Integrated Approach toward Reducing Exposure of Underground Miners to Diesel Emissions

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Diesel Aerosols and Gases in Underground
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Rules Regulating Exposure of Underground Miners to DPM

- Underground metal and nonmetal mines
  - 30 CFR Part 57.5060 - Diesel Particulate Matter Exposure of Underground Metal and Nonmetal Miners [2001];
  - Personal exposure limit, performance rule.
- Underground coal mines
  - 30 CFR Part 72 - Diesel Particulate Matter Exposure of Underground Coal Miners [2001].
  - Emissions standard, prescribed solution.

Rules Regulating Exposure of Underground Miners to Gases Emitted by Diesel Engines

- 30 CFR 57.5001. Safety and Health Standards Underground for Metal and Nonmetal Mines. Exposure Limits for Airborne Contaminants (MSHA 1985):
  - carbon dioxide (CO_2), ACGIH TLV-TWA is 5000 ppm;
  - carbon monoxide (CO), ACGIH TLV-TWA is 50 ppm;
  - nitric oxide (NO), ACGIH TLV-TWA is 25 ppm;
  - nitrogen dioxide (NO_2), ACGIH TLV-TWA is 3 ppm, ACGIH TLV-STEL (ceiling limit) is 5 ppm.

  NOTE: MSHA adopted 1973 ACGIH standards.

- 30 CFR § 70.1900. Coal Mine Safety and Health. Exhaust Gas Monitoring (MSHA 1997).
  - carbon monoxide (CO), ACGIH TLV-TWA is 50 ppm;
  - nitrogen dioxide (NO_2), ACGIH TLV-TWA is 3 ppm; ACGIH TLV-STEL (ceiling limit) is 5 ppm.

  NOTE: MSHA adopted 1972 ACGIH standards.

  An action level is set on 50 % of the TLV.

Other Regulations that Affect Use of Diesel Engines in Underground Mines

- Environmental Protection Agency [2001]. Clean Diesel Trucks, Buses, and Fuel: Heavy-duty Diesel Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements. Federal Register 66 (12), January 18, 2001. Page 5001-5193.

- Environmental Protection Agency [2004]. Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel. Federal Register 69 (124), June 29, 2004. Page 38957-39006.

- These technology-forcing regulations have been driving development of advanced engine and exhaust aftertreatment technologies and introduction of ultralow sulfur diesel and alternative fuels on on-road and nonroad markets.

Reducing exposure of underground miners to diesel particulate matter and gases is rather complex issue and requires elaborate plan.

- Multifaceted and integrated approach is needed to address this issue.

- The success in achieving this sometimes overwhelming goal depends on concerted efforts throughout mine organizational structure and considerable support from mine management
  - engine/vehicle/aftertreatment maintenance;
  - vehicle, engine and exhaust aftertreatment purchasing;
  - fuel purchasing and handling;
  - ventilation management;
  - exposure monitoring;
  - institution of administrative controls…

Exposures can be effectively reduced using combination of several strategies.

- **Controlling diesel emissions at their source:**
  - Engine-out emissions;
  - Exhaust aftertreatment technologies;
  - Crankcase emissions.
- **Controlling pollutants after those become airborne:**
  - Ventilation;
  - Environmental cabs;
  - Personal protective equipment.
- **Institutionalizing administrative controls:**
  - Better utilization and management of available resources;
  - No idling policy.

The most cost effective approach appears to be controlling diesel emissions at their source.

- **Reduction of engine-out emissions through:**
  - Replacement of older high-emitting engines with contemporary low-emitting diesel engines;
  - Implementation of emissions assisted maintenance programs;
  - Utilization of clean and alternative fuels.

- **Implementation of exhaust aftertreatment technologies to control:**
  - Particulate, and
  - Gaseous emissions.

- **Reduction of crankcase emissions using:**
  - Filtered open crankcase ventilation;
  - Closed crankcase ventilation.

Diesel Engines in Underground MNM Mining Industry

- Underground metal non metal industry can use MSHA or EPA (MSHA, 30 CFR Table 57.5067-1) approved engines:

EPA requirement	EPA category	PM limit
40 CFR 86.094–8(a)(1)(I)(A)(2)	light duty vehicle	0.1 g/mile.
40 CFR 86.094–9(a)(1)(I)(A)(2)	light duty truck	0.1 g/mile.
40 CFR 86.094–11(a)(1)(iv)(B)	heavy duty highway engine	0.1 g/bhp-hr.
40 CFR 89.112(a)	Tier 2 nonroad	Varies by power:
	kW< (hp<11)	0.80 g/kW-hr (0.60 g/bhp-hr).
	8≤kW<19 (11≤hp<25)	0.80 g/kW-hr (0.60 g/bhp-hr).
	19≤kW<37 (25≤hp<50)	0.60 g/kW-hr (0.45 g/bhp-hr).
	37≤kW<75 (50≤hp<100)	0.40 g/kW-hr (0.30 g/bhp-hr).
	75≤kW<130 (100≤hp<175)	0.30 g/kW-hr (0.22 g/bhp-hr).
	130≤kW<225 (175≤hp<300)	0.20 g/kW-hr (0.15 g/bhp-hr).
	225≤kW<450 (300≤hp<600)	0.20 g/kW-hr (0.15 g/bhp-hr).
	450≤kW<560 (600≤hp<750)	0.20 g/kW-hr (0.15 g/bhp-hr)
	kW≥560 (hp≥750)	0.20 g/kW-hr (0.15 g/bhp-hr)

Contemporary Diesel Engine Technology

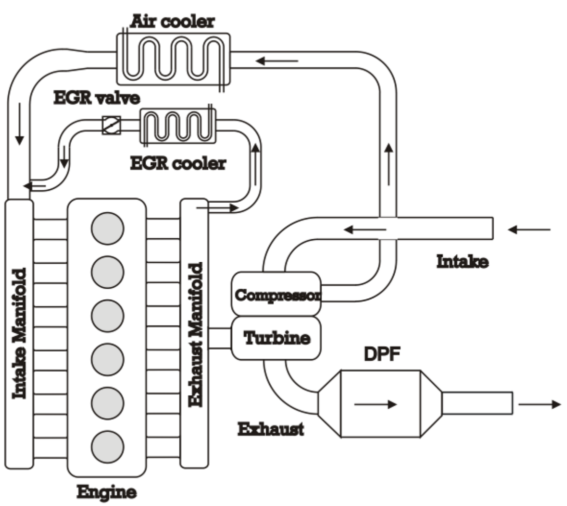
- Particulate and gaseous emissions from modern diesel engines have been substantially reduced over the past couple decades.

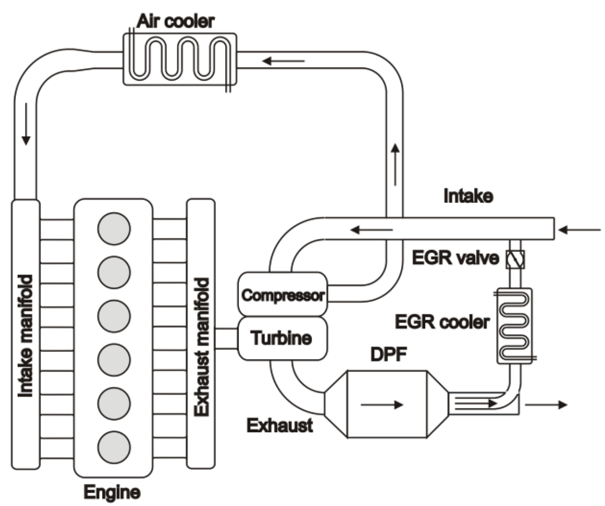
- U.S. Environmental Protection Agency (EPA) nonroad engines 130 < kW < 560 (175 < hp < 750):

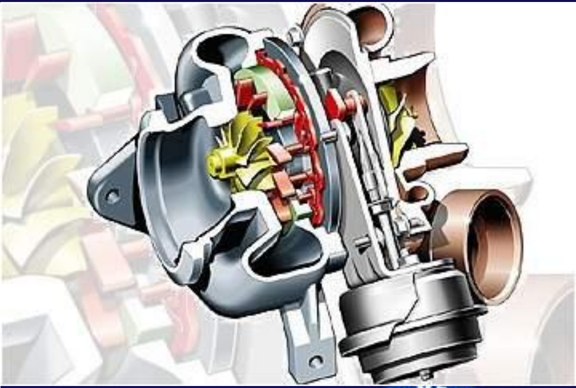
  – 1996 (Tier 1): PM = 0.54 g/kW-hr (0.40 g/hp hr);
  – 2003 (Tier 2): PM = 0.20 g/kW-hr (0.15 g/hp hr);
  – 2006 (Tier 3, never adopted): PM = 0.20 g/kW-hr (0.15 g/hp hr);
  – 2011-2014 (Tier 4): = 0.010 g/kW-hr (0.008 g/hp hr).

Design of Contemporary Diesel Engine Technology

- Tier 2 and Tier 3 engines achieve lower emissions by using some of the following tools:
  - high-pressure fuel injection with multiple injections per stroke;
  - increased peak cylinder pressures;
  - variable geometry turbocharger (VGT);
  - exhaust gas recirculation (EGR);
  - closed crankcase ventilation.







Contemporary Diesel Engine Technology

- Tier 4i engines (emphasis on PM control):
  - High pressure common rail fuel system with multiple injection;
  - Variable geometry turbocharger;
  - Advance engine management systems;
  - Exhaust aftertreatment system:
    - Diesel oxidation catalyst (DOC);
    - Catalyzed passive diesel particulate filter (DPF) system;
    - NO_X controls: Cooled EGR and Selective catalyst reduction (SCR).
- Tier 4 engines (PM and NO_X control):
  - Integrated advanced exhaust aftertreatment systems:
    - DPF systems;
    - SCR and Lean NO_X Catalyst (LNC) for NO_X control.

Tier 4i and Tier 4 engines in Underground Mining

- Tier 4 engines should have integrated advanced exhaust aftertreatment systems:
  - DPM and NO_x controls.
  - Are Tier 4 engines going to provide all answers?

- Engines that meet EPA 2007 on-highway standards (using DPM and NO_X controls) are available for on-highway applications.

Engine, drive train, vehicle, and exhaust aftertreatment are integral parts of the system and should be optimized for individual applications

- Engine replacement:
  - lower emissions lower ventilation requirements;
  - size and output;
  - electronic controls;
  - advanced exhaust aftertreatment technologies:
    - retrofit;
    - OEM.
- Optimization of torque converter / engine performance.
- Reduction in engine output (if feasible).
- Selection of a smaller harder-working engine to enable better performance of an exhaust aftertreatment (e.g. regeneration of DPF systems).

Optimization of Diesel Engines for Underground Mining Applications

- Confined space, limited ventilation, specific regulations:
  - NO and NO_2 vs NO_x;
  - Speed limit.
- Emissions at elevation over 5000 ft above see level:
  - Engine deration and recertification.
- Optimization of advanced exhaust aftertreatment technologies.

High requirements vs. relatively small market

Diesel Fuel in the U.S. Underground Mines

- 30 CFR 75.1901. Diesel Fuel Requirements (1997, coal) and 30 CFR 57.5065. Fueling and Idling Practices (2001, metal and nonmetal) and:
  - LSD < **500 ppm** sulfur fuel.

- 40 CFR Parts 9, 69 et al. Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel [EPA 2004]:
  - Ultra low sulfur diesel fuel (ULSD, diesel fuel containing no greater than **15 ppm** sulfur):
    - became available for on-road use in June 2006;
    - will be mandated for nonroad diesel fuels in June 2010.

- Direct emissions benefits from switching from LSD to ULSD are relatively minor.

- But, introduction of ULSD is driving development and implementation of advanced engine and exhaust aftertreatment technologies (effects of sulfur on catalysts).

Alternative Fuel Formulations

- Biodiesel:
  - Fatty-acid mono-alkyl ester (FAME) fuels;
  - Conversion of triglycerides (vegetable oil and animal fats) to esters through esterification process;
  - Renewable, nontoxic, biodegradable fuel.
  - Properties:
    - no sulfur
    - oxygenated (10-11% O_2)
    - higher Cetane number than petroleum diesel (>50).

- Synthetic diesel:
  - Fuel synthesized using gas-to-liquid (GTL) , coal-to-liquid (CTL), and biomass-to-liquid (BTL) processes
  - Superior properties:
    - no sulfur;
    - no aromatics;
    - high Cetane number (>70).

Biodiesel and Synthetic Diesel vs. ULSD: Emissions

- Effects of biodiesel on emissions:
  - lower particulate mass and CO emissions;
  - at light engine loads, potential for increase in emissions of unburned hydrocarbons and number of particles;
  - elevated NO_X emissions;
  - emissions in general depend on engine design and operating conditions.

- Effects of synthetic diesel fuels on emissions:
  - Substantial simultaneous reductions in PM, CO, HC, and NO_X emissions

Exhaust Aftertreatment Technologies

- CO and hydrocarbons:
  - Diesel oxidation catalytic converters (DOC).

- NO and NO_2:
  - Selective catalytic reduction (SCR) systems;
  - Lean NO_x catalyst.

- Diesel particulate matter (DPM) , total carbon (TC), and elemental carbon (EC):
  - Diesel particulate filter (DPF) systems;
  - Filtration systems (FS) with disposable filter elements (DPEs);
  - Flow through filter (FTF) systems.

- Exhaust aftertreatment systems integrated with engine systems

Implementation of aftertreatment technologies is perceived as important tool in reducing exposures to diesel pollutants

- **Current Trends (DOC OEM and DPFs retrofit)**
  - Diesel oxidation catalytic converters (DOCs) for CO and HC;
  - Flow trough filter (FTF) systems;
  - Diesel particulate filter (DPF) systems;
  - Filtration systems (FS) with disposable filter elements (DFE).
- **Future (OEM and retrofit, pending engine and aftertreatment technology development)**
  - DOC;
  - DPF or FTF systems;
  - Selective catalyst reduction (SCR).

Crankcase Emissions

- During normal diesel engine operation, a significant volume of combustion gases and particulates escape past the piston rings and enter the crankcase (blowby).
- Crankcase blowby can be an important source of particulate emissions:
  - up to 20% of tailpipe PM emissions from Tier 2 and Tier 3 engines;
  - can exceed tailpipe PM emissions from Tier 4 engines.
- Crankcase emissions are controlled using filtered open crankcase ventilation and closed crankcase ventilation systems.

Emission-Assisted Maintenance (EAM) Program for Engines and Exhaust Aftertreatment Systems

- Regulations:
  - M/NM: 30 CFR 57.5066 Maintenance Standards (MSHA 2001).
  - COAL: 30 CFR 75.1914 Maintenance of Diesel-Powered Equipment.

- Emission-assisted maintenance program vs. repair facility:
  - Emissions are used as diagnostic tools;
  - Measurements in regular intervals, e.g. 250 hr PM;
  - Develop in-house expertise;
  - Establish baseline and own action criteria;
  - Prompt action.

- The objective of the EAM program is to maintain emissions at "new" (baseline) level or even improve if possible.

Control of Airborne Pollutants

- Once released in the environment, diesel pollutants and miners exposure can be controlled by:
  - Ventilation;
  - Environmental cabs;
  - Personal protective equipment.

Ventilation

- Ventilation is traditionally used to control flammable and explosive gases, other pollutant concentrations, and heat in underground mines.

- Underground coal: 30 CFR 75.325. Air quantity (MSHA 1996)
  - In bituminous and lignite mines
    - the quantity of air shall be at least 3,000 ft^3/min reaching each working face;
    - the quantity of air reaching the last open crosscut shall be at least 9,000 ft^3/min;
    - In longwall and shortwall mining systems the quantity of air shall be at least 30,000 ft^3/min.
  - In anthracite mines
    - the quantity of air shall be at least 1,500 ft^3/min reaching each working face;
    - the quantity of air shall be at least 5,000 ft^3/min passing through the last open crosscut.

Ventilation

- Underground coal: 30 CFR 75.325. Air quantity (MSHA 1997):
  - The minimum ventilating air quantity for an individual unit of diesel-powered equipment being operated shall be at least that specified on the approval plate for that equipment:
    - Ventilation Rate (VR);
    - Particulate Index (PI).
  - The minimum ventilating air quantity where multiple units of diesel-powered equipment are operated must be at least the sum of that specified on the approval plates of all the diesel-powered equipment.

Ventilation Requirements for Metal and Nonmetal Underground Mines: Diesel Pollutants

- Adequate ventilation is important part of integrated approach solution and ranks high on the priority list.

- Diesel emissions control:
  - U.S.
    - 1973 ACGIH TLV-TWA for CO, CO_2, NO, NO_2 and ceiling level for NO_2;
    - PM.
  - Canada
    - CANMET: CSA ventilation rates (EQI);
    - Ontario: 0.06 $m^3/s/kW$ (100 $ft^3/min/hp$).

Ventilation for Control of Exposures to Diesel Pollutants in Underground Metal and Nonmetal Mines

- Quantities of air supplied per engine output (hp) in U.S. UG metal/nonmetal mines to dilute diesel emissions are generally lower than those in U.S. UG coal mines. Both are lower than quantities of air supplied per hp in Canadian UG metal mines.
- Controlling PM and gaseous emissions from diesel-powered equipment has become one of the major ventilation design factors;
- Quantities of air sufficient to dilute various pollutants are essential for overall quality of the air in production areas:
  - Control of CO_2 and NO emissions from diesel engines.

M/NM UG Mining Ventilation Issues

- Supplying sufficient quantities of fresh air to production areas presents particular challenge.
- Cascading ventilation is common practice and presents a problem.
- Problem of recirculation is particularly pronounced in large-opening mines.
- Capital and operational costs of reducing miners' exposure to DPM solely by means of ventilation might be prohibitive:
  - Increase in ventilation rate linked to increase in power requirement for the fans and consequently increase in energy consumption.

Environmental Cabs

- Air filtration/heating/air conditioning system:
  - Filter media needs to be designed to remove DPM (HEPA or similar filters).
- Cab integrity:
  - Positive inside pressure (~100 Pa).
- If properly designed and maintained, cabs protects operator from DPM, dust, and noise.
- Typical filtration system installed on cabs does not provide control for gaseous pollutants.
- Does not provide protection to workers outside the cab.

Environmental Cabs

- Issues:
  - Capital cost of acquiring cab;
  - Operational costs;
  - Reduced visibility;
  - Space requirements for retrofit applications;
  - Human factor;
  - CO, CO_2, NO, and NO_2.

Personal Protective Equipment (PPE)

- Air purifying respirator with:
  - HEPA filter certified by NIOSH under 30 CFR Part 11, or
  - filter certified by NIOSH under 42 CFR Part 84 as 99.97% efficient, or
  - filter certified by NIOSH for DPM.

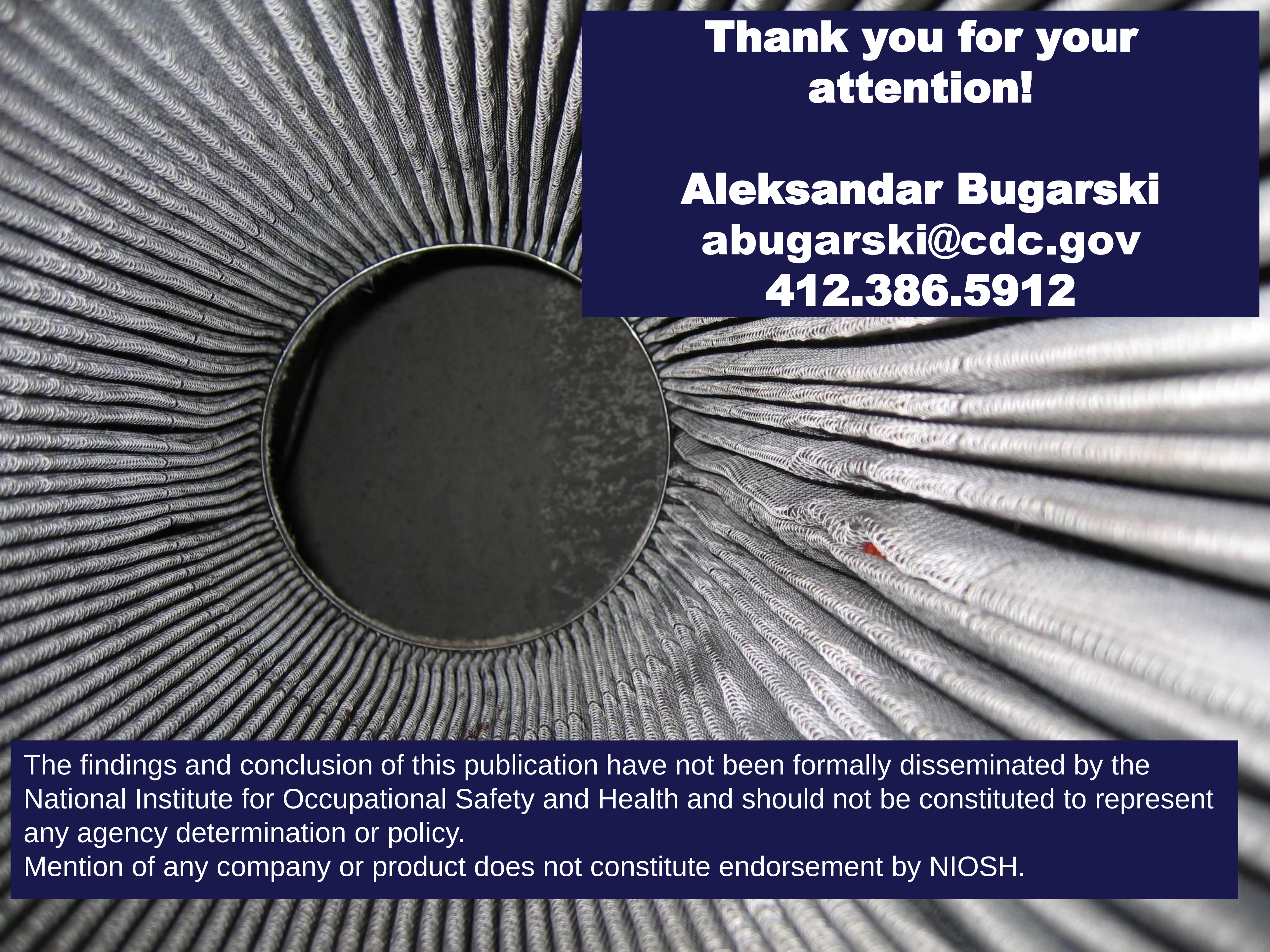
- Non-powered, negative pressure, air purifying, particulate filter respirators with:
  - R- or P-series filter, or
  - any filter certified by NIOSH for DPM.

Personal Protective Equipment (PPE) : Underground Metal/Nonmetal Mines

- PPE should supplement engineering and administrative controls only when those are found unfeasible or insufficient.
- Respirator fit test is crucial.
- CO, CO_2, NO, and NO_2 ???

Education

- Awareness of potential health effects related to exposure to diesel particulate matter and gases.
- Knowledge of general instituted strategies and their individual role in those:
  - OWNERSHIP.
- Knowledge of implemented technologies.



Thank you for your attention!

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