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Diesel Engine Systems – Emission Control Strategies
Report on Visit to America 27 July to 10 August 2003

This report follows a visit to America to gather information on diesel engine exhaust emissions, emission control technologies being evaluated by NIOSH (National Institute for Occupational Health and Safety) and strategies being implemented by MSHA (Mine Safety and Health Administration) to American coal, metal and nonmetal underground mines. The visit also included investigating the future direction of electronic controlled diesel engine systems (DES) and the associated issues / benefits with their use in underground coal mines.

The trip was organised by DBT Diesel Australia Pty Ltd. Details and information gathered during the trip is contained in NSW DMR files, C03/0454 & C03/0455.

People in the touring group include:

David Mackie	– Senior Inspector of Mines, Department of Natural Resources and Mines Qld
Peter Kacev	– Mechanical Engineer, DBT Diesel Australia
Stuart Vaccaneo	– Qld Industry & Safety Health Representative, CFMEU, District Union Inspector
JW (John) Smith	– Engineering Manager, DBT America
Peter Sunol	– Mine Safety Officer, Department of Mineral Resources NSW

1.0 Summary

Through the Code of Federal Regulations, (CFR30) MSHA have recently regulated to limit diesel particulate (DP) exposure in coal, metal and nonmetal mines. This has been carried out after significant research into the health effects of DP and various control technologies.

The Environmental Protection Authorities (EPA) of America and Europe have regulated for cleaner diesel engine systems on a worldwide scale. These regulations implement a tiered emission reduction program over a several year period. This has resulted in sophisticated electronically controlled diesel engines being developed for ‘onroad’ and ‘nonroad’ use by engine manufacturers.

While these electronic engines provide better emission and DP control they also create problems for underground coal mines where surface temperature is limited and explosion protection is required.

The trip to America was organised to gather information on these issues.

The strategy adopted by MSHA to control exposure to DP is based on setting maximum DP quantities for each diesel engine system in underground coal mines and setting DP exposure limits for metal and nonmetal mines. This has resulted in particulate filters being installed on all diesel engines in underground coal mines.

This is not a suitable risk based strategy for NSW mines. This is because our legislative framework is risk based around the Occupational Health and Safety (OH&S) Act 2000.

The American Federal Regulations for mines (CFR30) is not risk based, it is very detailed and prescriptive in its content. This is creating problems for new technologies being introduced in America.

The recommend risk based strategy for underground coal and metalliferous mines in NSW includes:

a) Revise MDG 29, 'Guidelines for Diesel and Operator Environment Testing in Underground Coal Mines', to give guidance on the management of all diesel pollutants in coal and metalliferous mines.
b) Adopt the NSW minerals councils recommended exposure limit of 0.2 mg/m^3 through a staged approach over a couple of years.
c) Require all mines to have a management plan for the control and monitoring of diesel emissions and DPM.
d) Limit pollutants at the source by requiring newly introduced engines to meet the tiered American EPA requirements for nonroad diesel engines.
e) As an OH&S responsibilities, require diesel equipment manufacturers to provide systems on new and existing equipment such that the $0.2mg/m^3$ limit can be achieved within normal mine ventilation quantities.

In regards to the issue with electronic engines it is important that we stay in contact with MSHA so that both countries have similar assessment criteria to ensure they are explosion protected. The implementation of electronic engines will improve emissions but it is not a singular solution. Tier 3 engines will not be available until 2006.

2.0 Visit to Caterpillar Mosville, Illinois – 28 July 2003

Morning Session *– Presentation & Discussions with Caterpillar Industrial Power Systems Personnel*

Bob Montgomery – Product Definition Manager,
Willian J Holt – Application & Installation Engineer
Tod Hopwood – Caterpillar Electronics
Rob K Johannsen – Product Manager
Dan Swords – Control Design Engineer
David Moore – Regional Manager South East Australia

(b) Caterpillar engine sales of ($6.7B) represent 30% of their total corporate sales ($20.1B). These engine sales include:

- Industrial 10%,
- Oil & Gas 26%
- Marine 9%
- On highway 27%
- Electric Power 28%

In the past 10-15 years in the coal market Caterpillar have averaged sales of 70-100 engines per year total. Australia is approximately 1/3 of these. In their local manufacturing plant, Caterpillar manufacture on average 400 engines per day.

(b) MSHA Engine Approval Requirements – Coal Mines

- All engines must be approved and certified by MSHA. Additional testing to EPA is required.

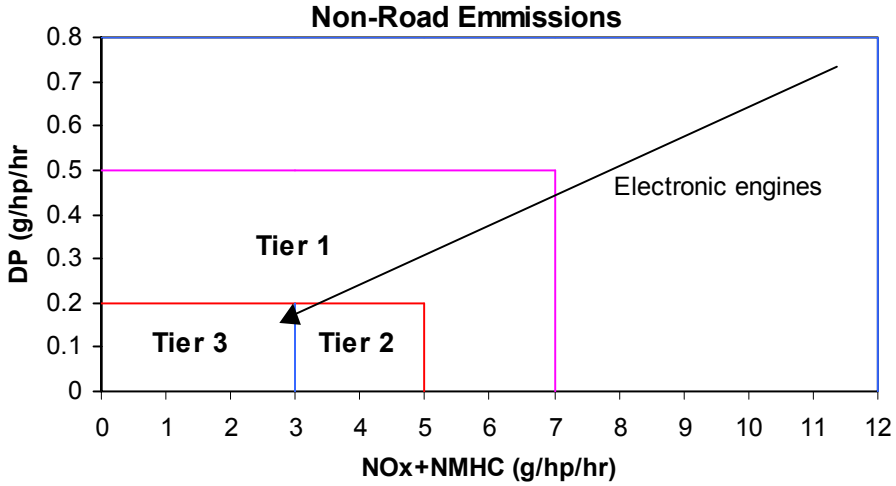
- The engine must be submitted for testing by the 'engine manufacturer' and not the 'power pack (equipment) manufacturer'. The 'bare engine' is tested without the mining required additions. It is assumed that any mining additions to the bare engine, such as heat exchanger, water scrubber, filter, etc., will be within the maximum exhaust back-pressure allowed by the engine manufacturer and therefore the emissions will be no worse when then mining additions are attached. The engine manufacturer can carry out testing provided a MSHA representative witnesses the test.
- Equipment manufacturers must use approved engines for power package approval (explosion testing) on permissible equipment.
- Engines categorised into category 'A' for permissible equipment (explosion protected), and category 'B' for non-permissible (flameproof) equipment. Non-permissible engines are further sub-categorised into 'light duty' and 'heavy duty'.
- Permissible and heavy duty engines must meet 2.5 g/hr DP. Light duty engines must meet 5.0 g/hr DP or be certified by the American EPA. To meet this requirement all diesel engines, including Tier 3 engines will require a particulate filter to be installed. Some Tier 4 engines may not require filters to meet the requirements, depending on the engine size.
- Testing is based on ISO 8178 C1, 8 mode steady state test cycle, refer also CFR 7.86, 7.88 & 7.89. Each engine is issued an approved ventilation rate and particulate index number. The ventilation rate is based on required ventilation to maintain NO (25ppm), NO_2 (5ppm), CO_2 (5,000ppm) CO (50ppm), to exposure standards in the mine atmosphere. The particulate index is the minimum ventilation required to dilute the exhaust particle emissions to $1mg/m^3$, refer CFR 7.84.
- Difference between category 'A' and category 'B' testing is category 'A' engines are tested with 1% methane injection. Category B engines do not undergo surface temperature testing.
- At this point in time there is no new Category A engine greater than 116hp available to the underground coal industry. Non of these engines meets EPA requirements. Current category A approvals include:
    - ⇒ Deutz, MWM 916 – 94hp
    - ⇒ Caterpillar, 3306 PCNA – 150 hp
    - ⇒ Caterpillar, 3304 PCNA – 100 hp
    - ⇒ Isuzu, QD 100-306 - 66 & 70 hp
    - ⇒ Caterpillar, 3306 PCTA – 190 hp
    - ⇒ Isuzu, 6BG1-MAP – 116 hp
- Caterpillar are in the process of gaining type 'A' approval for the 3126 MUI (Mechanical Unit Injection) and type 'B' approval for the 3126B (Electronic Injection EUI).
- MSHA approvals generally take 90-120 days.

(b) MSHA Engine Approval Requirements – Metal and Nonmetal Mines

- All engines must be certified as a category A or B engine per coal requirements above or alternatively meet EPA nonroad emission levels.
- Maximum DP exposure limit in mines is 400 g/m3. This is reduced to 160 μg/m3 in January 2006.

(c) EPA Requirements

- Both America and European EPA's have set emission requirements for nonroad diesel engine systems. The American and European EPA emission requirements line up in 2008 and are similar thereafter.
- Emission requirements exclude locomotive and marine engines.
- There is a 3dB noise reduction required in Tier 3 engines.
- Extract of American EPA emission requirements for nonroad diesel engines includes:



Graph Showing how DP and NOx varies for each Tier

Engine Power (kW)	Tier	Date	Emissions – g/kW.hr				% Smoke Opacity A/B/C
			NMHC	CO	NMHC + NOx	PM	
75 – 130	1	1997			9.2 (NO_x)		
	2	2003		5.0	6.6	0.30	20/15/30
	3	2007		5.0	4.0	0.30	20/15/30
	4	2012	0.19	5.0	0.40 (NO_x)	0.02	<22
130 – 225	1	1996	1.3	11.4	9.2 (NO_x)	0.54	20/15/30
	2	2002		3.5	6.6	0.20	20/15/50
	3	2006		3.5	4.0	0.20	20/15/50
	4	2011					<22
225 – 450	1	1996	1.3	11.4	9.2 (NO_x)	0.54	20/15/30
	2	2001		3.5	6.4	0.20	20/15/50
	3	2006		3.5	4.0	0.20	20/15/30
	4	2011	0.19	5.0	0.40 (NO_x)	0.02	<22

⇒ A/B/C, is acceleration, lug, peak load

⇒ Engine useful life to exceed 8,000 hours

⇒ NMHC can be corrected by measuring total hydrocarbons and deducting 2% for the nonmethane component

Table Showing Tier 1-4 Nonroad diesel emission standards – American EPA

(b) Future of Caterpillar Engines

- 3306 & 3304 engine ceased production in December 2002. CAT will support parts for long time.
- 3126 MUI (Mechanical Unit Injection) is Tier 1 product engine with mechanical injection and water-cooled manifolds. Planned production through to end of 2005 then production will cease.
- 3126B is a Tier 2 product engine with electronic injection and dry type manifolds. Available in 175, 225 & 275 hp.
- In 2006 CAT will produce Tier 3 engine with ACERT technology. Engine will be known as C7 not 3126. Will have same frame size as the 3126 engine.
- 3126MUI will shortly be approved by MSHA for category A and 3126B as category B
- Marine and Zone 2 (Oil and gas industry) version of 3126 currently being developed and available 2004. Will be a Tier 2 certified engines. Surface temperature limit for Zone 2 engine will be 200^0 Celsius.
- Other available engines; C9 275-350hp, C10 310-365hp. The C10 engine will have a water cooled option.
- Smaller engines will be in their 3,000 series. C6.6TA 119-225hp available mid 2005. C4.4 75-140hp available 2006. C4.4 64-80hp available 2007.
- Generally engines are planned to be released six months before EPA requires.

(e) ACERT^{TM} Technology for Nonroad Engines

- All Tier 3 & 4 engines will be based on the ACERT (Advanced Combustion Emission Reduction Technology)
- ACERT Technology is currently being introduced in on the road C15 truck engine and shortly to the C11 & C13. This is the onroad equivalent to Tier 4.
- Nonroad emission is approximately 3-4 years behind onroad emissions.
- For nonroad engines ACERT incorporates; Electronic Control Module (ECM) $\Rightarrow$ Catalytic converters $\Rightarrow$ variable valves $\Rightarrow$ multiple turbo's in series (onroad only) $\Rightarrow$ multiple fuel injections. Electronic controlled Turbo wast gates, no water cooled manifolds and Air to Air aftercoolers (ATAAC) will be utilised.
- The speed of engines is generally reducing from 2,500rpm to 1800 rpm for fuel economy.
- Caterpillar has concentrated all of their efforts and technology into ACERT to meet the EPA tiered requirements. Other engine manufacturers are concentrating on Exhaust Gas Recirculation (EGR) where exhaust gasses are being reintroduced into the combustion chamber depleting oxygen density.

Afternoon Session *– Inspection of Assembly Plant and Foundry*

Observations at Caterpillar

- Due to the limited quantity of category A engines used worldwide by the underground coal mining industry, it is uneconomical for Caterpillar to carry out the research and development. Caterpillar will assist the development of changes to their engine where possible.
- One issue with our industry is that the same research and development is carried out by each equipment manufacturer and therefore reduces the economy of scale.

- The majority of effort for the approval category A engines needs to be directed into the tier 3 engine, C7 and not the 3126B version. This must be approved for use in coal mines by 2006 when the 3126 MUI engine ceases production.

3.0 Meeting with Donaldson Filters, Louisville, Kentucky - 29 July 2003

Evening Meeting

Garry D Reeves – Manager, Exhaust/Emissions Application Engineering

Frederick W Schmidt – Sales Manager, Exhaust/Emissions

- All known fires on disposable paper type filters are due to the wet scrubber running out of water or people wiring up the scubber float.
- A MSHA approved control is to install a sprinkler head in the filter housing.
- Donaldson have developed a new high temperature disposable exhaust filter (P604516) approved by MSHA. The filter material degrades with heat over time. It is estimated at withstanding 260^0C for 150 hours continuous or 480^0C for 1 minute. They recommend the installation of this filter rather and not the paper based filter.
- Current use of the majority of filters on permissible equipment is a paper based filter. There will be an increase in cost for the new filter, but the filter could be cleaned and reused, although not supported by Donaldson.
- Donaldson also have a lightly platinum based converter which they use in onroad equipment. This will convert the organic fraction of the PM and the filter will remove the solid particles. However the catalyst needs a minimum of 150^0C operating temperature to become active and 300^0C for at least 30% of the time for self regeneration. NO_2 may also increase, depending of the amount of platinum used.

Observations with Donaldson

- Discussions with Donaldson were not held at their manufacturing plant. We were unable to witness their testing facilities.
- Information of problems and issues at the mines appear not to be getting back to Donaldson. While Donsoldson people understood their product, they appeared not to have first hand knowledge of what was actually happening at the mine.
- The new high temperature disposable filters appear to be quite good, however detailed temperature and endurance testing has not been carried out.

4.0 NIOSH Workshop, 'Control Technologies for Diesel Vehicles in Underground Coal Mines', Louisville, Kentucky – 30 July 2003

4.1 Item 2 – DPM Final Rule for Underground Coal Mines

Presented by George Saseen – Physical Scientist, MSHA Mechanical Safety Division

(b) Coal Rules

- *Permissible equipment* (Explosion protected) Each piece of diesel equipment within the mine must emit no more than 2.5 g/hr of DPM as of 19 July 2002. Section 72.5
- Compliance through the addition of a removable element type filter from MSHA's list. List includes paper filter, synthetic material, or fire retardant properties. List available on MSHA website www.msha.gov/01-995/dieselpart.HTM.

- MSHA are testing an improved low water shutdown device. Consists of low water level sensor in scrubber, flashing headlight system and sprinkler head in filter housing to shutdown engine.
- *Non-permissible heavy duty equipment*. Each piece of diesel equipment within the mine must emit no more than 5.0 g/hr of DPM as of 21 July 2003 or 2.5 g/hr as of 19 January 2005. Section 72.501.
- Compliance is obtained with a DPM control device; cordierite filter 85% efficient, Silicon carbide filter 87% efficient, paper / synthetic filter c/w heat exchanger.
- *Non-permissible light duty equipment*. Each piece of diesel equipment within the mine must emit no more than 5.0 g/hr of DPM as of 21 May 2001. Section 72.502.
- Exemptions – light duty engines that meet the EPA emission requirements are exempt from the 5.0 g/hr limit. Note: The engine still must be approved by MSHA as a category B engine.

(b) Metal and Nonmetal Rules

- Mine operator must limit operator DPM exposure to 400 $\mu g/m^3$ Total Carbon (TC) for 8 hour shift equivalent. Section 57.5060.
- After January 2006, exposure limit to reduce to 160$\mu g/m^3$ TC for 8 hour shift equivalent. Section 57.5060.
- Mine operators must monitor to effectively determine if any miners are overexposed to DPM. Section 57.5071
- DPM matter control plan to be established if violation occurs. Section 57.5062
- Any engine introduced into the mine after 5 July 2001 must meet coal engine approval requirements or meet EPA particulate emission requirements. Section 57.5067.
- Proposed new rule of 400$\mu g/m^3$ TC to be changed to 308$\mu g/m^3$ Elemental Carbon (EC). Based on TC = 1.3xEC, TC = OC + EC.

4.2 Item 3 – Emissions Assisted Maintenance

(b) Paper 1 – Maintaining Diesel Engines for Emission Control

Presented by Sean McGinn Consultant with DEEP project.

- Measure, measure, measure. Everything but be measured.
- Intake system; Visually inspect and test for integrity
- Exhaust system; Understand and measure the emissions, CO, NOx, SO_2, HC, DPM, SOF (Soluble Organic Fraction). Inspect and service.
- Fuel and injection system; Injectors, pumps, valves, air/fuel ratio, measure emissions.
- Cooling system; Clean, test and verify temperature measurement.
- Fuel quality and handling; 50ppm Sulphur best, eliminate contamination.
- Lubrication; Oil grade CH-4, oil analysis and quality filters
- Training
- Need appropriate tools for measurement and monitoring

(b) Paper 2 – Maintenance of Heavy Duty Diesel Powered Equipment

Presented by Steve Forbush, Canyon Fuel Company, Sulfco, Skyline and Dugout Mines

- Establish a baseline on emissions. Their emissions were 1597 ppm CO and 947 ppm NO_x. Enerac 500 Emissions analyser used for emission measurements.
- Optimised drive train components (torque converter with transmission) for the duty cycle required and mine elevation against engine performance and emission curves.
- NO_x and CO contour maps were used to identify sweet spots in the engine.
- Optimising driver training for duty cycle.
- Achieved 90% reduction in CO to 154ppm, 50% reduction in NO_x to 402 ppm.
- No engine or drive chain set at OEM specifications.

4.3 Item 4 – Overview of Control Technologies Available to Underground Mining Industry

Presented by Alesandar Bugarski – Research Associate, NIOSH

(b) Emissions

- Occupational Health & Safety diesel emissions are set by American Conference of Governmental Industrial Hygienists (ACGIH). TWA limits are; CO_2-5,000ppm, CO-50ppm, NO-25ppm, NO_2-3ppm, $NO_{2\ (STEL)}$-5ppm
- TC=EC+OC = 400μg/m^3 as interim standard for metal/nonmetal mines
- MSHA adopted ACGIH standards in 1973.
- Control emissions at the source; well maintained low emitting engines, alternative fuels, after treatment technologies to curtail gaseous and particulate emissions.

(b) Engine

- All permissible and non-permissible engines must be approved by MSHA. Approval requires testing and calculation of ventilation rates and particulate index.
- Replace old technology engines with new technology engines. New technology engines have not been approved for permissible equipment. The CAT 3126MUI is currently being assessed by MSHA.
- Multiple fuel injections and injection timing variable
- Exhaust gas recirculation
- Control fuel-to-air ratio and deration for higher altitudes
- Modern engines emit 10% of the total PM of the engines designed 10-15 years ago

(c) Fuel

- Sulphur content; sulphates SO_2 to form SO_3 and H_20 to form H_2SO_4. EPA sulphur limit <15ppm by mid 2006. Sulphur effects the performance of catalysts and competes with NO for the O_2.
- Low sulphur fuels reduce concentration of nano-particules by several orders of magnitude.
- Biodiesel; has very low sulphur content, reduces HC, CO & carbon particles (EC) but increases soluble OC. May increase NO_2 by 43%. Fuel economy penalty to 11%. Generally blended
- Synthetic Fuel; no sulphur, low aromatics, significant reduction in emissions, not readily available
- ULSF; <15ppm. available by 2006.
- Fuel additives; combustion enhancers, DPF regeneration aid. Must be approved by EPA.

- Water Fuel Emulsions; reduces combustion temperature NO_x and PM. Increase CO & HC emissions. Power loss of 10-15%.

Aftertreatment Technologies

(d) Diesel Oxidation Catalytic Converters (DOC)

- converts CO to CO_2, 70-90% reduction
- Hydrocarbons (HC) to CO_2, 70% reduction
- Reduce soluble organic fraction (SOF) of DP, 20-30% in total DP
- The catalyst can be poised by sulphur and lubricating oil compounds. Low sulphur fuel must be used.
- Unfavourable reaction are NO to NO_2 and SO_2 to SO_3.
- For NO_x reduction options; Selective catalyst reduction (SCR) are complex and suitable for stationary equipment only. Lean NO_x traps (LNT) not commercially available.

(e) Diesel Particulate Filter Systems (DPFs)

- Types of media; wall flow monoliths, deep bed filters, silicon carbide, cordierite, fiber wounded or knitted
- Non-catalysed, no regeneration aid needed
- Catalysed; Wash coat catalyst (platinum, palladium, rhodium, vanadium, magnesium, strontium….) or, Fuel borne catalyst (platinum, cerium, iron, strontium …)
- Efficiency of DPF systems by mass; Cordierite 85%, silicon carbide 85%, VERT 90%.
- Efficiency of DPF systems by Carbon; Over 95% on EC but not efficient for the organic proportion. America measures TC but will soon change to EC. Germany measures EC.
- Efficiency of DPF systems by number; Has potential to form large number of ultrafine and nanosize particles, as these are predominantly organic's.
- Secondary emissions; Platinum coated catalysts increase NO_2. Fuel borne catalyst do not. Avoid fuel borne catalysts if no PF filter installed on engine, otherwise metals content of exhaust increases
- Washcoated base metal catalysts do not have tendency to increase NO_2 emissions
- Passive regeneration requires over 30% of operating cycle to be; Non-catalysed DPF – over 550^0C, Base metal – over 390^0C, Nobel metal – over 325^0C.
- Exhaust temperature profile is critical for passive regeneration, idling should be reduced.
- Active regeneration - On board; uses a heating element, no need to remove filter, requires downtime.
- Active regeneration - Off board; requires removal of the filter elements, risk with handling brittle filters, regeneration station required. Filters should be sized to accumulate DPM between two active regeneration's. Silicon Carbine for express regeneration, Cordierite for slow regeneration (8 hour).
- Passive regeneration is low cost and low maintenance, increases NO_2 and required minimum heat.
- Active regeneration has higher cost and maintenance requirements.

- Periodic cleaning of filters for removal of ash is required every 1,000 to 2,000 hours. Can cause uncontrolled regeneration.
- Backpressure monitoring is essential.
- Oil consumption reduces filter life.

(f) Disposable Diesel Exhaust Filter (DDEF)

- Only methods suitable for permissible equipment due to lower temperature.
- Needs heat exchanger to reduce operating temperature
- Not discussed in conference

4.4 Item 5 – Control of Diesel Emissions in Underground Mines – Part I

(b) Paper 1 – Diesel Particulate Filters used in Underground Coal Mines

Presented by Steve Forbush, Canyon Fuel Company, Sulfco, Skyline and Dugout Mines

- Choices for DPM reduction; maintenance, cleaner engines, DP filters (active & passive), disposable filters
- Passive soot traps are highly catalysed; should regenerate itself, NO_2 increases., low cost, PIB02-07 notice for coal NO_2 shall not increase.
- Active soot trap; no NO_2 problem, designed for one shift only, needs power supply & place to regenerate, relatively high cost.
- Disposable paper filters; need heat exchanger, used for inbye coal engines only, high installation cost, Secondary shutdown and sprinkler head in filter.
- Disposable synthetic filters; non-combustible, cleanable and not effected by water.

Examples – Buchanan Mine, Brookville supply locomotive equipped with ECS diesel particulate filters with electric on-board regeneration

Highland Mine, A.L. Lee Microtrac Utility vehicle equipped with ECS diesel particulate filter with electronic on-board regeneration.

Brunswick Mine, particulate Trap project (DEEP), Performance evaluation of 4 diesel particulate filter systems.

Twentymile mine, diesel equipment maintenance and after treatment controls

4.5 Item 6 – Control of Diesel Emissions in Underground Mines – Part II

(b) Paper 1 – Summary of Testing @ MSHA A&CC Diesel Laboratory

Presented by Russell Stackpole – MSHA, Technical Support-Approval and Certification Centre

- Disposable filters for cooled exhaust; paper media, synthetic (poly) media, glass fiber media,
- Continuous use filters (Traps) for hot exhaust gas; high & lightly platinum filters, base metal catalysed, uncatalysed.
- Other types; diesel oxidation catalyst (DOC), disposable hot gas, fuel & additives, air/fuel ratio, electronic engines
- A&CC diesel laboratory equipment; two engine dynameters 400 & 1,000hp, Superflow pro-ATC control & DA system, Sierra BG-2 particulate sampling system (gravimetric or total dpm mass), Horiba gas measurement system, EC/OC sent to NIOSH for analysis.

- Disposable filter tests; use CAT 3306 engine and do comparison (equivalence under same conditions) to standard Donaldson paper filter (P530866). Use 8 mode ISO test for 1.25 hours after 45-minute warm up period. Approximately 50 tests carried out to date.
- Disposable filter fails if; cannot achieve 97% of Donaldson paper filter, filter shows excessive backpressure during test, filter is physically damaged by exposure to exhaust stream.
- Hot gas filter; testing similar to disposable but with Deutz F6L92W engine. measure DPM output of filter and NO_2 emissions.

(b) Paper 2 – Evaluation of Control Technologies in Underground Mines

Presented by Alesandar Bugarski – Research Associate, NIOSH

- Short term evaluation; emissions, installation and operational issues
- Long term evaluation; reliability, durability, cost benefit estimate
- Overview of current evaluations, most of metal / nonmetal mines. Findings at Deer Creek Study 2002;
  - The maximum fuel rate for the CAT 306 PCNA as set by CAT was found to be excessively high. Resulting in high PM emmissions.
  - PM emissions from properly tuned engines were significantly lower than those obtained during MSHA certification tests.
  - PM emissions with water scrubber and paper filter were greater than 2.5 g/hr.
  - Modifications to the water seperator & water level in the scrubber resulted in extending filter life.
  - After several minutes of operating with a Pt based catalyst concentrations of NO_2 exceeded 5 ppm.

4.6 Item 7 – Strategy for selection of Diesel particulate Filters

Presented by George Schnakenberg, Jr – Research Associate, NIOSH

- Coal rule requires aftertreatment devices, choices include; disposable filters for permissible systems, high temperature disposable filters, regeneration permanent DPF.
- Filter selection based on space, exhaust temperature, vehicle deployment & schedule,
- Additional maintenance requirements; properly derate for elevation, check oil consumption, continually track emissions from bare engine,
- Lower engine PM emissions give longer run time on filter,
- Temperature profile exhaust; needed for filter type selection,
- $T_{30\%} < 325^0C$, active regeneration is needed.
- Active regeneration, minimise and insulate exhaust run between engine and DPF, monitor backpressure and temperature, clean DPF approx 1,000 hours. Can be off board (DPF exchange) or on board.
- $T_{30\%} > 325^0C$, passive (self) regeneration is possible, $T_{30\%} < 550^0C$ use uncatalysed "bare"trap, $T_{30\%} > 380^0C$ use base metal catalysed trap, $T_{30\%} > 330^0C$ use lightly Pt-catalysed trap+fuel borne catalyst, $T_{30\%} > 325^0C$ use "50g" Pt-catalysed trap.

- Passive regeneration; consistent work cycle is require to ensure high temperatures for regeneration, must install back pressure monitor and alarm, observe and sample increase in NO_2 emissions depending on Pt loading

NIOSH Report Issued – 'Review of Technology Available to the Underground Mining Industry for Control of Diesel Emissions / 2002'

- This report reviews the performance and applicability of technology for control of emissions from diesel powered equipment used in underground coal and metal/nonmetal mines.
- A copy of this report is available at www.cdc.gov/niosh/mining/pubs/pdfs/ic9462.pdf
- The report covers health concerns, exhaust composition, exposure and control technologies (maintenance, engine design and selection, fuels, after treatment technologies)
- The report summarises the '*best available technology*' for reducing hazardous diesel emissions as the combination of;
  - a low-PM-emitting diesel engine (possible derated),
  - a Diesel Oxidation Catalyst (DOC) to reduce CO, HC and organic fraction of PM
  - diesel particulate filter (DPF)
  - low Sulphur diesel fuel < 50ppm
  - an effective maintenance program
- The preferred DPF is to use high exhaust temperature to burn off soot during engine operation. However this is not suitable for permissible equipment.

Observations of Conference

While the conference had a lot a good information I was disappointed with some of its content. A majority of the conference was based on catalytic type converters and regeneration type filters that are not suitable for permissible equipment in coal mines due to the high temperatures required. Examples were mainly metal mine based and the conference material appeared to be a repeat of previous metal conferences with only minor adjustments for underground coal mines.

There was very little information given in regard to particulate control methods for permissible engines in coal mines. While in America only 600 out of 3,000 (20%) diesel engines in underground coal mines are permissible, I believe these permissible engines represent the highest emission exposure to people. This is because of longwall relocation requirements and development diesel's. In NSW 100% of diesel engines in underground coal mines are of the permissible type.

There was also little or no information given as to what is a safe exposure level for DP and how that relates to historical medical evidence.

5.0 Visit to MSHA, Triadelphia, West Virgina – 31 July 2003

Robert Setren – Supervisors Engineer, Diesel Power Systems Branch

Dennis L Ferlich – Chief, Mine Equipment Branch, Mechanical Safety Division

General discussions with Bob and Dennis took place. Points of interest include:

- All of their testing requirements are detailed 30 CFR Section 7, 'Testing by applicant or third party', Subparts E ' Diesel engine systems intended for use in

underground coal mines' and Subpart F diesel power packages intended for use in areas of underground coal mines where permissible electrical equipment is required.

- Generally the Federal rules are very specific and detail all requirements. Even the type of apparatus is detailed in their regulations. There regulation appears not to be OH&S based.
- Testing is carried out by the engine manufacture or by a third party. MSHA representative must witness the test. However all Category A engines are still tested at MSHA because of the 1% methane injection requirements.
- The bare diesel engine is tested for emissions and DPM. This is then used to calculate the minimum ventilation rate for the particular engine. Ventilation rates are based on the raw exhaust emissions. For permissible equipment methane injection is included. The maximum fuel/air ratio is calculated and fixed.
- A particulate index is assigned to each engine. This is based on the required ventilation quantity to achieve $1g/m^3$ in the mines ventilation atmosphere.
- The method of measuring particulate is detailed in 30CFR. It is similar to the NIOSH method 5048.
- Typically NO set ventilation rate for permissible equipment and NO_2 sets ventilation rate for permissible equipment.
- There is a lot of requirements in the regulation which have been around for a long time, but have not been updated for technology.
- There is no temperature limits for category B engines.
- A new technology section is available to cover areas, which are outside the prescribed regulations. MSHA must determine that the new technology is at least as safe.
- DP levels for coal are considered feasibility levels, not OH&S levels. They were based on a Cat 3306 engine c/w Donaldson paper type filter and measuring output particulate. This test was carried out at the south west research centre. It has been difficult to re-establish.
- Coal regulations take the DP limit down to the lower level (140µg/m3) of the non-coal regulations. DP measured in a dilution tunnel, SIERRA Instruments Model BG-2.
- Discussions of AS 3584.2 –2003. There is a difference in the amount of charcoal being used for the spark arrester test and MSHA does dynamic testing of the engine for the explosion testing. After looking at the facilities this is a better test and is relatively simple to do.
- There was general discussion on the acceptance level of damaged filters and housings after testing. MSHA have had some powerpacks where the filter was tested as the spark arrester.
- Pressure testing of components is 4 x explosion pressure or 1,000 kPa which ever is the lesser.
- All filter fires are due to failure of scrubber float. MSHA see dry systems as more reliable. They do not require dual floats in the scrubber.
- In service there is approximately 3000 diesel engines in service. Of these approximately 600 are permissible engines.
- There is currently no modern type permissible engines approved.

- Carried out a inspection of their engine dynamometer and explosion testing facilities.

6.0 Visit to MSHA, Triadelphia, West Virgina – 1 August 2003

Robert Setren – Supervisors Engineer, Diesel Power Systems Branch

Wayne Colley – Electrical Engineer

David Chirdon – Supervisory Electrical Engineer

General discussions on the issues with the testing of electronic diesel engines in permissible areas of the mine:

- Issues raised with new engines and discussed options for assessment of the electronics.
- Surface temperature is another problem. On manufacture has attempted to install lagging over the hot surfaces.
- MSHA have not yet made a final position on how they will assess the electronics on these newer engines. A Draft guideline was prepared, based on the electrical requirements in Part 18. However, it is now believed that they will most likely assess electrical equipment contained within the engine, eg, electronic injectors, valves, etc., to the mechanical requirements of Part 7 of CFR30.
- A committee is being formed to determine the criteria for assessment of permissible electronic engines. MSHA will keep David and myself informed as they progress within this group. The group is being headed up by
- An application to MSHA is expected within the next six weeks for a electronic permissible engine. It was agreed that we would pass information on to each other as applications were submitted.
- It was agreed that this is a large problem for the industry and due to the limited number on engines being used, both countries should try and use a similar criteria although not identical paths.
- Australia has approved the Cat 3126 MUI engine. MSHA are in the process for type A approval but has no application for a power package.
- DBT Australia Pty Ltd will send their approved Australian 3126 MUI power package to MSHA for review and comment before any modifications are carried out.
- MSHA are in the process of evaluating the IEC electrical standards for relevancy against 30 CFR.
- Part ‘6’ of the revised regulation deals with testing and evaluation by independent laboratories.
- Carried out inspection of their electrical and filter testing facilities.

7.0 4 August 2003 – Visit to Galatia Mine

7.1 General Mine Information

- The Galatia Mine, in Illinois produces 14 million US ton of ROM coal per year at 50% yield (7 million US ton of washed coal).

- The mine has two separate entries, the North Portal and the Millennium Mine. These entries are not joined underground. We went down the North Portal to a development unit.
- 800 people are employed
- The mine is a non-union mine
- The mine is 150 to 300m below ground. The working seam is 1.7m high.
- There was 180 pieces of diesel equipment in the mine
- Planned production was 24 hours per day, seven days per week.
- Manning was four crew seven day rotation roster for three shifts. Roster was 7 days, 2 off, 7 afternoons, 2 off, seven nights, 3 off.
- Each shift was 8 hour with changeover at the face. Resulted in generally 10 hour days, was 35 min travelling to face.
- Emergency egress was to a return materials shaft. A crane would be brought in to lower or raise materials and bring people out of the mine in an emergency.
- Noticeboard – Citations for the month was 71. Citations for the year to date were 320. I was told the first citation was not a usually fine, just a notice to get something fixed.

Longwall

- The mine operated two longwalls of 260m width and six development units. One longwall and three units at each mine entry.
- One down shift to carry out power moves (belt, power & service retractions) in the longwall was planned.

Development

- Development was cut and flit. Cut-out distance was generally 3.5m (10ft).
- Unit operated with a Joy 12CM15 or 14CM15 continuous miners
- No auxiliary fan used, brattice (forced) ventilation was used.
- Pillar centres were 55m with headings @ 5.5m wide
- Roof bolting was spot bolting only, not straps or mesh, at 1m centres and 4 wide.
- There was no rib bolting.
- Manning in unit generally; 11 people. 2-4 roof bolt operators, 3-4 ram car operators, 2 miner operators, 1 scoop operator & 1 foreman (deputy)
- Advancement was stated as 30 to 45m per shift.

Belts

- Longwall belts were 1200 mm wide at 4.1m/s
- Trunk belts were 1600mm wide at 4.1 m/s

Diesel's

- The mine operated 180 pieces of diesel equipment. I was unable to get a detailed split of these. The engineer in charge of the diesel was called away when we came out of the mine. My understanding is approximately ¼ would be permissible and ¾ would be non-permissible.
- Diesel in each unit included 4 x Ram cars, 1 x scoop, Supply vehicle, Man trips (transporters). One vehicle is set up as a portable lubrication centre.
- The man trip, which we drove into the unit in, was a nonpermissible vehicle c/w Isuzu QD engine. It had a Platium based catalytic converter for filter removal.

- Two filter fires have occurred at this mine. Both with ram cars that run out of water in the scrubber.
- Filters on the rams cars where changed every shift. They were the Donaldson paper type.
- All permissible and non-permissible equipment has fire suppressions systems fitted.
- Diesel welders were used underground.
- Weekly gas checks on CO, NO & NO_2 were carried out by the mines safety department rather than the diesel maintenance department.
- CO was done as raw exhaust with limit as stated by testing person as 2,500 ppm.
- CO, NO & NO_2 was checked at the operators cabin. Limits stated by testing person was CO – 25 ppm, NO_2 – 3ppm & NO – 35ppm
- Gas checks were done with an electronic device, 'Industrial scientific T80 for NO_2 & CMX270 for CH_4, CO & O_2.

8.0 Recommendations

Following the visit to America and reviewing their system it is recommend NSW does not adopt the American regulatory requirements in respect to diesel engine emissions. Reasons for this are:

- The American 30 CFR regulations are not risk based. NSW legislation is Occupational Health and Safety based.
- The 2.5g/hr limit on permissible diesel engine systems in coal mines does not look at the overall risk in the mine. It was intended to force operators to install particulate filters. There is no methodology for evaluating risk of exposure or compliance to the rule for in service diesel engines.
- The 2.5 g/hr does not consider all of the other things, which need to be managed to reliably control, the pollutants from diesel engines. These are just as important as filters in diesel pollutant reduction.
- The 2.5 g/hr limit penalises larger engines and is more lenient for smaller engines. It also does not consider particle size distribution, fuel type and mass flow of air through the engine for dilution.
- The ventilation index is based on an exposure of $1mg/m^3$ DP. This is 5 time higher than the average global recommended exposure limit of $0.2mg/m^3$. There is no correlation between this particulate index and the 2.5 g/hr limit.

Whatever strategy is adopted in NSW it must be risk based. One thing that is certain, the lower the DP and NO_2 emissions the lesser the probability of health effects to people. There is a trade-off between NO_2 and DP on engine performance, this must be managed and a 2.5g/hr limit does not achieve this.

The American's have taken a better approach with the metal and non-metal mines by setting both a staged exposure limit plus controlled the amount of emissions being generated at the source by the diesel engine. This is a good risk based strategy. The problem with this is measuring DP in a coal mine is more difficult due to the coal dust content. But this can be overcome.

An appropriate strategy for both NSW coal and metalliferous mines includes:

- Firstly MDG 29 needs to be updated, through a consultative process, to incorporate all diesel pollutants and both underground coal and metalliferous mines.
- MDG 29 should provide guidance on developing management systems to identify, evaluate, control and monitor diesel emissions on minesites.
- A diesel pollutant management plan should be mandatory for all coal and metalliferous underground mines. The mine management plan should show how the mine complies with the regulated exposure limit.
- The NSW minerals council recommended exposure limit of 0.2 mg/m^3 should be adopted as a universal standard. This may need to be implemented by a stagged approach over a couple of years. Periodically monitoring of particulate in the mine atmosphere needs to be carried out.
- Manufacturers of DES should be required demonstrate how the pollutant limits (including DP of $0.2mg/m^3$) can be achieved by using practical ventilation rates or the $0.06m^3/kW$ as currently required by legislation. This is an occupational, health and safety duty of equipment manufacturers. It should be able to be supported by adequate engine dynamometer testing. In addition a staged approach for compliance of existing engines should also be implemented. To achieve this all engine types being should be tested for gravimetric particulate emissions on the ISO cycle. This needs to be able to be carried out at TestSafe.
- Consideration should be made to gaseous ventilation rates being varied based on the raw exhaust emissions at dynamotor testing. This is risk based and would allow lower ventilation quantities for modern electronic engines. It would also promote the use on modern engines.
- To control the hazard at the source, all new engines approved should meet the EPA tier criteria relevant at the time of approval. There should be a 12 month lag behind the EPA's implementation.
- The diesel fuel notice should be updated to reflect current practices.
- Electronic engines should be promoted. If not there will be not be any engines available to the industry after 2006. Electronic engines are mush cleaner than existing engines, however they are not the singular solution for the control of diesel pollutants in underground mines.
- The explosion protection assessment of electronic engines will be a difficult task due to temperature and electrical issues. It is important that both Australia and America follow similar paths on this issue. We should maintain contact with MSHA on any future developments.

Peter Sunol
Mine Safety Officer – Mechanical Engineering

3 September 2003

Report on Visit to America August 2003

List of Abbreviations used in this Report

ACERT^{TM}	Advanced combustion emission reduction technology
ACGIH	American Conference of Governmental Industrial Hygienists
C	degrees Celsius
Category 'A'	Engines used on permissible equipment
Category 'B'	Engines used on nonpermissible equipment
CFR 57.5060	Limit on Concentration of diesel particulate matter
CFR 57.5062	Diesel particulate matter control plan
CFR 57.5067	Engines
CFR 57.5071	Environmental monitoring
CFR 7.84	Technical requirements
CFR 7.86	Test equipment and specifications
CFR 7.88	Test to determine the gaseous ventilation rate
CFR 7.89	Test to determine the particulate index
CFR 72.500	Emission limits for permissible powered equipment
CFR 72.501	Emission limits for nonpermissible heave-duty diesel-powered equipment, generators and compressors
CFR 72.502	Requirements for nonpermissible light-duty diesel-powered equipment other than generators and compressors
CFR30	Code of Federal Regulations volume 30, 'Mineral Resources'
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DDEF	Disposable Diesel Exhaust Filter
DES	Diesel Engine System
DMR	Department of Mineral Resources NSW
DP	Diesel Particulate
DPF	Diesel Particulate Filter
DPM	Diesel particulate Matter
EC	Elemental Carbon
ECM	Electronic Control Module
EGR	Exhaust Gas Recirculation
EPA	Environmental Protection Authority
EUI	Electrical Unit Injection
H_2O	Water
H_2SO_4	Sulphuric acid
HC	Hydrocarbon
heavy duty	includes nonpermissible equipment that; cuts or moves rock or coal, performs drilling or bolting operations, moves longwall components, fuel and lube transport units,
light duty	includes nonpermissible that is not heavy duty.
MDG 29	Mechanical Design Guideline No.29, 'Guidelines for Diesel and Operator Environment Testing in Underground Coal Mines'
MSHA	Mine Safety and Health Administration

MUI	Mechanical Unit Injection
NIOSH	National Institute for Occupational Health and Safety, America
NMHC	Nonmethane Hydrocarbons
NO	Nitrous Oxide
NO_2	Nitrous Dioxide
NO_x	Oxides of Nitrogen
NSW	New South Wales
O_2	Oxygen
OC	Organic Carbon
OEM	Original Equipment Manufacturer
OH&S	Occupational Health and Safety
permissible equipment	Diesel or electrical operated equipment taken in top or used inbye the last open crosscut of an entry.
PIB	Program Information Bulletins from MSHA, See www.msha.gov/01-995/dieselpart.HTM and follow either coal or nonmetal link
SO_2	Sulphur dioxide
SO_3	Sulphur trioxide
SOF	Soluble Organic Fraction
STEL	Short Term Exposure limit
$T_{30\%}$	Engine exhaust temperature for 30% of the operating time
TC	Total Carbon
TWA	Time Weighted Average - normal over eight hour period
ULSF	Ultra Low Sulphur Fuel < 15ppm
VERT	Verminderung der Emissionen von Realmaschinen im Tunnelbaui