19th Annual MDEC Conference

Diesel emission in underground mining – A program for control, shared learning from Queensland, Australia.

Kevin Hedges, CIH, COH

Weight of the evidence or Wait for the Evidence? Protecting Underground Miners from Diesel Particulate Matter

"It doesn't look to *me* like it could do any chromosomal damage."

“Approximately 10% of all deaths in the industrialised world are due to lung cancer”

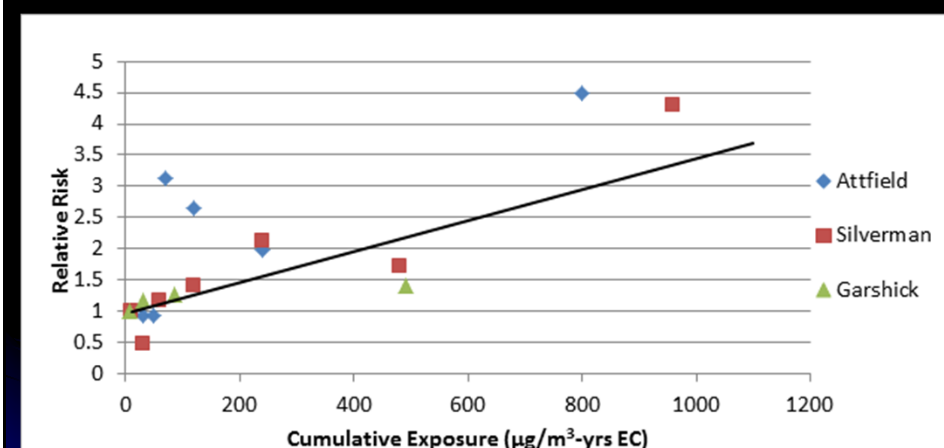
Professor Jimmy L Perkins
University of Texas - 2005

“Importantly, if the relative risk of lung cancer after diesel exposure is increased to 1.2, this means that the fraction of deaths caused by lung cancer would increase from **10% to 12%.** Within a large multi-national company this would amount to **few or perhaps as many as 10 deaths per year”.**

Professor Jimmy L Perkins
University of Texas - 2005

Study	Risk per 1000 µg/m³-yr EC	Notes
i. Attfield et al. (2012)	3.62 (1.99 – 6.60)	15-year lag, restricted to <1280 µg/m³-yrs, excl <5yr tenure
ii. Silverman et al. (2012)	3.46 (no CIs reported)	From 15-yr lagged linear-exponential model in Suppl Table 1 at CE=1000 µg/m³-yr EC; excluded from pooled estimate
iii. Garshick et al. (2012)	2.77 (0.85 – 9.00)	10-yr lag, excl. mechanics
Overall	3.45	Inverse-variance weighted, i & iii only

Courtesy of - Joanne Kim, MPH Research Associate |
Occupational Cancer Research Centre



Courtesy of - Joanne Kim, MPH Research Associate |
Occupational Cancer Research Centre

Diesel Exhaust Lung Cancer Risk Calculator

years of exposure	16	years	years exposed	16	years
average respirable elemental carbon (REC) exposure (in μg/m^3)	100	μg/m^3	exposure concentration	100	μg/m^3
year lagged cummulative respirable elemental carbon exposure (in μg/m^3-yrs)	100	μg/m^3 - years	cumulative exposure	100	μg/m^3 - years
model estimated odds ratio (OR) =	1.26		**lung cancer odds ratio**	1.41	

model taken from: Debra T. Silverman, Claudine M. Samanic, Jay H. Lubin, Aaron E. Blair, Patricia A. Stewart, Roel Vermeulen, Joseph B. Coble, Nathaniel Rothman, Patricia L. Schleiff, William D. Travis, Regina G. Ziegler, Sholom Wacholder, and Michael D. Attfield, "The Diesel Exhaust in Miners Study: A Nested Case–Control Study of Lung Cancer and Diesel Exhaust", J Natl Cancer Inst **104**:855-868 (2012) - Supplementary Data II (available online at: http://jnci.oxfordjournals.org/content/suppl/2012/01/28/djs034.DC1/Supp_methods_and_tables_4-30-12.pdf)

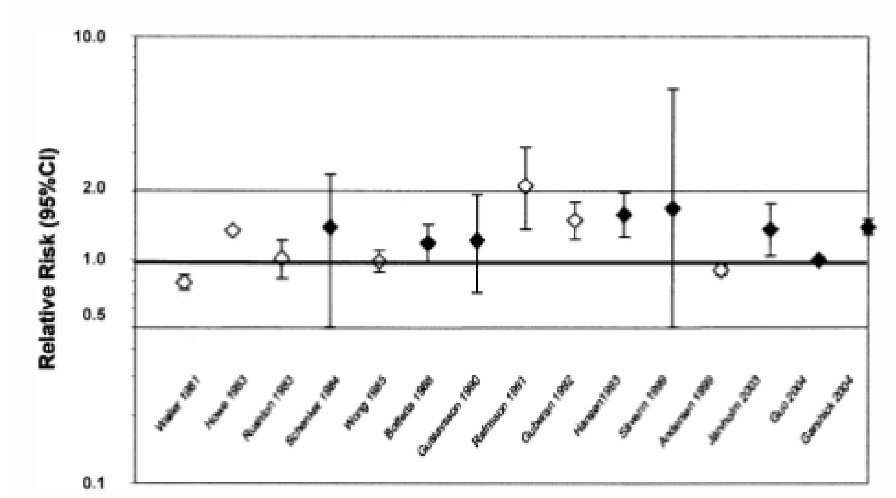
Courtesy of – John Oudyk, MSc CIH ROH
Occupational Hygienist Occupational Health Clinics for Ontario Workers

Diesel Exhaust Lung Cancer Risk Calculator

years of exposure	16	years	years exposed	16	years
average respirable elemental carbon (REC) exposure (in μg/m^3)	308	μg/m^3	exposure concentration	308	μg/m^3
year lagged cummulative respirable elemental carbon exposure (in μg/m^3-yrs)	308	μg/m^3 - years	cumulative exposure	308	μg/m^3 - years
model estimated odds ratio (OR) =	1.91		**lung cancer odds ratio**	2.11	

model taken from: Debra T. Silverman, Claudine M. Samanic, Jay H. Lubin, Aaron E. Blair, Patricia A. Stewart, Roel Vermeulen, Joseph B. Coble, Nathaniel Rothman, Patricia L. Schleiff, William D. Travis, Regina G. Ziegler, Sholom Wacholder, and Michael D. Attfield, "The Diesel Exhaust in Miners Study: A Nested Case–Control Study of Lung Cancer and Diesel Exhaust", J Natl Cancer Inst **104**:855-868 (2012) - Supplementary Data II (available online at: http://jnci.oxfordjournals.org/content/suppl/2012/01/28/djs034.DC1/Supp_methods_and_tables_4-30-12.pdf)

Figure 1.0 (Source: Hoffman 2006, page 256)



Cited in Hedges et al, 2007 http://qrc.org.au/conference/?page_id=527

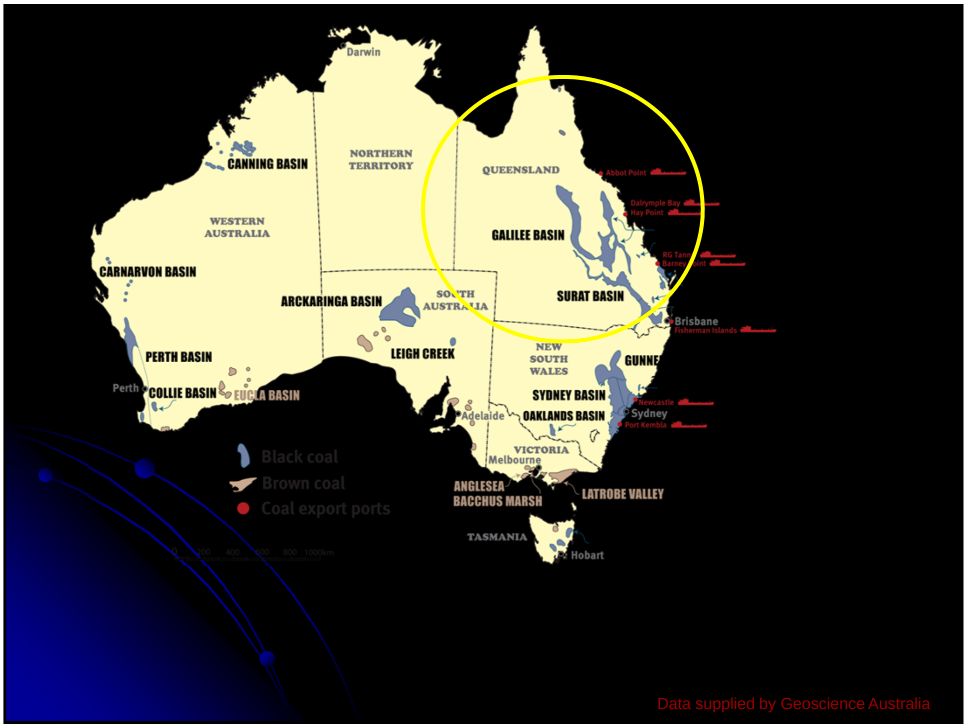
Caveat

"A number of preliminary toxicological studies have been conducted on diesel emissions from contemporary post 2007 diesel engines. The Advanced Collaborative Emissions Study (ACES) found **no changes in DNA and only mild inflammatory effects in the lungs of rats and mice exposed**"
(HEI, 2012, cited in AIOH, 2013 position paper)

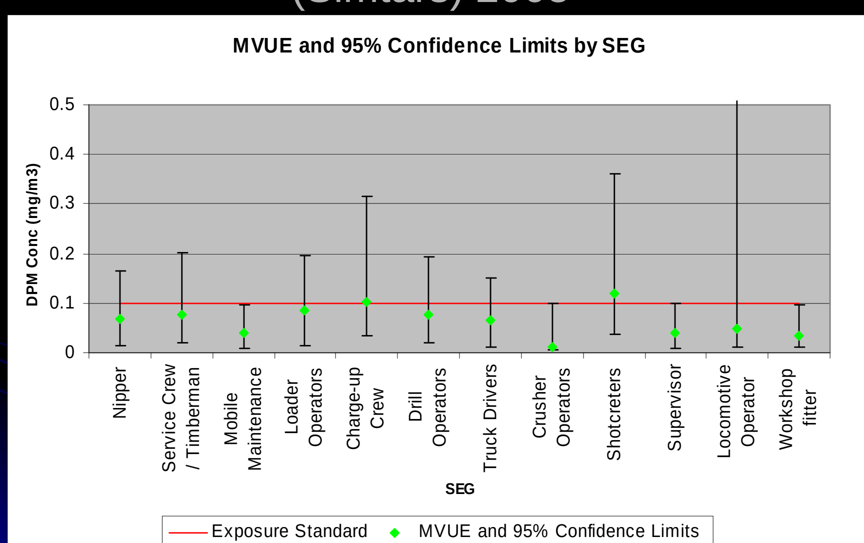
"The altered chemical emission profile found with contemporary engines, improved mining ventilation and improved fuels is now quite different to past DPM exposures upon which the epidemiology studies were based".

Australian Institute of Occupational Hygienists (AIOH) position paper (2013):

http://www.aioh.org.au/downloads/documents/PositionPapers/AIOHPostionPaper_DPM.pdf



Baseline study carried out by G Irving (Simtars) 2005



Questionnaire Feedback 2005

Main gaps from questionnaire responses.

Parameter:	Sulphur in fuel	Ventilation	Maintenance	
Mine Id	Nominal sulphur (ppm)	Secondary ventilation design rate (m3/s/kW)	Exhaust back pressure monitored.	Procedure to diagnose after exhaust treatment.
8	45	0.05	No	Yes
7	45	0.05	No	Yes
6	45	0.05	No	Yes
5	500	0.06	No	No
4	500	0.06	No	Yes
12	<500	0.05	Yes	Yes
10	500	0.04	No	Yes
1	100	0.04	No	No
9	320	0.04	No	No
11	Not reported	0.05	Yes	Yes
3	200	0.04	Yes	No

Parameter	National standard	Date of effect	Test Method
Biodiesel [1]	5.0% volume by volume (max)	1-Mar-09	EN 14078
Sulfur	500 ppm (max)	31-Dec-02	ASTM D5453
	50 ppm (max)	1-Jan-06	
	10 ppm (max)	1-Jan-09	
Cetane Index	46 (min) index	1-Jan-02	ASTM D4737
Derived Cetane Number (of diesel containing biodiesel)	51.0 (min)	21-Feb-09	ASTM D6890
Density	820 (min) to 860 (max) kg/m^3	1-Jan-02	ASTM D1298
	820 (min) to 850 (max) kg/m^3	1-Jan-06	
Distillation T95	370°C (max)	1-Jan-02	ASTM D86
	360°C (max)	1-Jan-06	
Polyaromatic hydrocarbons (PAHs)	11% m/m (max)	1-Jan-06	IP391
Ash	100 ppm (max)	1-Jan-02	ASTM D48
Viscosity	2.0 to 4.5 cSt @ 40°C	1-Jan-02	ASTM D44
Carbon Residue (10% distillation residue)	0.2 mass % max	16-Oct-02	ASTM D4530
Water and sediment	0.05 vol % max	16-Oct-02	ASTM D2709
Water (all diesel containing biodiesel)	200 mg/kg (max)	21-Feb-09	ASTM 630
Conductivity @ ambient temp	50 pS/m (Min) @ambient temp (all diesel held by a terminal or refinery	16-Oct-02	ASTM

http://www.environment.gov.au/atmosphere/fuelquality/standards/diesel.html

UNITED STATES DEPARTMENT OF LABOR

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Mine Safety and Health Administration

MSHA - Protecting Miners' Safety and Health Since 1978

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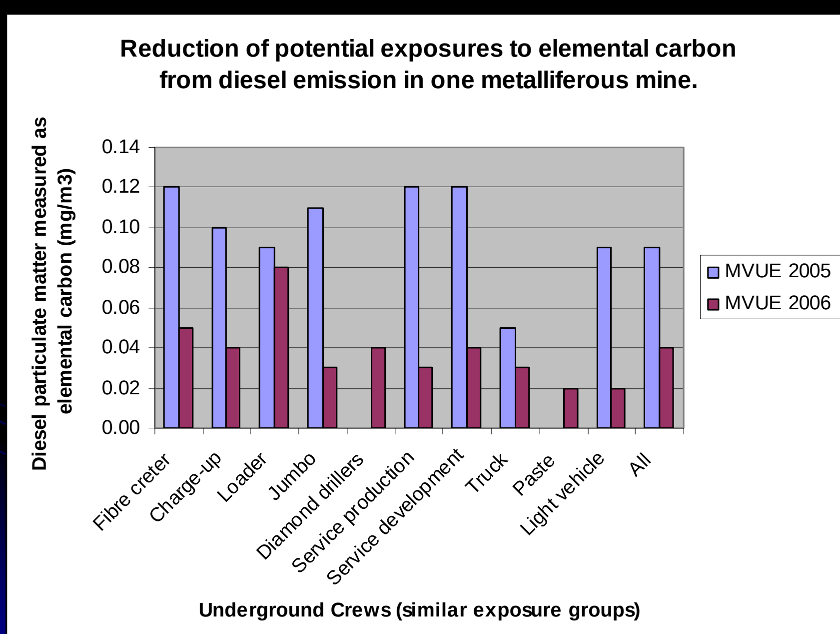
Approval Number	Engine Manufacturer	Model	HP @ RPM at 1000ft Elevation	Ventilation Rate CFM	Particulate Index CFM	DPM grams/hr weighted	DPM grams/hp-hr weighted	Filter Eff. for 5.0 grams/hr
07-ENA030001	MITSUBISHI	S4S	63 @ 2500	3000	4500	7.65	0.26	35
07-ENA030002	PERKINS	404C-22 *RETIRED*	51 @ 3000	2500	3000	5.1	0.2	2
07-ENA040001	CUMMINS	QSB-155C	155 @ 2500	9000	5500	8.87	0.11	44
07-ENA040002	DEUTZ	BF4M2012	100 @ 2500	6000	3000	4.51	0.08	0
07-ENA040003	DEUTZ	BF4M2012C	127 @ 2200	5500	3000	4.52	0.07	0
07-ENA040003	DEUTZ	BF4M2012C	138 @ 2500	6500	3000	4.57	0.06	0
07-ENA040004	DEUTZ	BF4L 2011	78 @ 2800	6000	2500	3.7	0.08	0
07-ENA040004	DEUTZ	BF4M 2011	87 @ 2800	6000	2500	3.7	0.08	0

http://www.msha.gov/TECHSUPP/ACC/lists/lists.htm

Approval	Engine Ma	Model	HP @ RPM	Ventilatio	Particulat	DPM gram	DPM gram	Filter Eff.	Filter Eff.	Date Issued	EPA Compliant p	Exhaust BP Max Limit, in.H2O
07-ENA03(	MITSUBISI	S4S	63 @ 2500	3000	4500	7.65	0.26	35	67	10/22/2003	Y	41
07-ENA03(	PERKINS	404C-22 *I	51 @ 3000	2500	3000	5.1	0.2	2	51	12/20/2003	Y	40
07-ENA04(	CUMMINS	QSB-155C	155 @ 250	9000	5500	8.87	0.11	44	72	06/25/2004	Y	41
07-ENA04(	DEUTZ	BF4M2012	100 @ 250	6000	3000	4.51	0.08	0	45	07/12/2004	Y	40
07-ENA04(	DEUTZ	BF4M2012	127 @ 220	5500	3000	4.52	0.07	0	45	07/12/2004	Y	30
07-ENA04(	DEUTZ	BF4M2012	138 @ 250	6500	3000	4.57	0.06	0	45	07/12/2004	Y	30
07-ENA04(	DEUTZ	BF4L 2011	78 @ 2800	6000	2500	3.7	0.08	0	32	08/24/2004	Y	30
07-ENA04(	DEUTZ	BF4M 201:	87 @ 2800	6000	2500	3.7	0.08	0	32	08/24/2004	Y	30
07-ENA04(	DEUTZ	BF4L 2011	78 @ 2800	6000	2500	3.7	0.08	0	32	09/27/2005	Y	30
07-ENA04(	DEUTZ	BF4M 201:	87 @ 2800	6000	2500	3.7	0.08	0	32	09/27/2005	Y	30
07-ENA04(	DEUTZ	BF6M 101:	268 @ 230	12000	5500	9.24	0.06	46	73	08/24/2004	Y	30
07-ENA04(	CUMMINS	C8.3	185 @ 220	9000	14500	24.45	0.22	80	90	09/23/2004	N	41
07-ENA04(	DEUTZ	BF4M 101:	157 @ 220	6500	3000	4.88	0.06	0	49	09/15/2004	Y	40
07-ENA04(	DEUTZ	BF4M 101:	173 @ 230	7000	4000	6.2	0.07	19	60	09/15/2004	Y	40
07-ENA04(	DEUTZ	BF4M 101:	150 @ 230	7000	4000	6.2	0.07	19	60	01/11/2006	Y	40
07-ENA04(	DEUTZ	BF4M 101:	158 @ 230	7000	4000	6.2	0.07	19	60	01/11/2006	Y	40
07-ENA04(	DEUTZ	BF4M 101:	157 @ 220	6500	3000	4.88	0.06	0	49	01/11/2006	Y	40
07-ENA04(	DEUTZ	BF4M 101:	173 @ 230	7000	4000	6.2	0.07	19	60	01/11/2006	Y	40
07-ENA04(	DEUTZ	BF6M 201:	208 @ 250	9000	3500	5.58	0.05	10	55	09/16/2004	Y	40
07-ENA04(	KUBOTA	V2203-E2	48.4 @ 28(	2500	4000	6.36	0.27	21	61	10/06/2004	Y	34
07-ENA04(	DEUTZ	F2L 2011 (I	30.2 @ 28(	1500	2000	3.26	0.2	0	23	11/02/2004	Y	19
07-ENA04(	DEUTZ	F2M 2011	31.5 @ 28(	1500	2000	3.26	0.2	0	23	11/02/2004	Y	19

Participatory mines were asked to provide feedback on good practices since the survey and monitoring

- Poor performing engines were fitted with new injectors and in some instances removed from service.
- Active reporting of emission issues as part of pre-start.
- Reduced vehicles working in same area of mine.
- Scheduled maintenance of catalytic converters.
- In one mine it was noted that “where there is no cabin air conditioning then it is not operated”.



Feedback provided from mine

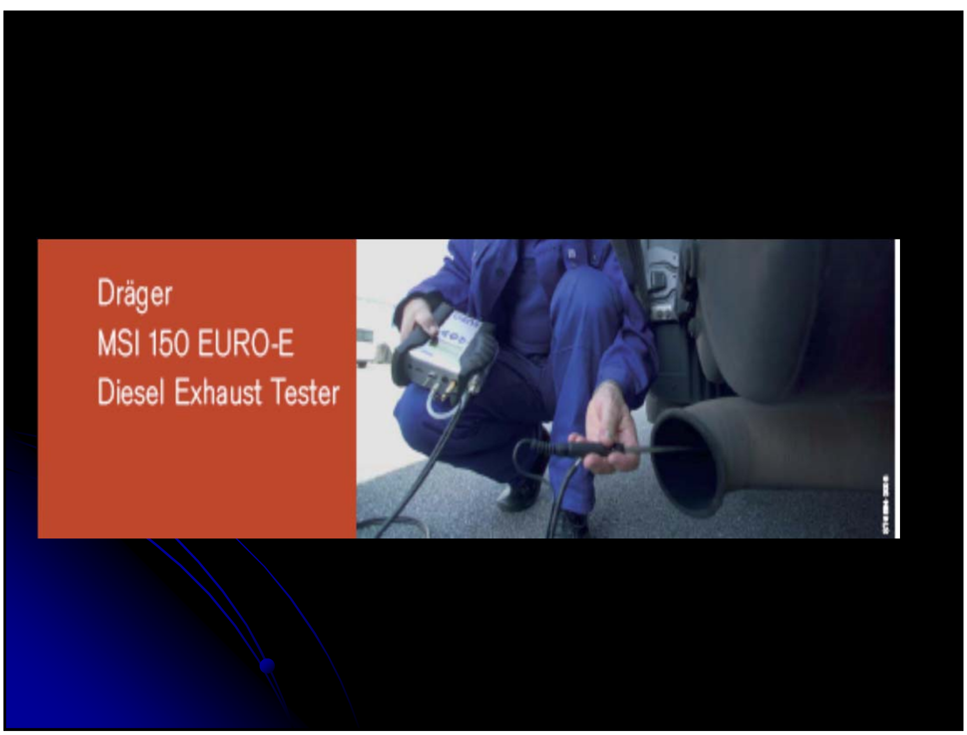
- Complete engine midlife service including replacement of injectors, turbo chargers and water pumps.
- Performance tests carried out every 2000 hours and that the air filters were routinely replaced and catalytic converters were inspected and tested at 250 hr. intervals.
- Since 2005 two full time dedicated personnel had also been assigned to monitor and improve the ventilation.
- Personal monitoring was also routinely being conducted at this mine.

Feedback provided from mine

- A multi disciplinary approach was employed.
- A six sigma black belt was assigned to lead the diesel reduction strategy.
- Personal exposure monitoring was utilized to identify deficiencies.

MEASURE, MEASURE, MEASURE

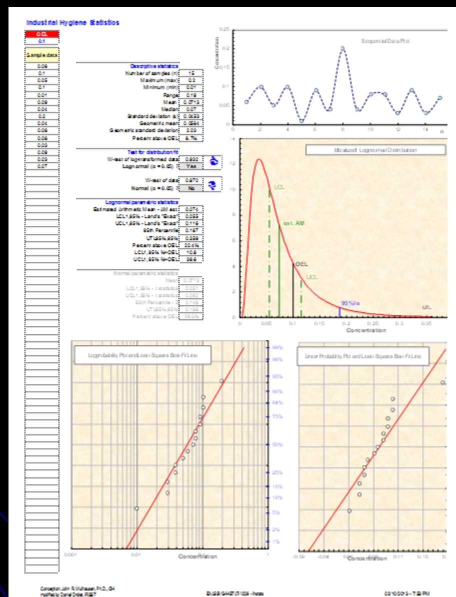

COAL MINES TECHNICAL SERVICES
MOBILE LABORATORY


Dräger
MSI 150 EURO-E
Diesel Exhaust Tester

Need to understand what the exposures are by carrying out a baseline exposure assessment for DPM measured as elemental carbon.

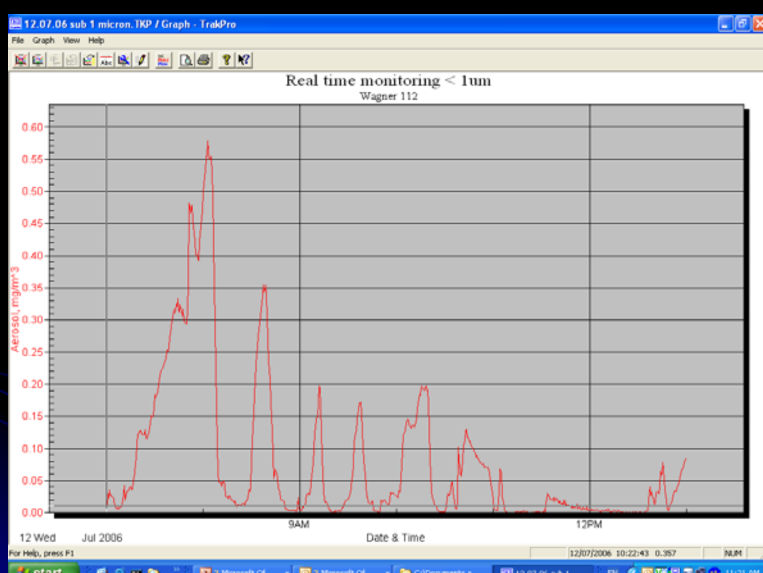
NIOSH 5040

Carry out statistical analysis to understand exposure profiles, identify outliers and risk rank exposure groups to prioritize controls.



http://www.aiha.org/get-involved/VolunteerGroups/Pages/Exposure-Assessment-Strategies-Committee.aspx

Carry out real time monitoring (inside cabin).



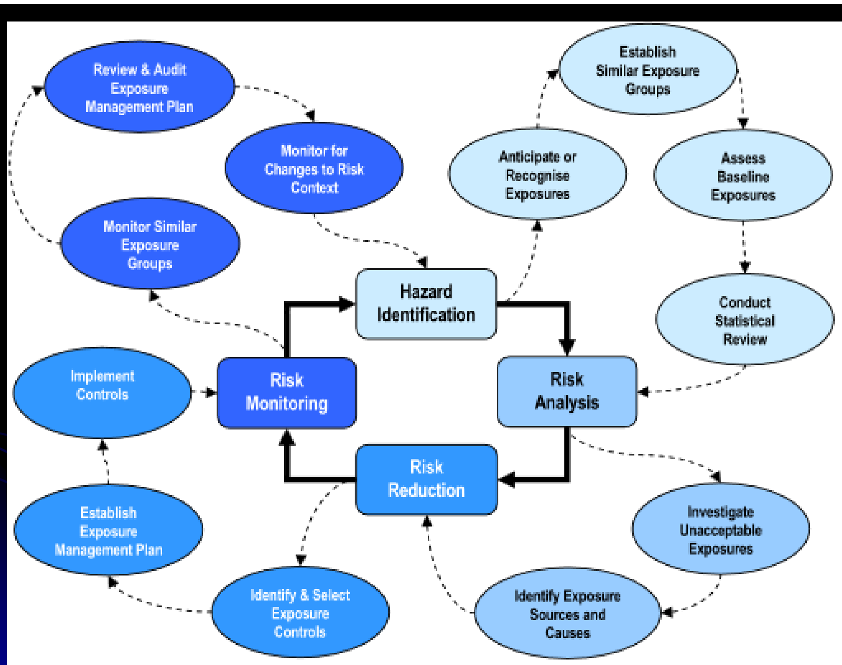
Average particulate matter 0.08 mg/m3.

Hierarchy of controls.

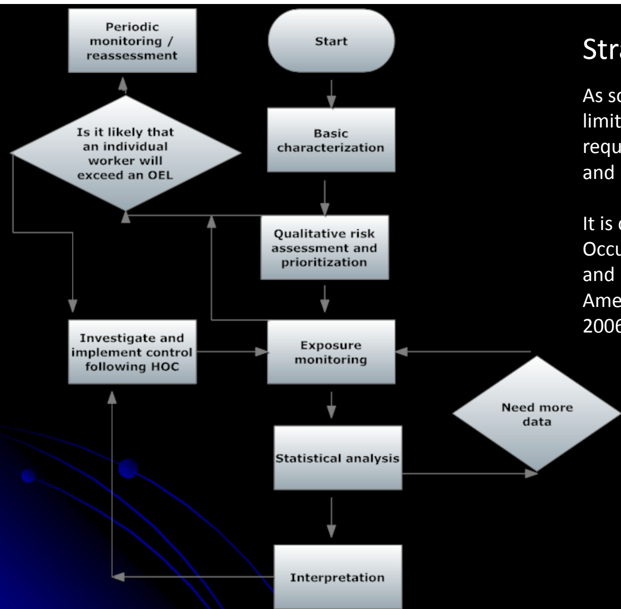
Hierarchy of control	Control measures (examples)
Elimination	Use of non-diesel powered vehicles.
Substitution	Use of biodiesel, biodiesel blend, use of ultra-low sulphur diesel fuel (ULSD)
Modification	Use of "higher technology level" off road, tier emission engines. Mid service-life major engine overhaul. Preventative maintenance. Remove the worker from exposure such as remote mucking from surface control rooms.
Containment	Enclosed diesel engine cabins with high efficiency filtered supply air.
Ventilation	Increased volume of primary, secondary / auxiliary ventilation. Reduced re-circulated air and where possible provision of single pass through ventilation.
Work practices	Training on preventative maintenance to fitters. Improved operating driving practices such as reduced idling. Pre-start checks. Storage and handling of diesel fuel. Rotation of workers.
Personal protective equipment	Respiratory protective equipment.

The primary control must be to control emission at source. A purchasing policy should consider low emission engines, diesel after-treatment devices, air-conditioned and filtered operator cabins, alternative power systems (eg. electric) and low emission fuel. It is also important that there **are requirements established for contractor or hire vehicles** to minimise exhaust emissions.

Risk management approach.



Source: Manthey, G, Djukic, F and Taylor, C, 2013



Strategy

As soon as an occupational exposure limit (OEL) is exceeded, this strategy requires operations to investigate and reduce exposure.

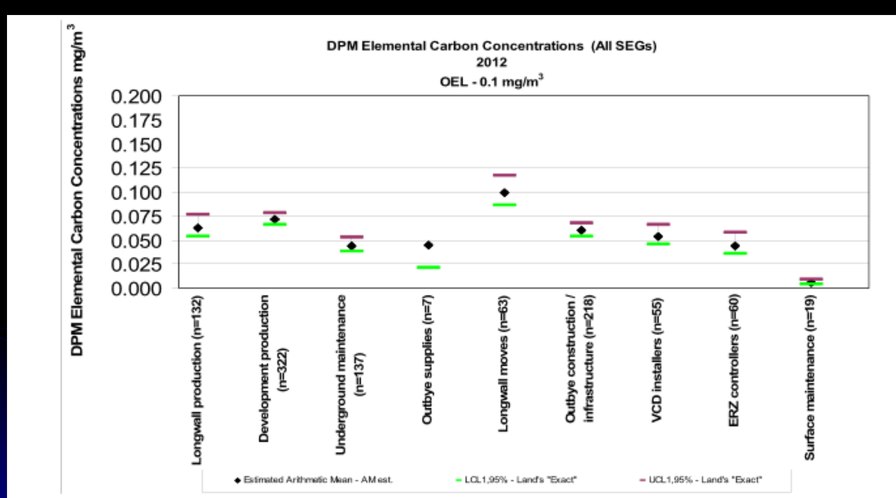
It is consistent with the joint British Occupational Hygiene Society (BOHS) and Netherlands strategy 2011 and American Industrial Hygiene (AIHA) 2006.

Source: Hedges, et al, 2012

Visibility to the highest level of management in a clear and concise way!

What gets measured gets noticed……

Can an Occupational Exposure Limit (OEL) of 0.1mg/m^3 (EC) be achieved?



Source: Manthey, G, Djukic, F, Taylor, C, 2013

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