to facilitate selection and introduction of new viable engines in underground mines.

- Reductions of the emissions at their source due to implementation of advanced engines in underground mines should result in substantial reductions in general levels of DPM in the mines.
- This would benefit all occupations.
- Since advanced engine and exhaust aftertreatment solutions dramatically change physical and chemical properties of diesel emissions, it is necessary to prevent potential introduction of engines with undesired secondary emissions.



At least one representative engine for HD applications (EPA T4f with SCR - based solution) and one for LD applications (EPA Tier 4 final with DOC/DPF-based solution) will be evaluated.

- The evaluations would take place at the NIOSH PMRD Diesel Laboratory.
- The engines will be operated at selected steady-state and transient test conditions
- Detailed characterization of regulated and unregulated emissions will be produced.
- Special attention will be given to potential generation of undesired secondary emissions of NO_2, N_2O, nucleation mode aerosols, metallic aerosols, and other pollutants.



The laboratory evaluations will be complimented with field evaluations at the participating mine(s).

- Selected engines will be installed on the production vehicles and evaluated in underground mines using an isolated zone methodology or in selected production scenarios using portable emissions measurement systems.
- The findings will be disseminated in peer-reviewed journals, conferences, and workshops.

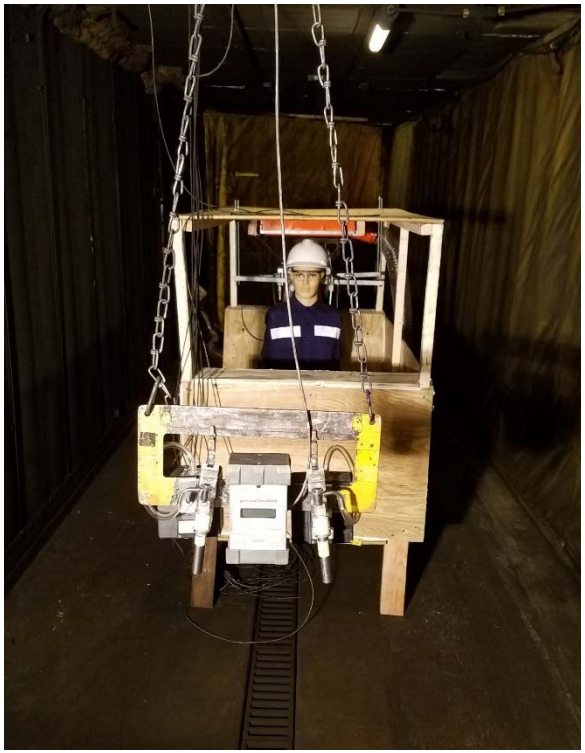
SA3: Develop and evaluate canopy air curtains for mobile underground mining equipment as a control strategy for diesel aerosols.

Specific Aim 3: Develop and evaluate canopy air curtains for mobile underground mining equipment as a control strategy for diesel aerosols.

- Various designs of canopy air curtains for roof bolter and shuttle car are currently evaluated at NIOSH PMRD as a control strategy for reducing exposures of underground miners to respirable dust .

- The objective of this task would be to assess if redesigned canopy air curtains with adequate filtration systems could be used to reduce DPM exposures of operators such as bolters, drillers, and scalers.

- The canopy air curtains for DPM applications would be developed by third party organizations under contract with NIOSH.



The development and implementation of such air curtain would be supported by evaluations of existing and novel air curtain systems at NIOSH PMRD and in operations interested in the deployment of such technology.

- The existing and most promising designs will be extensively evaluated in the underground environment contaminated with high concentrations of dust, diesel, and other aerosols.

- The findings will be disseminated in peer-reviewed journals, conferences,

SA4: Develop and evaluate filtration and pressurization systems for environmental enclosures for mobile underground mining equipment as a control strategy for diesel aerosols.

Environmental cabs are traditionally used to provide a safe environment and reduce exposure of underground miners to elements, noise, and dust.

- NIOSH PMRD extensively researched environmental enclosures as a strategy for reducing exposure of underground miners to dust and DPM [Organiscak et al. 2013, Cecala et al. 2014, Noll et al. 2014].

- The environmental enclosures with tightly sealed pressurization and filtration/HVAC systems and adequate filter elements were shown to offer adequate reduction in exposure of workers to diesel particulate matter (DPM) [Noll et al. 2016].

- Evaluations at the NIOSH PMRD laboratory and field showed that only MERV16 and HEPA rated filter elements could provide adequate protection to operators [Noll et al. 2014].

However, recent surveys showed that additional efforts are needed to improve protection provided with existing and newly introduced environmental enclosures.

- The objective of this specific aim is to improve efficiency of existing and develop new more efficient and viable environmental enclosures and systems that should better protect truck drivers, LHD operators, drillers, and some other occupations.

- The specific aim will be executed in partnership with OEMs and aftermarket filtration and pressurization companies.

- Novel environmental enclosures with adequate filtration and pressurization system will be evaluated in the field and eventually implemented with help from industry partners interested in the deployment of such technology.

- The effectiveness of enclosures in reducing exposures of operators to diesel and other aerosols will be tested in the underground environment in cooperation with industry partners.

- The findings will be disseminated in peer-reviewed journals, conferences, and workshops.

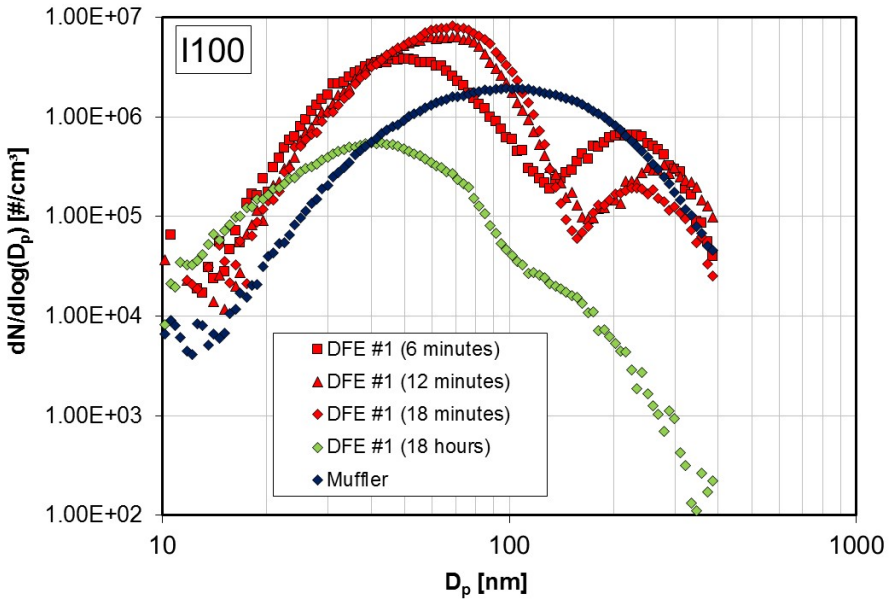
SA5: Develop and evaluate, in the laboratory and field, advanced disposable filter elements for use in filtration systems for permissible diesel-powered equipment.

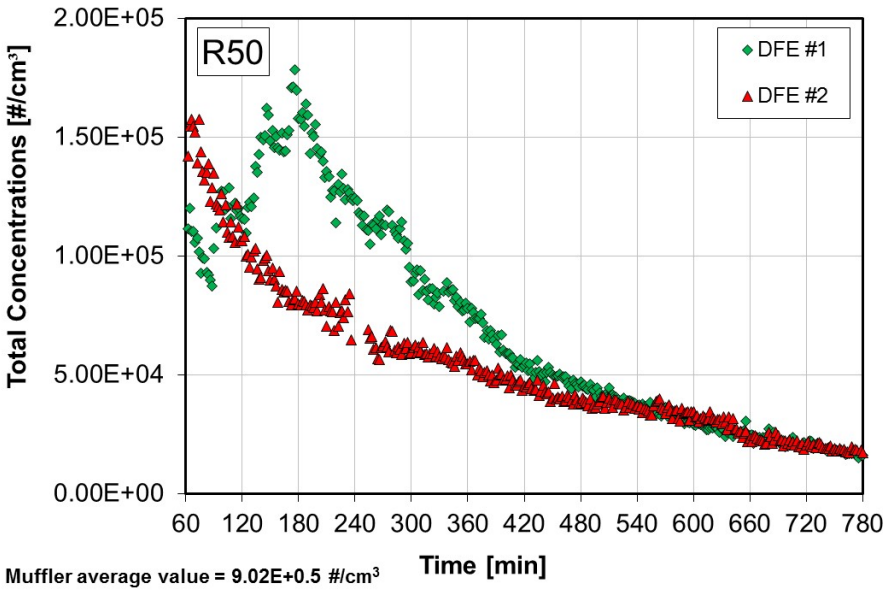
Filtration systems with DFEs have been successfully used to filter exhaust of permissible and nonpermissible vehicles in operated in underground coal mines in the U.S. [Bugarski and Barone 2016].

- All permissible heavy-duty vehicles, substantial fraction of nonpermissible heavy-duty vehicles, and small fraction of nonpermissible light-duty vehicles are equipped with a DFEs.
- DFEs allow those to meet the 2.5 g/hr PM emissions standard [30 CFR 72.500].
- Aged DFEs are recognized to be very effective in removal of DPM mass [Bugarski et al. 2009].

However, it might take a couple hours before some of currently used DFEs reach their terminal efficiency [Bugarski et al. 2011].

- During the off-gassing process, the filter media used in DFEs gives off aerosols.
- The efficiency of DFEs increases with the accumulation of DPM in the media.





NIOSH PMRD will work with manufacturers to develop and evaluate new designs of DFEs that should provide better DPM protection to underground coal miners.

- The development will be supported by NIOSH PMRD evaluations of the effectiveness of filtration materials and products.
- The selected new models of DFEs will be benchmarked against models currently used by industry through a series of laboratory evaluations at NIOSH PMRD.
  - HD engine equipped with a dry heat exchanger and filtration system.
- Pending the availability of partners, the laboratory evaluations will be followed with a long- and short-term evaluation at selected underground mining operations.
- The results will be used to assess the effectiveness of DFEs as a control strategy for reducing the exposure of underground miners to diesel aerosols.
- The findings will be disseminated in peer-reviewed journals, conferences, and workshops.

We are looking for partners, comments, suggestions, ideas…

The findings and conclusion of this publication have not been formally disseminated by the National Institute for Occupational Safety and Health and should not be constituted to represent any agency determination or policy.

Mention of any company or product does not constitute endorsement by NIOSH.

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