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JOINT COAL BOARD HEALTH & SAFETY TRUST

RESEARCH PROJECT No. 20080

EXPOSURE TO DIESEL PARTICULATES UNDER VARIOUS OPERATING CONDITIONS IN QUEENSLAND UNDERGROUND COAL MINES

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PROJECT OUTLINE

1. RESEARCH QUESTION

The main study was designed to determine if different operating conditions in Queensland coal mines lead to higher workforce diesel particulate (DP) exposures than is found in NSW.

A secondary aspect was to provide information as to the extent of compliance in Queensland mines with the proposed occupational health exposure limits and if necessary the degree of controls which have to implemented to achieve compliance.

2. RESEARCH OBJECTIVES

The aim of the research is to;

- to measure workforce exposure to diesel particulates (DP) under various operating conditions in a number of Queensland coal mines.
- to relate the degree of exposure in the workforce to the work practices, machinery, maintenance practices, mine ventilation, fuel quality and other control strategies.
- to determine if exposures in Queensland coal mines differ from those in NSW coal mines, and if so why.

3. RESEARCH DESIGN

The project was initiated by numerous requests made by the Queensland Coal Mines Inspectorate for assistance in determining the extent of workforce exposures to diesel particulates. They were of the opinion that operating conditions such as working thicker seams with larger equipment may result in higher levels of diesel particulate than is experienced in NSW mines. After discussions with the inspectorate and a number of mining companies, four mines were selected to reflect various mining operations and conditions.

MINE	DIESEL FUEL	MINING ACTIVITY	SEAM HEIGHT
Southern (German Creek)	Shell Mining Fuel (not LED)	Long wall/general duties	2.5 - 3 m
Crinum	Eramanga (natural low sulphur)	Long wall/general duties	3.6 m
Alliance	Shell (UMF)	Punch long wall/general duties	2.2 m
Moranbah North	Shell (LED) Unknown fuel for contractors vehicles	Long wall development, general duties	~3 m

3.1 Field Program:

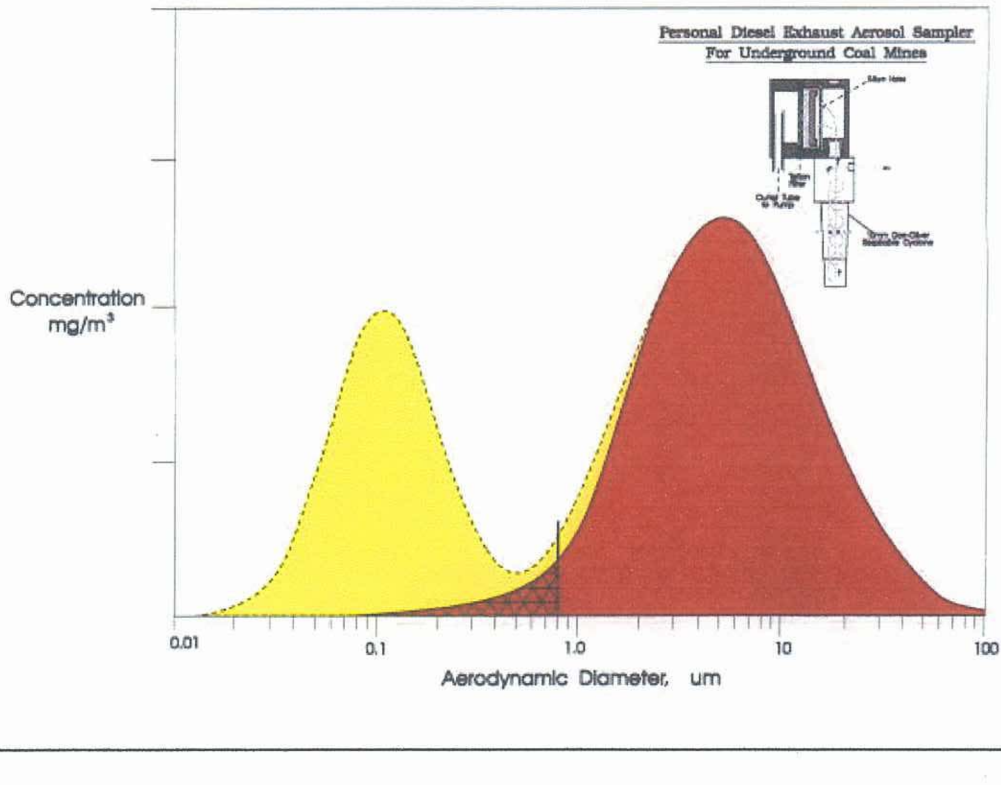
As far as possible full shift personal and area monitoring was conducted in a manner similar to the strategies employed at Tower Colliery and other underground coal mines in NSW. This covered routine coal mining activities as well as high diesel work such as long wall changes (Pratt et al 1993, Pratt et al 1995).

3.2 Diesel Particulate Capture

DP was sampled by collecting the sub-micron fraction of mine dust which has been found to consist mainly of diesel particulate matter (Rogers 1993). Research samplers currently in use have a two stage separation with a traditional respirable mass cyclone to remove the coarser fraction with subsequent splitting of the respirable size aerosol into the submicron fraction by the use of greased impactor plates (Cantrell 1992) or virtual impaction devices (Marple 1995). Due to the high pressure drop in some instruments low flow resistant open mesh Teflon® filters are used when only gravimetric and Scanning Electron Microscope analysis is required. For carbon species analysis, quartz fibre filters are necessary as the collection medium.

The sub micron samplers were constructed in the USA under contract to the specific engineering tolerances required to obtain exact particle cut-off at 0.8 um. Commercial versions of the instruments were not available at the time that project carried out. A commercial one-off sample disposable separation cassette is now available however it is still undergoing extensive field trials in the USA and we have just commenced trials on this instrument in Australian mines. The price is relatively high due to the requirements of exact size separation, precision machining with a cost per sample of A$160 for the sampler cassette which does not include analysis costs for carbon species.

The following diagram of a typical bimodal dieselised mine aerosol size distribution and the sub micron cut (red is mine/mineral dust and yellow is diesel particulate fraction)

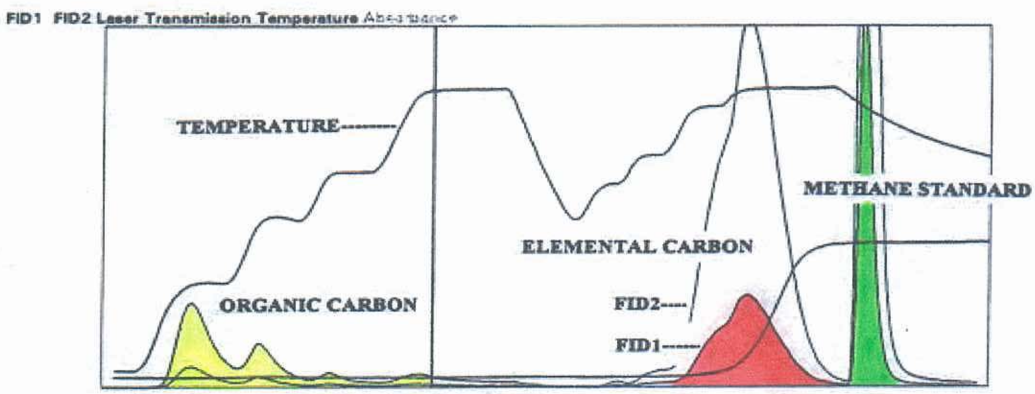


3.2 Analytical :

Diesel particulate matter is a complex mixture of many chemicals and there is no universal international method for the measurement of diesel particulate matter, although 3 systems of monitoring are currently being used throughout the world. The JCBHST NSW diesel particulate project is gathering data that allows comparison between exposures in NSW and Queensland to the various different exposure indices and exposure standards commonly measured by researchers and inspection agencies in USA, Canada and Europe.

Elemental carbon (EC) and organic carbon (OC) analysis was carried out by placing a punched section of the filter in an oxygen free helium atmosphere flow furnace. (Chow 1993, Bauer 1994). The temperature in the furnace was increased step wise (500°C to 700°C) to remove all organic carbon followed by carbonates. Pyrolised products are flushed off as CO_2 which is then catalytically converted to CH_4 for detection by the FID. The oven is cooled to 25°C, a mixture of 2% O_2/He introduced and the temperature raised in steps to 850°C to oxidise elemental carbon which is then converted to CH_4 for detection. Monitoring laser transmission through the filter during the cycle allows minimisation of interferences caused by elemental carbon formed during the pyrolysis of organic carbon. At the end of the cycle a known volume of CH_4 is injected into the furnace for calibration purposes. Analysis time is less than 10 minutes with a LOD of ~ 2 ug/m^3 and a working range of 5 - 300 ug/m^3 for 8 hour samples. The method is now formalised in the USA as NIOSH Method 5040 and forms part of the regulatory requirements listed by the Mine Safety and Health Administration (MSHA). Gravimetric determination was carried out in some instances on samples collected on Teflon® filters (these cannot be used for carbon species as they melt and char). Quartz filters which are excellent for carbon species analysis were found not to be suitable for gravimetric analysis due to their inconsistent electrostatic properties.

The following diagram shows a typical thermogram of diesel particulate sample collected on a quartz filter. The peaks of organic carbon and elemental carbon are quantified against the methane standard. Total carbon is also reported being the sum of elemental and organic carbon.



The indices of exposure used in the two JCBHST projects are;

DPM diesel particulate matter defined as sub micron fraction of mine aerosol measured as the mass of material captured in the US BOM sub micron impactor sampler.

EC elemental carbon content of the sub micron fraction of the mine aerosol captured in sub micron virtual impactor sampler measured by thermal optical carbon analyser (NIOSH Method 5040).

TC total carbon content of the sub micron fraction of the mine aerosol captured in sub micron virtual impactor sampler measured by thermal optical carbon analyser (NIOSH Method 5040).

EC/TC the ratio of elemental carbon to total carbon of the sub micron fraction of the mine aerosol captured in sub micron virtual impactor sampler measured by thermal optical carbon analyser (NIOSH Method 5040).

4. RESULTS

4.1 Individual Mines

Detailed reports as supplied to each of the mines are attached as appendices to this report.

In summary the results are as follows.

Moranbah North:

This mine was using new equipment (Ramcars and EJC 130) for place change mining in the development stage to prepare long wall headings. Dry Systems Technology control units (heat exchanger and paper filter element) were fitted to the diesel equipment operating in the development area. Some Eimco's carrying out LHD duties were fitted with the standard wet scrubber system. This was the second round of monitoring at the mine and difficult road conditions were still present. Levels of 0.14-0.32 mg/m^3 DPM, 0.068-0.100 mg/m^3 EC and 0.190-0.210 mg/m^3 TC were found during the period of monitoring which was similar to those found during the first monitoring exercise. The average elemental carbon (EC) to sub micron diesel particulate mass (DP) was found to be 0.42 which is similar to the ratios found in the first survey other diesel operated coal mines.

Tests were repeated to determine the efficiency of the Dry Systems Technology control units (heat exchanger and paper filter element) the results are as follows.

Mining Machine	Filtration Efficiency DP	Filtration Efficiency EC	Filtration Efficiency TC
Eimco # 7	52 %	51 %	24 %
Ramcar CH002	13 % *	50 %	28 %
Ramcar CH001 filter housing leaking	0 %	0 %	0 %

* lower value presumably due to sub micron coal dust interference in DP result

The filter on Ramcar CH001 was found to have an ineffective seal between the filter and the housing as indicated by the black soot stains on the external surface of the filter, CH002 and Eimco # 7 appeared visually to have no leaks around the external surface of the filter.

A similar survey conducted in May 1998 indicated a filtration efficiency based on DP of about 50% for the Ramcars and 0% for the EJC however there was no visual inspection of the interior of the filter housing to determine if any leakage existed.

The DST has been removed due to various operational requirements.

Testing of the Toyota 4 wheel drive transport vehicles indicated that these vehicles emitted very low levels of diesel particulate in comparison to larger traditional underground coal mine vehicles.

A later survey conducted on two Eimcos tramming road ballast in convoy under difficult conditions found elevated diesl particulate levels. Similar findings have been observed in NSW mines.

Crinum:

The second longwall move at the mine was monitored. Levels of 0.12-0.46 mg/m^3 DP, 0.090-0.299 mg/m^3 EC, and 0.046–0.402 mg/m^3 TC were found and are similar to the levels monitored during the first long wall move. The average elemental carbon (EC) to sub micron diesel particulate mass (DP) was found to be 0.38 which is at the lower end of the range of ratios found in other diesel operated coal mines.

Southern:

Exposures during general duty activities were monitored in July 1998. Results of 0.04-0.40 mg/m^3 DPM and 0.022-0.243 mg/m^3 EC and 0.074-0.364 mg/m^3 TC were obtained which are in the middle to lower end of the spectrum of results obtained from other mines. Average ratio EC/DP ratio was found to be 0.51 which is similar to results obtained from other Queensland and NSW coal mines.

Alliance:

The punch long wall change at this mine was studied. Results of 0.13-0.64 mg/m^3 DPM and 0.046-0.339 mg/m^3 EC and 0.108-0.575 mg/m^3 TC were obtaine. These are in the middle to upper end of the spectrum of results obtained from other mines. The average EC/DP ratio was found to be 0.51 which is similar to other Queensland and NSW coal mines.

4.2 Comparison of Exposures in Queensland versus NSW Mines

For simplification in this presentation, geometric means have been used in the analysis to express the "average" exposures to the various diesel particulate components in the mines.

Occupational and environmental exposure measurements have been found to follow a log normal distribution and a cursory examination of the diesel particulate data indicated similar distribution of exposure values. With such distribution of exposures, logarithmic transformation of the data provides a better method of statistically describing and comparing the data.

The following table summarises the range of geometric mean exposures obtained during long wall moves.

Table 1 Long wall moves (range of geometric mean of exposures for the mines)

	NSW mines	Queensland mines
DPM (mg/m^3)	0.22 - 0.43	0.18 – 0.28
DPM (mg/m^3) BHP 8 mine study	0.3 –1.7	na
EC (mg/m^3)	0.095 – 0.350	0.058 – 0.137
TC (mg/m^3)	0.210 – 0.440	0.147 – 0.246
EC/TC	0.45 – 0.80	0.38 – 0.51

BHP 8 mine study investigations carried out in NSW coal mines as part of an ACARP project 1995.

It would appear from the data in the table that the upper limit of exposures in Queensland is lower than that found in NSW. However this high value arises from one NSW mine where diesel equipment was operating under very difficult and boggy conditions. In addition the vehicles were not fitted with any specialised diesel particulate control technology and were using standard on the road diesel fuel (the mine has since implemented various control technologies and exposures have been reduced).

For general duty type activities, again exposures at the higher levels in NSW appear to be higher than those found in Queensland. However it was noted that the range of work and operating conditions varied considerably from mine to mine.

Table 2 General duties all activities monitored (range of geometric mean of exposures for the mines)

	NSW mines	Queensland mines
DPM (mg/m^3)	0.08-0.70	0.06 – 0.36
DPM (mg/m^3) BHP 8 mine study	0.05 – 0.60	na
EC (mg/m^3)	0.010 – 0.220	0.030 – 0.184
TC (mg/m^3)	0.032 - 0.488	0.056 – 0.266
EC/TC	0.38 – 0.57	0.42 – 0.72

BHP 8 mine study investigations carried out in NSW coal mines as part of an ACARP project 1995.

When the general duties data was split into light and heavy work loads the difference between the mines in the 2 States became less apparent.

Table 3 General duties light load / transportation (range of geometric mean of exposures for the mines)

	NSW mines	Queensland mines
DPM (mg/m^3)	0.08 – 0.12	0.06 – 0.09
DPM (mg/m^3) BHP 8 mine study	0.05-0.20	na
EC (mg/m^3)	0.012 – 0.070	0.030 – 0.053
TC (mg/m^3)	0.032 – 0.123	0.056 – 0.119
EC/TC	0.38 – 0.57	0.44 – 0.45

Table 4 General duties heavy work and development (range of geometric mean of exposures for mines)

	NSW mines	Queensland mines
DPM (mg/m^3)	0.10 – 0.70	0.17 – 0.36
DPM (mg/m^3) BHP 8 mine study	0.10 – 0.60	na
EC (mg/m^3)	0.010 – 0.220	0.061 – 0.184
TC (mg/m^3)	0.488	0.118 – 0.266
EC/TC	0.49	0.42 – 0.72

Overall a comparison of the exposure data for Queensland and NSW mines indicates that there is little difference in the range of geometric means between underground mines in the 2 states. Any such differences are more than likely to be due to differences in load conditions placed on the diesel equipment. In addition factors such as engine maintenance and fuel quality contribute to diesel particulate output.

The proportion of time spent on either light or heavy duties may vary between the two States. The current research methodology did not allow for testing such hypothesis beyond a general observation that the Queensland mines studied were younger and involved in more development work than those studied in NSW.

4.3 Compliance with Future Exposure Standards

Based on concerns for potential health outcomes various overseas health and mining authorities have seen fit to develop exposure standards for diesel particulates.

There is no legislative exposure standard for diesel particulate matter applicable to Australian coal mines. However the NSW Minerals Council on the basis of our research in NSW coal mines and some Australian metalliferous mines have recommended so as to minimise irritation, a level of 0.2 mg/m^3 DPM (~ 0.17 mg/m^3 Total Carbon). (NSW mineral Council 1999)

In January 2001, the USA based MSHA has produced a Final Rule on DPM for underground coal mines. (MSHA 2001) Compliance is based on two laboratory measurements; engine DPM emission factor plus the % DPM filtration efficiency of the emission control device installed on the engine to bring the engine DPM emission below 2.5 g/hr. It is expected that, in most cases, meeting the limit will require the use of particulate filters. Only the smallest engines will be able to meet the 2.5 g/hr limit without after-treatment. There is no requirement for in-mine testing of engine raw exhaust to determine if performance deteriorates.

MSHA has **not** established an exposure limit for the concentration of DPM found in the ambient air of coal mines. This we believe is due partly to the interference of sub-micron coal dust which results in some imprecision in assessing exposure. This imprecision would most likely make prosecution difficult under the US system although in the future there may be some in built acceptance of the variability of the method of measurement so as to make use of a practicable exposure standard.

In contrast at the same time, MSHA set a DPM exposure standard and testing requirements for underground metal and non-metal mines of 0.4 mg TC/m^3 (interim standard) with 0.16 mg TC/m^3 (by 5 years time). (MSHA 2001) In addition the US ACGIH, has posted Notice of an Intended Change for a TLV for diesel exhaust particulate applicable to general industry of 0.02 mgEC/m^3 measured as the submicron fraction and NIOSH method 5040.

With the current survey data it is not possible to determine the degree of overall day to day compliance of the with the proposed exposure standards. Much of the sampling was conducted at times to target and compare extreme work conditions such as long wall change outs. The trend in the results from Queensland mines parallels that found in NSW in that under conditions where engines are working hard, high diesel particulate loads are emitted into the mine atmosphere.

Under such hard operating conditions special attention needs to be paid to ensuring a multitude of control technologies are operating. (Pratt et al 1995, NSW Mineral Council 1999, Davies & Rogers 2001)

Proportion of Samples Collected during Selected Operations in Queensland Underground Coal Mines that Exceeded Specified Limits

Queensland Coal Mine	Range of Exposures TC mg/m^3	Number of samples taken on operators	% exceed MSHA & NSW Min Council 0.16 mgTC/m^3	% exceed MSHA 0.4 mgTC/m^3
A	0.074-0.364	29	38 %	7 %
B	0.046-0.402	28	54 %	7 %
C	0.108-0.575	9	56 %	22 %
D	0.070-0.210	29	48 %	0 %

In comparison, the following data has been obtained during similar surveys conducted in metalliferous mines throughout Australia. (Davies and Rogers 2001)

Australian Metaliferrous Mine	Range Exposures TC mg/m³	% exceed MSHA & NSW Minerals Council 0.16 mgTC/m³	% exceed MSHA 0.4 mgTC/m³
1	0.11-0.57	82 %	57 %
2	0.16-0.63	96 %	31 %
3	0.12-0.29	82 %	0 %
4	0.06-0.46	53 %	6 %
5	0.05-0.42	30 %	5 %
6	0.13-0.53	75 %	10 %

5. PUBLICATIONS AND PRESENTATIONS ARISING OUT OF THE RESEARCH

Rogers A and Whelan W, *Australian Research into Workforce Exposures to Diesel Particulates*, Joint Coal Board Diesel Particulate Seminar, Singleton, September 1998

Rogers A and Whelan W, *Comparison of Different Analytical Approaches for Measuring Constituents of Diesel Emissions in Australian Mines*, HEI Diesel Workshop, Stone Mountain, Atlanta, Health Effects Institute, Communication no 7, 149-156, 1999.

Joint Coal Board, *Diesel Particulate: Clearing the Air*, An educational video on the hazards and appropriate control methods associated with diesel particulate in the Coal Mining Industry. (video includes a brief coverage of some of the research findings), 1999

Rogers A and Whelan W, *Worker Exposure to Diesel Particulate Across a Range of Diesel Vehicle Usage*, NSW Joint Coal Board Health & Safety Trust: Project Seminars, Belmont 21 July 1999.

Rogers A and Whelan W, *Assessment of Exposures to Diesel Particulates in NSW and Queensland Underground Coal Mines*, NSW Joint Coal Board Health & Safety Trust: Project Results and New Project Seminars, Belmont 6th March 2001 and Moranbah 13th March 2001.

Rogers A and Davies B, *Diesel Particulate (soot) Exposures and Methods of Control in some Australian Metalliferous Mines*, Queensland Mining Industry Health and Safety Conference, Townsville, 8 pp, August 2001.

Davies B and Rogers A, *Diesel Particulates, Measurement, Exposure Standards and Control Technologies*, Professional Development Course, Proceedings 20th Annual Conference of AIOH, December 2001.

Joint Coal Board, www.jcb.org.au website has a summary of diesel particulate exposure results from various mines and mining activities associated with this project.

6. SUMMARY AND CONCLUSIONS

The research arose out of an original supposition put in the mid 1990's that differing mine operating procedures used in Queensland underground coal mines due to thicker seams and larger machinery would potentially result in higher exposures to diesel particulate emissions.

To test this hypothesis, field testing was conducted in a number of mines during the period mid 1998 to early 2001 under various operating conditions

Data obtained during long wall change outs indicated that the upper limit of exposures in Queensland mines is lower than that found in NSW. This difference was found to be due one NSW mine where diesel equipment was operating under very difficult boggy conditions, without the application of various control options. Otherwise there appears that there is little difference between the high to very high exposure levels experienced by mines in each state during long wall moves.

At first glance there appeared to be a difference between the mean values of exposure found in general duty type activities. The levels in NSW appear to be higher than those found in Queensland although it was noted that the range of work and operating conditions varied considerably from mine to mine. However when the general duties data was split into light and heavy work loads the difference between the mines in the 2 States became less apparent.

The overall results indicated that in general exposures to diesel particulate for specific mining operations in Queensland underground coal mines do not appear to differ greatly from the diesel particulate exposures found during similar operations in NSW underground coal mines. The findings may be confounded by differences between the mines in the proportion of time spent on either light or heavy duties or long wall moves as it was observed that the Queensland mines studied were younger and involved in more development work than those studied in NSW.

In each state during periods when the diesel machinery was subject to heavy load conditions, high diesel particulate levels were found. Such levels would exceed the proposed future exposure standards. Under such conditions there is a need to implement control strategies that involve a number of complimentary control technologies. These control technologies include ventilation, low emission fuel, engine emission testing, engine tune and maintenance programs, sensible driving attitudes and systems to control the number of vehicles in each panel.

Consideration should be given to compliance testing of the mine atmosphere and testing of gaseous and particulate raw exhaust emissions when adverse operating conditions are expected.

Recent research in a NSW has found that if the above control strategies are correctly implemented then exposure of the workforce to diesel particulates can be maintained below the level of approximately 0.16 mg/m^3 total carbon recognised by the NSW Mineral Council and MSHA in the USA.

7. REFERENCES:

Cantrell, B. K.; Rubow, K. L. (1992), *Measurement of Diesel Exhaust Aerosol in Underground Coal Mines.* In: Proceedings: Bureau of Mines Information and Technology Transfer Seminar, Minneapolis, MN, US Bureau of Mines, 11-17.

Chow J. Watson J. Pritchett L. Pierson W. et al. (1993), *The dri thermal/optical reflectance carbon analysis system: description, evaluation and application in US air quality Studies*, Atmospheric Environment 27A, 8, 1185-1201.

Marple V. Rubow K. Olson B. (1995), *Diesel Exhaust / Mine Dust Virtual Impactor Personal Aerosol Sampler: Design, Calibration and Field Evaluation*, Aerosol Sci, 22, 140-150.

MSHA (2001) US Department of Labour Mine Safety and Health Administration, *Diesel Particulate Matter Exposure of Underground Metal and Nonmetal Miners* 30 CFR Part 57, Federal Register, 66, No 13, January 19, 2001.

MSHA (2001) US Department of Labour Mine Safety and Health Administration, *Diesel Particulate Matter Exposure of Underground Coal Miners* 30 CFR Part 72, Federal Register, 66, No 13, January 19, 2001.

NIOSH (1995), *Elemental Carbon (Diesel Exhaust)* Manual of Analytical Methods, Draft 1/15/95.

NSW Mineral Council (1999), *Diesel Emissions in Underground Mines: management and Control.*

Pratt, S.; Todd, J.; Davies,B.; Rogers, A. (1993), *Diesel Particulate Exhaust Emissions, Worker Exposure and Control Technology in Some Australian Underground Mines*, In Minesafe International, Chamber of Mines and Energy of Western Australia, 23 March 1993, 57-70

Pratt S, Grainger A, Todd J, Meena G, Rogers A, Davies B (1995), *Evaluation and Control of Exposure to Diesel Particulate at Several Australian Coal Mines*, Second International Conference on the Health of Miners, Pittsburgh November 11-13, 1995, Appl Occup Environ Hyg, 12(12), 1997

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