

Controlling Diesel Particulate Exposures in Underground Mines

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MSHA Baseline Compliance Assistance Sampling Results

- ◆ 183 Mines Sampled
- ◆ Specific mine results on web site
- ◆ **68 Mines over 400 ug/m³**
- ◆ 115 Mines below 400 ug/m³
- ◆ 49 Mines below 160 ug/m³
- ◆ Median concentration - 271 ug/m³
- ◆ Median max. concentration - 278 ug/m³
- ◆ **High Risk – Powder Crews, Bolters, Scalers, Equip. wo cabs**

Compliance Assistance Activities

- ◆ **Mine visits**
- ◆ **Alternative fuels evaluations**
- ◆ **Filter and cab tests**
- ◆ **DPM Workshops and Seminars**
- ◆ **Laboratory tests**

Available Control Strategies

- ◆ **Ventilation**
- ◆ **Clean Engines**
- ◆ **Environmental Cabs**
- ◆ **Work Practices**
- ◆ **Alternative Fuels**
- ◆ **After-Filters**

Ventilation

- ◆ Particulate Index – amount of air required to dilute whole emissions to 1000 $\mu\text{g}/\text{m}^3$.
- ◆ Double this airflow would dilute whole particulate to 500 $\mu\text{g}/\text{m}^3$, which is the same as 400 $\mu\text{g}/\text{m}^3_{\text{TC}}$ or 308 $\mu\text{g}/\text{m}^3_{\text{EC}}$.
- ◆ For approved engine PI, see MSHA website.

Typical Particulate Indices

- ◆ For non approved engines –

$$\text{PI} = \frac{\text{HP} \times 0.55 \times 35,315 \times \text{E (gm/hp-hr)}}{60}$$

- ◆ 275 hp Loader – 8900 cfm
- ◆ 300 hp Haul Truck – 9700 cfm
- ◆ 150 hp Drill (PC Engine) – 24,000 cfm

Ventilation Rates

- ◆ Most mines had optimized the ventilation system.
- ◆ Successful mines had mine airflow greater than the sum of the PI's for all operating equipment (150,000 to 250,000 cfm).
- ◆ Mechanical ventilation is needed.
- ◆ Intake should not be next to exhaust.
- ◆ Natural ventilation is not reliable for these airflow rates due to low pressure developed and seasonal changes.

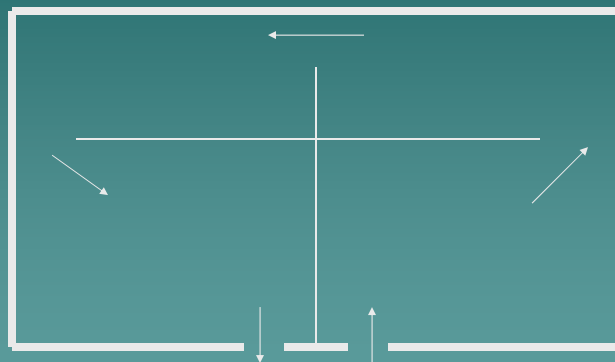
Natural Ventilation with Fan

- ◆ Works with fan in winter
 - Ventilation increases around 10 %
- ◆ Works against fan in summer
 - Ventilation decreases around 10 %
- ◆ Flow direction remains the same

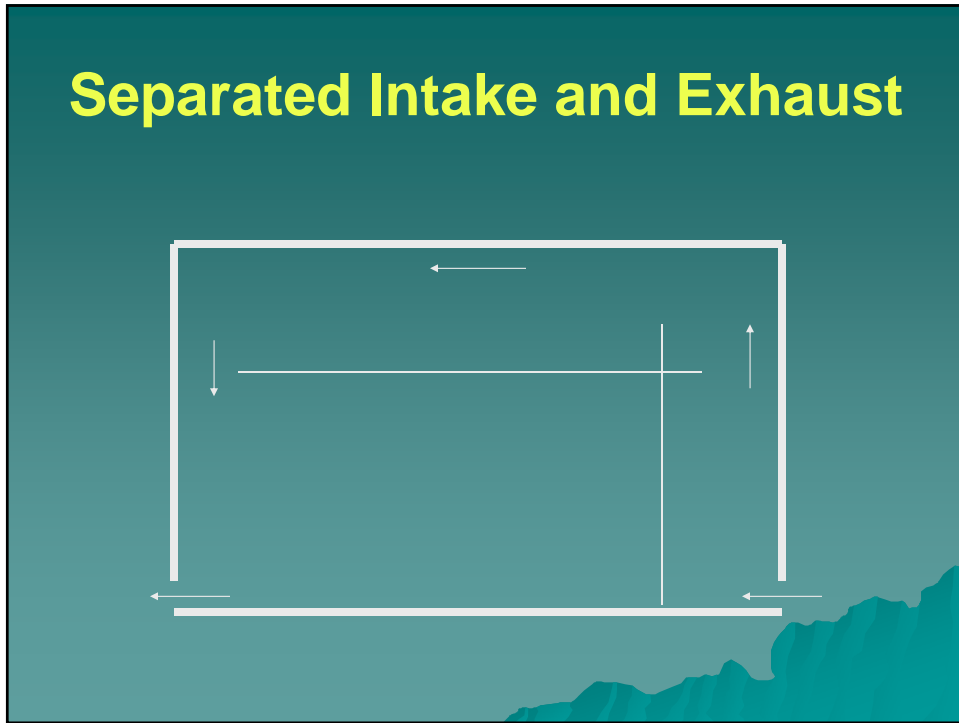
Ventilation Layouts

- ◆ Adjacent intake and return
- ◆ Separated intake and return
- ◆ Flow through – shaft or mountain

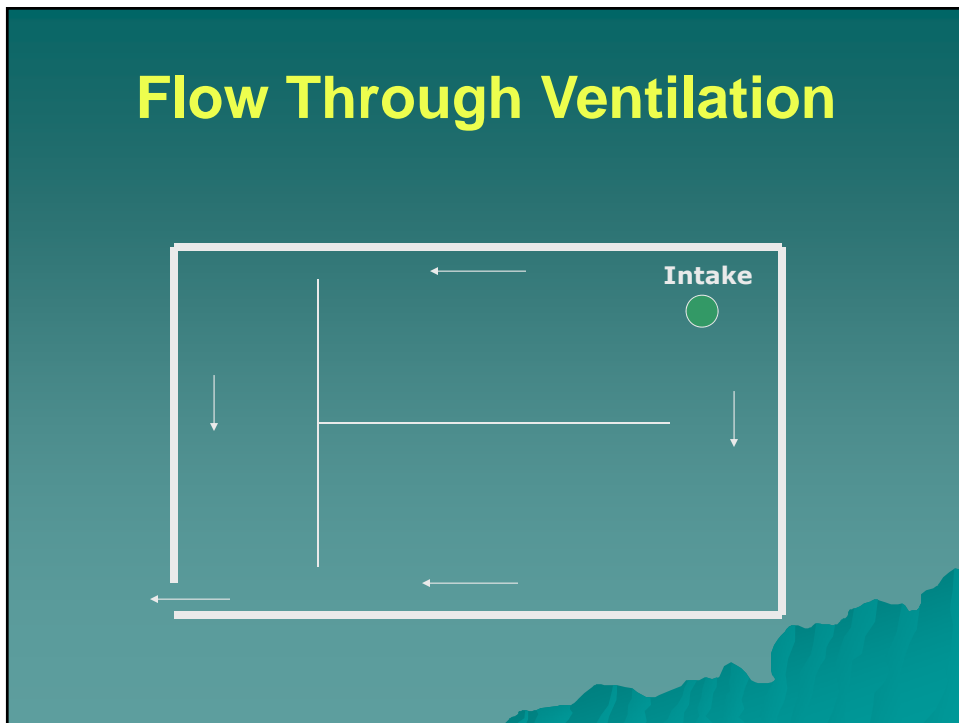
Adjacent Intake and Exhaust



Separated Intake and Exhaust



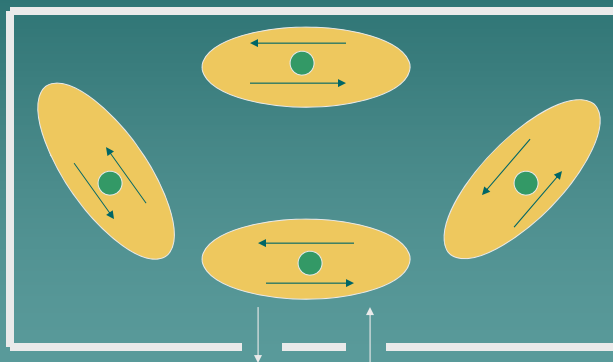
Flow Through Ventilation



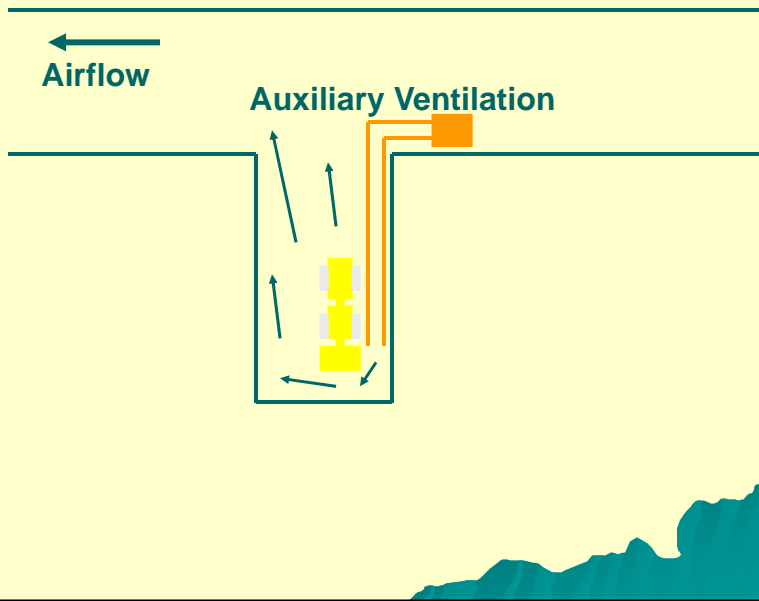
Distribution Systems

- ◆ All methods need distribution system:
- ◆ Long blocks
- ◆ Brattice lines
- ◆ Auxiliary fans and tubing
 - Inlet needs to be in fresh air

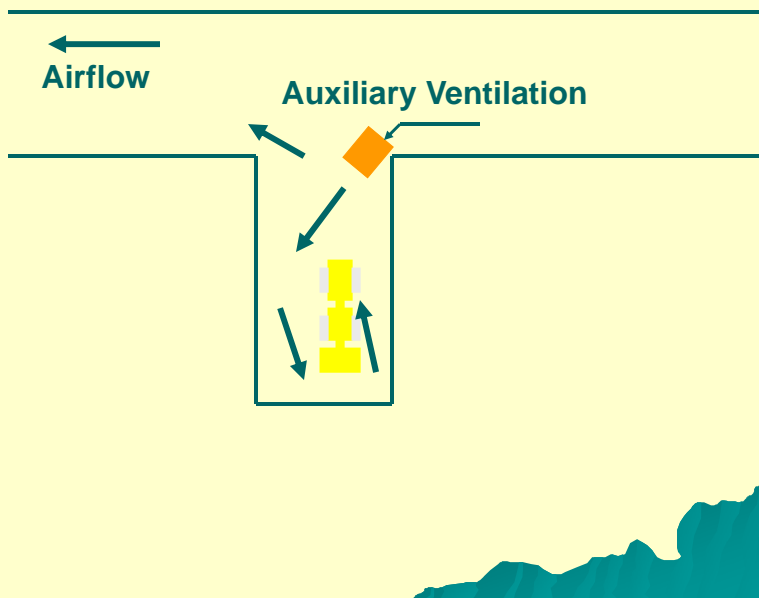
Recirculation With No Controls



Dead Ends - Fan and Vent Bag



Dead Ends - Free Standing Fan



Ventilation vs. Clean Engines

- ◆ **Ventilation is important, but it is expensive unless improvements can be made by improved distribution.**
 - 25% increase in mine air flow doubles the ventilation cost.

- ◆ **Clean engines reduce emissions by 80 to 90%.**
 - Fuel savings pay for engine in 2 to 3 years.

Engines Emissions

- ◆ **Pre 1993 Direct Injection Engines**
 - 0.5 – 1.0 gm/hp-hr.
- ◆ **Indirect Injection (Pre Chamber) Engines**
 - 0.3 – 0.5 gm/hp-hr.
- ◆ **Post 1993 Direct Injection Engines**
 - 0.05 – 0.2 gm/hp-hr.
- ◆ **1997 - EPA Tier 2**
 - High Pressure Fuel Injection
 - Turbocharged
 - Computerized Fuel Injection

- ◆ **MSHA Approval**

Replace PC and Old DI engines with New DI engines

MSHA Approval

- ◆ Limits (derates) exhaust pipe CO to 2500 ppm.
- ◆ Nameplate with Calculated Ventilation Rate.
- ◆ Engine specs and Particulate Index available on web site.
- ◆ Must be maintained in approved condition.

Engine Emissions

- ◆ Total Emissions =
$$\text{Hp specific emissions} \times$$
$$\text{Horsepower} \times$$
$$\text{Hours of use.}$$

Total Engine Emissions

<u>Emissions</u>		<u>Horsepower</u>		<u>Hours</u>
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◆ **Loader:**

– 0.1 x 275 x 8

– Total = $0.1 \times 275 \times 8 = 220$ grams

◆ **Drill:**

– 0.5 x 150 x 4

– Total = $0.5 \times 150 \times 4 = 300$ grams

Three Strikes and It's Out

◆ **Strikes:**

- High horsepower (greater than 150),
- High emissions (greater than 0.3 gm/hp-hr),
- High use (greater than 6 hours per shift).

◆ **Target Equipment:**

- Production Loaders and Trucks (primary),
- Drills and Scalers (secondary)
- PC engines (specialty mining equipment).

◆ **One bad engine can spoil the entire fleet.**

Environmental Cabs

- ◆ **Environmental cabs are an option on most new equipment.**
- ◆ **Retrofit cabs can be expensive.**

- ◆ **Environmental Cabs Can**
 - Reduce DPM Exposure
 - Reduce Noise Exposure
 - Reduce Silica Dust Exposure

- ◆ **Cabs Should Be:**
 - Pressurized With Filtered Breathing Air
 - Operated With Doors/Windows Closed (May Need Air Conditioning)
 - Maintained In Good Condition

Environmental Cabs

- ◆ Reduce dpm exposures by 50 to 80 percent.
- ◆ Seal holes in cabs.
- ◆ 1 air change per minute (100 cfm for a 100 cubic foot cab). Drill pressurizers are undersized.
- ◆ Replace filters when pressure drops.
- ◆ Target pressure – 0.25 inches w.g.
- ◆ Measured with a Magnahelix.



Environmental Cab



Work Practices

- ◆ **Keep powder crews upwind of production loader and trucks.**
- ◆ **Provide separate air course for powder crew.**
- ◆ **Schedule powder crews on different shift than production loader and trucks.**
- ◆ **Operate haulage vehicles (with environmental cabs) in exhaust air courses.**

Alternative Fuel Testing

- ◆ Low Sulfur D2
- ◆ D1 / Jet A / Kerosene – 10 to 20 % reduction
- ◆ Bio-diesel Blends – 15 to 50 % reduction
 - Recycled Vegetable Oil (RVO)
 - Virgin Soy Oil (VSO)
 - Fuel Filter Maintenance
 - 1 cent / percent / gal
 - 20% Minimum Blend
- ◆ Water Emulsions

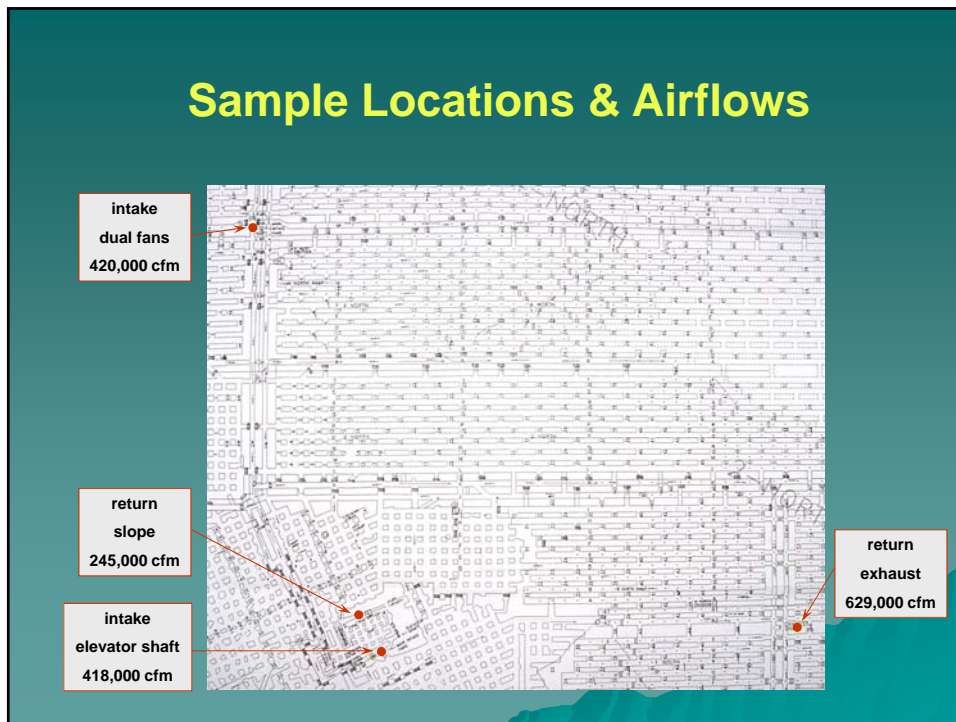


Water Emulsion

- ◆ Winter Blend – 10%
- ◆ Summer Blend – 20%
- ◆ Injector / Fuel Pump Maintenance
- ◆ Same price but increased fuel use
- ◆ Loss of horsepower
- ◆ Good for level mines



Sample Locations & Airflows



Test Procedure

- ◆ **Sample:**
 - Intake openings
 - Exhaust openings
 - Intake and Exhaust airflows
 - Personal exposures

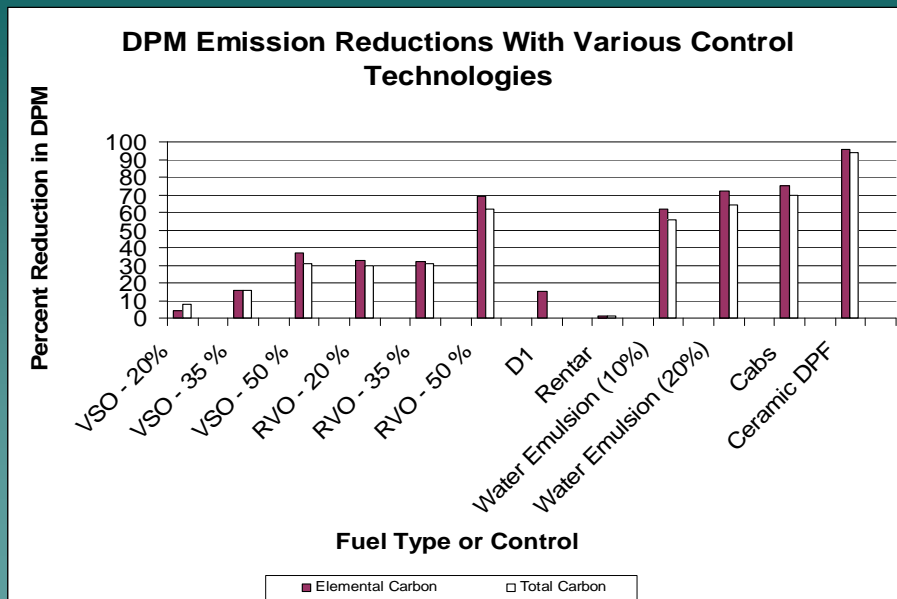
- ◆ **Total emissions evaluation:**
 - Summation of dpm concentration x airflow for all exhaust openings

Test Results

- ◆ Compare total emissions
- ◆ **Mine Emissions Reduction (EC)**

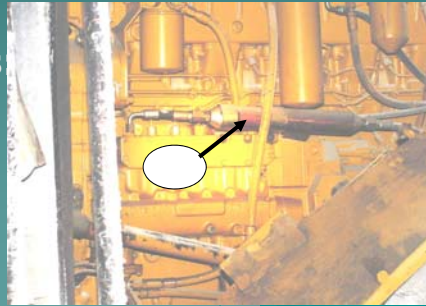
1	49%	Old equipment
2	81%	
3	73%	
4	74%	Multi-level
- ◆ Personal exposure reductions are similar to emission reductions, but more variable due to operational considerations.

Alternative Fuels and DPM Controls



Fuel Additives and Fuel Catalyst

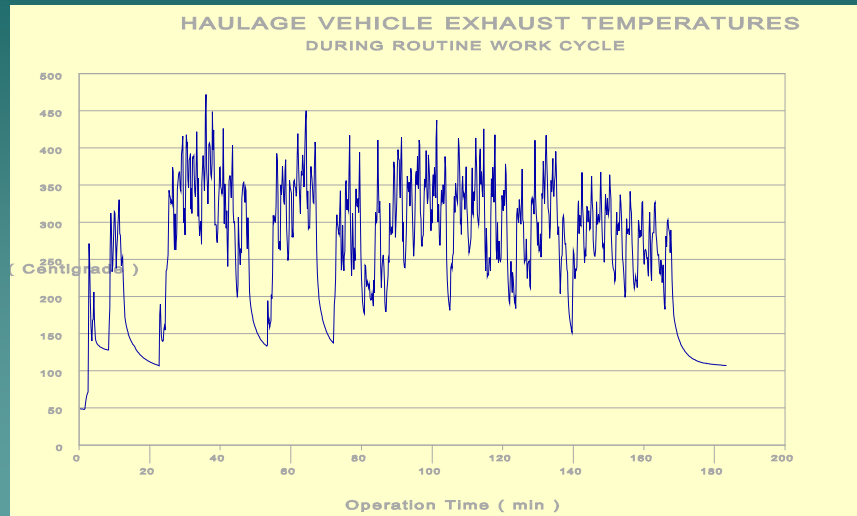
- ◆ **Combustion Enhancers**
 - Cetane booster
- ◆ **Lubricity Increaseers**
- ◆ **Fuel Catalyst Devices**
 - Rentar
 - ECONET - Magnet technology



After-Filters

- ◆ **Passive regenerated ceramic filters,**
 - Self regenerate based on duty cycle.
- ◆ **Active regenerated ceramic filters,**
 - Need regeneration station.
- ◆ **High temperature “paper” filter,**
 - Filter life based on duty cycle and operating time.
- ◆ **Fuel burner with ceramic filter**
 - Creates temperature as in passive type system

Exhaust Temperature Trace



Guidelines for Passive Regeneration After-Filters

- ◆ Based on temperature profile of engine exhaust, if:
 - T30% >550°C, Uncatalyzed "bare" trap,
 - T30% >420°C, Base-metal catalyzed trap,
 - T30% >365°C, Heavily Pt-catalyzed trap,
 - T30% >330°C, Lightly Pt-catalyzed trap plus fuel borne catalyst.

After-filters

- ◆ Have not been used in stone or nonmetal mines.
- ◆ Limited use in metal mines.
- ◆ Filters filter.
- ◆ Operational issues.

Dpm Ceramic Exhaust Filters

- ◆ Filter Media:
Cordierite or
Silicon Carbide
- ◆ Efficiency: 80 to
99% efficient



Active Systems On Board Regeneration

- ◆ Located anywhere in exhaust, not depend on temperature
- ◆ Requires off-duty time or between shifts
- ◆ Controller subject to shock and vibration



Active Systems Off - Board Regeneration

- ◆ Keep Dpm filter small enough for one person to handle
- ◆ Locate for easy access
- ◆ Gas-tight, quick connects
- ◆ Develop exchange logistics: When, Where, How to Transport



Conclusions

- ◆ **Ventilation – mechanical ventilation and distribution system is needed. Total mine airflow should be > the sum of equipment PI's.**
- ◆ **Clean Engines – a must. Replace PC and old DI engines with new DI engines.**
- ◆ **Environmental Cabs – maintain seals blower and filtration system.**

Conclusions

- ◆ **Work Practices – Apply particularly to blasting crews. Work upwind or on different shift from production equipment.**
- ◆ **Alternative Fuels – 10 to 50 % reduction. Must weigh cost vs. benefit.**
- ◆ **After-Filters – Selection is based on temperature profile. Not generally needed for interim limit. Most likely will be needed to meet the final limit.**