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HEALTH & SAFETY LABORATORY

Controlling and Monitoring Exposure to Diesel Engine Exhaust Emissions in Coal Mines

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EXECUTIVE SUMMARY

Most coal mines use diesel powered vehicles and equipment underground and consequently, in the confined spaces of a mine, the potential for worker exposure to diesel engine exhaust emissions (DEEEs) is high.

This document provides practical advice on how to control exposure to diesel engine exhaust emissions in coal mines and so protect the health of employees. It details an on-site method which allows mines to measure for themselves general body or personal exposures to DEEEs and so be able to confirm that any controls in place are still effective and that exposures are being kept to a minimum in line with the Control of Substances Hazardous to Health (COSHH) requirements.

1 INTRODUCTION

This document provides practical advice on how to control and measure exposure to diesel engine exhaust emissions (DEEEs) in coal mines, and so protect the health of employees and others who may be exposed.

2 DIESEL ENGINE EXHAUST EMISSIONS

Diesel Engine Exhaust Emissions (DEEEs) contain a complex mixture of gases, vapours, liquid aerosols and particulates. These substances are the products of combustion and the major constituents are listed below:

- Nitrogen (N_2)
- Carbon Dioxide (CO_2)
- Water (H_2O)
- Carbon Monoxide (CO)
- Oxides of nitrogen e.g. Nitric Oxide (NO) & Nitrogen Dioxide (NO_2)
- Oxides of sulphur e.g. Sulphur Dioxide (SO_2)
- Various hydrocarbons
- Alcohols, Aldehydes, Ketones
- Particulates (soot)
- Polycyclic aromatic hydrocarbons (PAHs)

Exhaust emissions from diesel engines are usually more visible than those emitted from petrol engines because they contain over ten times more soot particles. In general diesel engines produce less carbon monoxide than petrol engines but more oxides of nitrogen, oxides of sulphur (although very little with modern low sulphur fuels), aldehydes and particulate matter.

The soot particles associated with diesel engine exhaust are extremely fine with aerodynamic diameters less than 1 micrometre. They consist of an elemental carbon (EC) core comprising 40 – 80% of the particle mass onto which are adsorbed hundreds of organic substances, referred to as organic carbon (OC), some of which are potentially harmful to health.

The quantity and composition of DEEEs depend mainly on:

- The type of engine e.g. direct or indirect injection, turbocharged or non-turbocharged;

- Whether the engine has been regularly maintained and tuned;

- The specification and type of fuel used;

- The workload demand on the engine, e.g. whether the engine is required to work near to its capacity;

- The engine temperature, e.g. starting from cold.

3 HEALTH EFFECTS

There are essentially two health issues associated with exposure to DEEEs. In the short term, exposure to high concentrations of DEEEs will cause irritation of the eyes and respiratory tract. Nitrogen oxides, sulphur oxides and aldehydes are all respiratory irritants and are present in DEEEs. It is probable that they all contribute to the overall problem and the ultrafine soot particles may also be a contributory factor.

In the long term there is some evidence to indicate that sustained exposure to DEEEs may slightly increase the risk of lung cancer. Research has shown that this is due to the fine, often ultrafine, soot particles associated with DEEEs and the substances absorbed onto them.

4 LEGISLATION

The HSE believes there is insufficient evidence for DEEEs to be classed as a carcinogen and at present in the UK there are no occupational exposure limits for DEEEs. However, under the Control of Substances Hazardous to Health Regulations[1], DEEEs are classed as a substance hazardous to health and as such these require that exposure be prevented or, where this is not reasonably practicable, adequately controlled. To achieve this the law requires that employers make a suitable and sufficient assessment of the risks to health which arise from exposure to hazardous substances, such as DEEEs, and that the necessary steps are taken to prevent or adequately control exposure.

[1] The Control of Substances Hazardous to Health Regulations (Fifth Edition, 2005)
Her Majesty's Stationery Office, ISBN 0 7176 2981 3

5 WORKPLACE EXPOSURE

The potential for worker exposure to DEEEs in mines is greater than in surface industries. With large diesel powered equipment operating in confined spaces it is inevitable workers, especially drivers and those working close to or down ventilation of the diesel engine, will be exposed to DEEEs. It is important that this exposure is properly controlled.

6 MEASURING EXPOSURE TO DEEES

6.1 INTRODUCTION

As outlined above, DEEEs consist of a complex mixture of gases, vapours and particulates and deciding which component or components to monitor to provide a representative measure of exposure to DEEEs is difficult and different components have been used in the past. However, one method which is thought by many to be the best is to collect, using a respirable cyclone sampler, a sample of airborne diesel soot particulate onto a quartz filter and to analyse the exposed filter for carbon; both the organic carbon (OC) associated with the absorbed organic substances and elemental carbon (EC) from the soot cores themselves. Research has shown that the diesel particulate EC concentration provides a good surrogate measure of exposure to DEEEs and a number of countries now have occupational exposure limits based on EC and there are distinct advantages in measuring EC for the following reasons:

- ***Specific*** In most workplace environments* the only source of airborne particulate EC is from DEEEs and consequently measuring airborne EC is very specific to diesel particulate. The analysis is also very specific for carbon and so any other dusts collected during sampling will not affect the EC result.

  *** Coal mines are an exception and EC from coal dust does interfere with the analysis. However, the problem can be overcome with the use of a size selective sampler and this is outlined in the next section.**

- ***Appropriate*** It is now thought that the ultrafine EC associated with diesel particulate is the primary cause of the health problems associated with long term exposure to DEEEs and so measuring EC is an appropriate surrogate measure of exposure.

- ***Representative*** Diesel particulate is extremely fine with very little mass. Once airborne it behaves like a gas and stays airborne for a long time. Consequently, measuring diesel particulate EC is fairly representative of the other gases and vapours associated with DEEEs. If the EC concentration is high then it is likely the concentration of other exhaust gases will also be high. However, it must be understood that there is no direct correlation between particulate EC and carbon monoxide or nitrogen oxides and therefore the concentration of these gases must be determined independently using other methods.

7 MONITORING EXPOSURE IN COAL MINES

In coal mines the EC method is seriously compromised due to the presence of coal dust in the mine air and the fact that the analytical method cannot discern between the EC from coal dust and EC from diesel particulate. To overcome this problem a sampler is used called a Personal Diesel Aerosol Sampler or PDAS (More information about the sampler and how it works can be found in Appendix A). Briefly this sampler incorporates an inertial impactor which is designed to collect only the very fine (sub-micron) fraction of airborne particles. Research has shown that over 95% of diesel particulate has an aerodynamic diameter of less than one micron, whereas virtually all coal dust has particles larger than 1 micron. Consequently by collecting the sub-micron fraction the coal dust is eliminated. Trials have shown that as long as the respirable airborne coal dust concentration is not significantly above the regulatory limit, then particulate EC analysis of filter samples collected with this type of sampler do provide a good measure of exposure to diesel exhaust emissions in coal mines.

A commercially available version of the PDAS is now available from SKC® Ltd., an American company with an agency in the UK. They market the device as a ‘Diesel Particulate Matter Cassette with Precision-jewelled Impactor’. This is a single use, sealed and tamper proof cassette that incorporates the inertial impactor and filter. Supplier details can be found in Appendix E.

8 TYPICAL EXPOSURES

In the mid 1990s HSE carried out a technical development survey (TDS) of surface operations where workers over the working day were exposed to DEEEs. With respect to diesel particulate EC the report indicated that:

- Fork-lift truck drivers were the highest exposed group with personal exposures up to 403 µg/m³ EC with a median value of 75 µg/m³ EC.

- For the purposes of control 200 µg/m³ EC should be considered high exposure.

Research work carried out in coal mines showed that Free Steered Vehicle (FSV) drivers had EC exposures ranging from 18 to 123 µg/m³ EC with an average EC exposure of 59 µg/m³. In the general body of main return roadways the range was 13 to 77 µg/m³ with an average EC exposure of 48 µg/m³.

Exposures should be kept as low as reasonably practical (ALARP). Research has shown that exposures below 100 µg/m³ EC should be achievable.

To make it possible for mines to measure their own EC exposure levels the HSE/HSL has developed an on-site method. This will allow mines to confirm that any controls in place are still effective and that exposures are being kept to a minimum in line with the Control of Substances Hazardous to Health (COSHH) regulations.

9 WAYS TO CONTROL EXPOSURE

Research has shown that exposure to diesel engine exhaust emissions (DEEEs) in coal mines tend to be lower than in non-coal mines and in general Time Weighted Average (TWA) exposures are below the target value of 100 µg/m³ EC. To some degree this is due to lower numbers of diesel engines but more especially it is due to higher ventilation velocities when compared to non-coal mines. This coupled with the FSV onboard exhaust dilution arrangement ensures rapid dilution, mixing and dispersal of the diesel emissions as soon as they enter the mine air. This substantially reduces the possibility of drivers and workers close by being exposed to raw or partially diluted exhaust emissions.

Nevertheless, it is still important for mines to carefully plan FSV routes to ensure driver exposure is properly controlled. Worst-case scenarios for FSV drivers are when travelling against the ventilation airflow with the engine forward, travelling with the ventilation airflow with the engine trailing or at the same speed as the ventilation.

9.1 HOW TO LIMIT FSV DRIVER EXPOSURE

For FSVs travelling against the ventilation always try to ensure the engine is trailing the driver. If there are no other FSVs inbye, then under these conditions driver exposure to DEEEs will be very low. However, travelling against the ventilation flow with the engine forward can lead to very high driver exposure and where possible this should be avoided or at the very least reduced to as short a time as possible.

When travelling with the airflow it is more difficult to minimise exposure, because no matter what speed the FSV travels, the driver will be exposed. The following Table outlines the exposure risk.

FSV Driver Exposure Risk when Travelling with the Ventilation

Engine Position Relative to the Driver	FSV Speed Relative to the Ventilation Velocity	Potential Exposure of FSV Driver to DEEEs	Comments
Engine Trailing	Slower	High	Exhaust fume overtakes the FSV
	Same	Very High	FSV operating in ever increasing concentration of exhaust fume
	Faster	Medium	Concentrated exhaust left behind, running into well diluted exhaust
Engine Leading	Slower	Low to Medium	Most of the exhaust fume carried away ahead of the FSV
	Same	Very High	FSV operating in ever increasing concentration of exhaust fume
	Faster	High	FSV constantly running into concentrated exhaust fume

The main message here is never travel at the same speed as the ventilation because the FSV driver will be operating in an ever-increasing concentration of diesel exhaust emissions and consequently, exposure could be very high. If the FSV is likely to be travelling faster than the ventilation airflow then have the engine trailing and if the FSV is slower than the ventilation have it orientated with the engine forward of the driver. By observing these rules exposure to DEEEs will be kept to a minimum but will not be eliminated altogether. To further reduce their exposure, FSV driver's should seriously consider wearing an electrostatic dust mask.

9.2 ELECTROSTATIC DUST MASKS

Some dust masks offer little or no protection against diesel exhaust particulate. Only electrostatic masks rated to FFP1, FFP2 or FFP3 provide protection against diesel particulate exposure, with greater than 90% of diesel particles being trapped by the filter mask. Research carried out at HSE/HSL has shown that FFP2 type masks are the most efficient but there is an increased resistance to breathing with this type of mask. Masks rated to FFP1 offer good protection coupled with relative ease of breathing.

All workers who are working in close proximity to diesel engines should be encouraged to wear an FFP1 electrostatic face mask. These simple and relatively inexpensive devices will help to reduce exposure to diesel exhaust particulate.

9.3 VENTILATION

Good ventilation to dilute and disperse the exhaust emissions is possibly the most important factor for ensuring exposure is kept to a minimum. Research has shown that exposure to DEEEs in coal mines is lower than exposures in non-coal mines. This is mainly due to the much higher ventilation velocities in coal mines. Therefore, every effort must be taken to ensure ventilation losses and leakages are kept to a minimum and that the maximum amount of air possible is passing through the areas where the diesel engines are operating and personnel are working.

Appendix B presents two tables which demonstrate the importance of maximising ventilation volume. The tables are based on test bed exhaust emissions data from a 7 litre diesel engine, of a design and capacity typical to engines used in coal mines and operated over a range of conditions of speed and load. The data presented assumes the same engine operating in a coal mine roadway and calculates the fully mixed particulate EC concentration for a range of ventilation volumes. These figures are for guidance only and for various reasons will be higher than in the real situation.

9.4 POSITION OF PERSONNEL

The closer personnel are to diesel powered equipment the higher their exposure to DEEEs, especially if they are working downwind of the exhaust. Therefore, keep to a minimum the number of people working in close proximity to diesel engines and where possible arrange it such that they are upwind of the exhaust fume. In certain situations higher exposure may be unavoidable. If this is the case then try and limit the time a worker is exposed by swapping their duties with a less exposed worker mid way through the shift.

9.5 NUMBER OF ENGINES

The more engines operating in the mine the more exhaust emissions. Only operate engines that are necessary and switch off engines not in use. Do not leave engines idling.

9.6 ENGINE DESIGN

Manufacturers are continually improving the design of diesel engines and modern engines are cleaner and produce far less exhaust emissions than older engines. To reduce worker's exposure mines should try to upgrade old equipment sooner rather than later. <u>It only requires one dirty engine to raise the general body DEEEs concentration to unacceptable levels</u>.

9.7 VEHICLE MAINTENANCE

Poorly serviced and/or badly tuned engines produce far more exhaust emissions than well maintained engines. For example a partially blocked air filter can greatly increase the exhaust emissions, especially particulates.

A program to regularly monitor the tailpipe particulate emissions from vehicles under a standard condition of operation will provide useful information about the operating condition of the engine. It is recommended that this be done when the statutory 30 day diesel exhaust gases are sampled. Regular measurements on each vehicle will soon provide a baseline result for that vehicle or engine such that any deviations from the norm can be quickly spotted and addressed.

One simple and relatively inexpensive piece of equipment for monitoring tailpipe particulate emissions is the BOSCH Smokemeter (see Appendix C for details). This device consists of two parts; a sampling pump which can be inserted into the exhaust pipe and which draws a metered quantity of exhaust through a filter disc: And a smoke meter evaluating unit which photoelectronically measures the 'blackness' of the sampled filter disc and provides a reading (Bosch No.) of between 0.0 (white) and 9.9 (intense black). The more soot particles present in the exhaust emissions the 'blacker' the filter and the higher the Bosch No.

Some engines will naturally produce more particulate than others and consequently it will be necessary to determine baseline norms for each engine and have specific action levels for each vehicle. In the longer term, consideration should be given to replacing the 'dirty' engines with more modern and cleaner versions.

9.8 FUEL

Diesel fuels are being improved all the time to make them cleaner burning and so reduce emissions. One major improvement has been the reduction in the sulphur content of diesel fuel which, over recent years, has been reduced by a factor of ten and ultra low sulphur fuels are now the norm. Low sulphur fuels produce less particulate and sulphur dioxide (SO_2), a toxic and potent respiratory irritant gas, has been virtually eliminated.

Other fuels which can directly replace standard diesel can also be considered. One such example is biodiesel a diesel fuel derived from natural plant oils (e.g. in Europe rape seed oil is used and in the USA soya bean oil). Research carried out by HSE and HSL has shown that emissions are greatly reduced using biodiesel, especially particulates where overall reductions of around 60% were measured, and a 30% blend of biodiesel with standard diesel saw reductions in particulates greater than 40%.

At the present time in the UK the availability of biodiesel and the cost are to some degree prohibitive. But this is changing and the government is looking more favourably on alternative fuels and it is likely biodiesel will become more readily available over the coming years and tax incentives could make it cost effective. For use underground biodiesel has much to offer in reducing exposure to DEEEs.

Note: Only diesel fuels approved by HSE can be used underground in mines.

10 ON-SITE METHOD FOR MEASURING EC EXPOSURES

10.1 RESEARCH

Over recent years HM Inspectorate of Mines have commissioned a number of research projects with the Health and Safety Laboratory (HSL) to provide information on the exposure of mineworkers to DEEEs, and some of this research is mentioned in the section on 'Ways to Control Exposure'. One primary objective of this research was to develop a simple and inexpensive on-site method for measuring EC exposure, which would allow mines to determine personal or general body EC exposure measurements themselves without the need for laboratory analysis. The following sections detail an on-site method for coal mines and provides information on how this is achieved and the equipment required.

10.2 BACKGROUND TO THE ON-SITE METHOD

As outlined above, exposure to DEEEs in coal mines is normally determined using an SKC diesel particulate matter cassette and cyclone sampler operating at 2.0 litres/min and collecting a sample of diesel particulate onto quartz glass fibre filters. The samples are analysed for organic and elemental carbon using laboratory based equipment. From the mass of EC on the filter and the volume of air sampled the diesel particulate EC concentration is determined. This is used as a measure of exposure to DEEEs.

However, there exists a strong correlation between the 'blackness' of a diesel particulate filter sample and the amount of EC present on the filter, and a relationship equating 'blackness' and

EC can be determined[1]. This relationship makes it possible to estimate, without the need for laboratory methods, how much EC is present on a filter by simply measuring the 'blackness' of the filter.

Notes:

(1) There are limits to the relationship and once the filter is totally black then it cannot get any blacker and the relationship breaks down. This can be a problem in areas where exposures are high. In these areas the sampling time is reduced to prevent overload.

10.3 BOSCH SMOKE EVALUATOR UNIT

One device designed to measure the 'blackness' of filters is the Bosch Smokemeter Evaluator Unit which is mentioned in Section 9.7 and detailed in Appendix C. This device is normally used in conjunction with the Bosch Smokemeter Sampling Pump to measure the 'blackness' of tailpipe particulate samples collected using the pump. However, it can be used to measure general body or personal diesel particulate samples collected with an SKC Diesel Particulate Matter Cassette, provided a relationship equating filter 'blackness' (Bosch No.) and the EC mass on the filter has been determined.

Devices such as the Bosch Smokemeter, can be used regularly to monitor tailpipe emissions and, using an SKC cassette and cyclone sampler, determine personal and general body EC exposures.

11 STEP BY STEP GUIDE TO SETTING UP THE ON-SITE METHOD AND HOW TO MEASURE EXPOSURE

To determine and control exposure to DEEEs on an ongoing basis then a practical and reliable method of measurement is required. The simple on-site approach described below provides a suitable method for measuring EC exposure in coal mines.

Note: The following is a suggested guide and there may be other suitable methods. However, the method described has been used in the HSE/HSL research previously mentioned and has been tried and tested on several occasions.

11.1 DETERMINATION OF THE BOSCH NO. TO EC RELATIONSHIP

In non-coal mines, a relationship equating Bosch No. and EC has to be determined for each mine and this is because the background mineral dust collected along with the diesel particulate affects the 'blackness' of the sample. However, because the PDAS/SKC sampler used in coal mines only collects the very fine diesel particulate and eliminates all other extraneous dust, then research has shown that essentially one equation will satisfy all coal mines. From data collected in coal mines this equation has been determined and is presented in Appendix D along with a simple look up table derived using the equation.

Although the on-site method is reasonably straight forward it is advisable that the person/s whose task it will be to carry out the exposure monitoring are given some initial training.

11.2 COLLECTING DIESEL PARTICULATE SAMPLES

11.2.1 Equipment

A list of the equipment required to carry out diesel particulate sampling and a number of suggested suppliers is shown in Appendix E. There has been no attempt to recommend one supplier over another and all provide perfectly good equipment. The list is not exhaustive and there are other suppliers but the ones mentioned here are established recognised suppliers of airborne monitoring equipment and would be able to give advice if necessary.

11.2.2 Setting up Samplers

Diesel particulate samples are collected using an SKC DPM Cassette in series with a nylon Dorr-Oliver respirable cyclone. The cassette and cyclone are held together by a stainless steel holder that allows the sampler unit to be either attached to a workers clothing for personal sampling or to fixed locations for background, general body sampling. Before sampling commences a rotameter is connected in series with the pump and sampler, and the sampling pump adjusted to provide a sampling flow rate of 2.0 litres/minute, see Figure 1. The initial flow rate is recorded onto a result sheet, an example of which is shown in Appendix F.

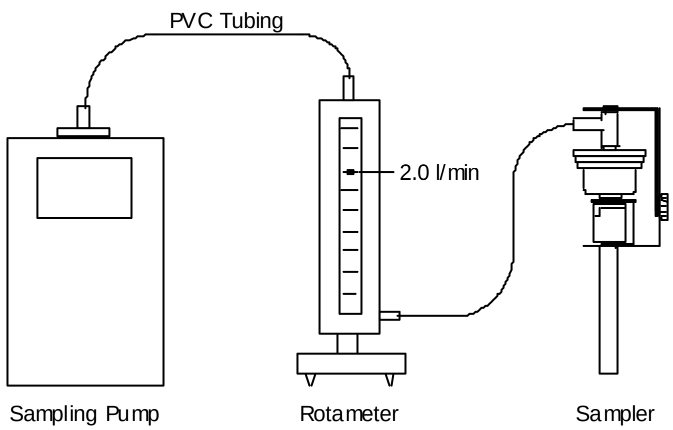


Figure 1. Using a Rotameter to Set the Flowrate Through the SKC Cassette and Cyclone

Once the flowrate is set the pump is switched off and the rotameter removed and the sampler reconnected to the pump. The sampler is then ready for use. Once positioned the pump is switched on and the start time, sampling location, date and any other relevant information recorded on the result sheet.

Sampling should be for as long as possible to provide a representative time weighted average (TWA) concentration. However, with the 'blackness' method it is important the filter is not overloaded and therefore this limits to some degree the sampling time. With experience the optimum sampling time soon becomes apparent but 1 to 4 hours is typical. At the end of sampling switch off the pump and record the time. Back on the surface measure the final flowrate with the rotameter and record this on the sheet.

Using the result sheet column headings in Appendix F for guidance and the example given, determine the mean flow rate and the total sampling time in minutes and calculate the sample volume in cubic metres (m^3).

Remove the filter and measure the ‘blackness’ using the Bosch Smoke Evaluator Unit as per the manufacturer’s instruction and obtain a Bosch No. reading for the sample and record the result on the results sheet. From the Bosch No. v EC look up table given in Appendix D, determine the mass of EC equivalent to the Bosch No. result and record this on the result sheet.

Determine the EC exposure concentration by dividing the Mass of EC by the sample volume to give a TWA result in micrograms per cubic metre ($\mu g/m^3$).

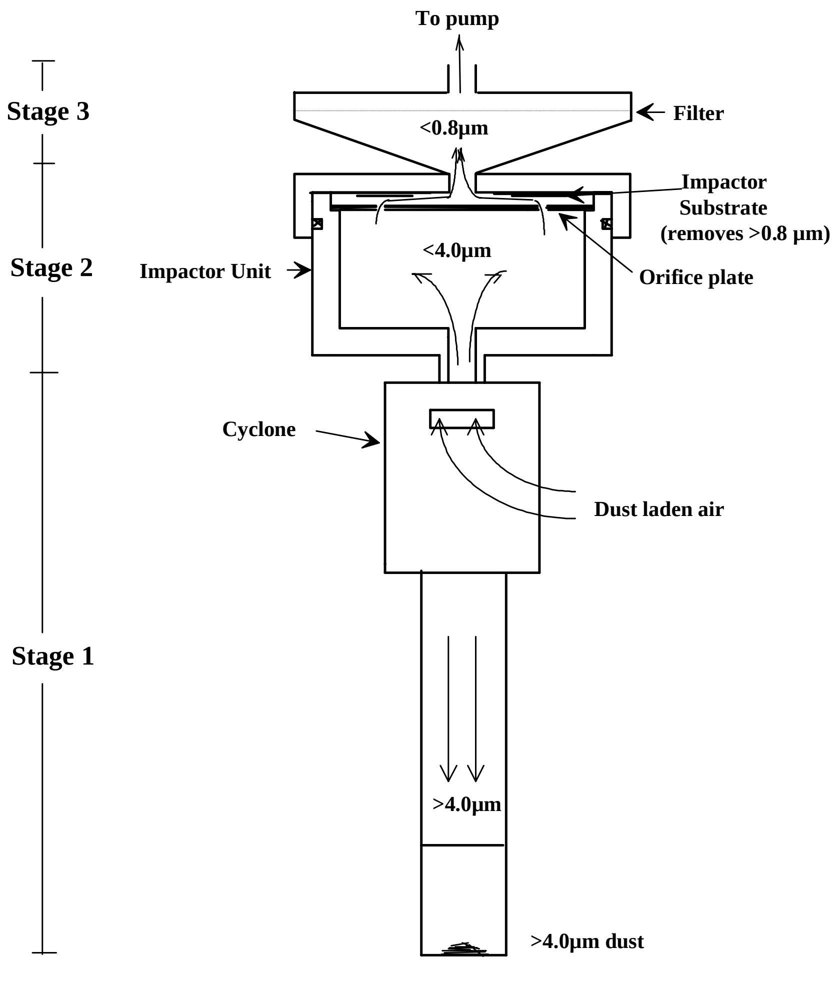
Record the result in line with Regulation 10 of the COSHH regulations.

12 APPENDICES

Appendix A - Size Selective Personal Diesel Aerosol Sampler (PDAS)

In the early 1990's the US Bureau of Mines (USBM) along with the University of Minnesota developed a Personal Diesel Aerosol Sampler (PDAS) specifically for measuring diesel engine exhaust particulate in the presence of coal dust (McCartney & Cantrell, 1992)[1]. The sampler uses three consecutive stages to separate and collect respirable mineral and diesel particulate from sampled air. The first stage is a 10 mm Dorr-Oliver cyclone which acts as a respirable pre-classifier and eliminates all particles >4.0 µm. The second stage is an inertial impactor that traps particles greater than 0.8 µm in size but allows smaller particles to pass through to be collected on a quartz fibre filter in the third stage. The sampler is designed to operate with a sample flow rate of 2.0 l/min and a schematic diagram of the sampler is shown below.

[1] McCartney, T. C. & Cantrell B. K. A Cost Effective Personal Diesel Exhaust Aerosol Sampler. Diesels in Underground Mines: Measurement and Control of Particulate Emissions. Proceedings: Bureau of Mines Information and Technology Transfer Seminar, Minneapolis, MN, September 29-30, 1992.



Schematic Diagram of the Three Stage Personal Diesel Aerosol Sampler (PDAS)

A number of studies have shown that diesel exhaust particulate is very fine with >95% of particles having an aerodynamic diameter of < 1µm. Conversely, mechanically generated dusts such as coal dust have larger particles, with >95% of the particles having aerodynamic diameters >1 µm. The inertial impaction stage in this sampler has been designed to remove particles >0.8 µm and so essentially traps the coal dust whilst allowing the finer diesel particulate to pass through to be collected onto a quartz filter in the third stage of the sampler. The filter sample can then be analysed for OC & EC providing a measure of diesel particulate exposure in the presence of coal dust.

Previously this sampler was very much bespoke and was not commercially available. However, SKC® now market a Diesel Particulate Matter (DPM) Cassette which incorporates in a single cassette a precision jewelled inertial impactor, plus a heat treated quartz filter. The cassette when purchased is sealed with tamper proof tape and is designed for single use only.

Appendix B – Estimated mine roadway diesel particulate EC concentrations

The following table is derived from test bed diesel emissions and assume the emissions are fully mixed with the mine ventilation. The table is for guidance only and in a real situation the concentrations are likely to be lower.

Cat. 3304 (7 litre engine)		Ventilation Vol. (m³/sec)					
Engine Condition		5	10	20	30	40	50
RPM	Load	[Fully Mixed Airborne Particulate EC Conc. (µg/m³)]					
910	0%	41.2	20.7	10.4	6.9	5.2	4.2
1300	50%	166.4	83.8	42.1	28.1	21.1	16.9
1300	75%	293.9	148.0	74.3	49.6	37.2	29.8
1300	100%	1231.3	620.3	311.3	207.8	156.0	124.8
2200	10%	470.2	238.1	119.8	80.0	60.1	48.1
2200	50%	1181.3	598.2	301.0	201.1	151.0	120.9
2200	75%	1104.4	559.2	281.4	188.0	141.1	113.0
2200	100%	1491.7	755.3	380.1	253.9	190.6	152.6
	Mean Conc. =	747.6	378.0	190.0	126.9	95.3	76.3

Note: Shaded boxes identify conditions where the particulate EC concentration is likely to be above 100 µg/m³

Appendix C - BOSCH Smoke Meter

The Bosch Smoke Meter consists of two parts: (1) A sampling pump which is inserted into the exhaust pipe and which draws a defined quantity of exhaust through a filter disc and this is shown in the foreground of the photograph. (2) A smokemeter evaluating unit which photoelectronically measures the ‘blackness’ of the sampled filter disc using a ‘light pen’ to provide a Bosch No. result between 0.0 (white) to 9.9 (intense black), and this is shown at the rear of the photograph.

Appendix D - A look-up table relating Bosch No. to EC for coal mines

Bosch No.	EC (µg)	Bosch No.	EC (µg)	
2	6.4	**5.6**	23.6	
2.1	6.7	**5.7**	24.4	~ 100 µg/m³ for 2 hrs
2.2	6.9	**5.8**	25.3	
2.3	7.2	**5.9**	26.3	
2.4	7.4	**6**	27.2	
2.5	7.7	**6.1**	28.2	
2.6	8.0	**6.2**	29.3	
2.7	8.3	**6.3**	30.3	
2.8	8.6	**6.4**	31.4	
2.9	8.9	**6.5**	32.6	
3	9.2	**6.6**	33.8	
3.1	9.6	**6.7**	35.0	
3.2	9.9	**6.8**	36.3	
3.3	10.3	**6.9**	37.7	
3.4	10.7	**7**	39.0	
3.5	11.1	**7.1**	40.5	
3.6	11.5	**7.2**	41.9	
3.7	11.9	**7.3**	43.5	
3.8	12.3	**7.4**	45.1	
3.9	12.8	**7.5**	46.7	
4	13.2	**7.6**	48.4	~ 100 µg/m³ for 4 hrs
4.1	13.7	**7.7**	50.2	
4.2	14.2	**7.8**	52.1	
4.3	14.8	**7.9**	54.0	
4.4	15.3	**8**	56.0	
4.5	15.9	**8.1**	58.0	
4.6	16.4	**8.2**	60.1	
4.7	17.0	**8.3**	62.3	
4.8	17.7	**8.4**	64.6	
4.9	18.3	**8.5**	67.0	
5	19.0	**8.6**	69.5	
5.1	19.7	**8.7**	72.0	~ 100 µg/m³ for 6 hrs
5.2	20.4	**8.8**	74.6	
5.3	21.2	**8.9**	77.4	
5.4	21.9	**9**	80.2	
5.5	22.7	**9.1**	83.2	

EC = Exp{1.143 + (0.3602 x Bosch No.)}

Note: **(1)** Above Bosch No. 9.1 the relationship between the Bosch No. and EC starts to break down and this defines the upper limit. The sampling time must be arranged such that the Bosch No. is below 9.1.

(2) Shaded area exposures assume a 2.0 l/min sampling rate

Appendix E - Equipment and suggested suppliers

EQUIPMENT	SUPPLIER
Bosch Smokemeter - Sampling pump ETD 020.00 - Diesel smoke evaluator ETD 020.50	**Robert BOSCH Ltd** PO Box 98, Broadwater Park North Orbital Road Denham, Uxbridge Middx., UB9 5HJ Tel: 01895 834466 Fax: 01895 838388
Diesel Particulate Matter (DPM) Cassette with Precision-jewelled Impactor Catalogue No. 225-317 (Sold in packs of 10)	**SKC Ltd.** Unit 11, Sunrise Park, Higher Shaftesbury Road Blandford Forum Dorset, DT11 8ST. Tel: 01258 480 188 Fax: 01258 480 184
Stainless Steel Holder and Nylon Cyclone Assembly Part No. 456243	**MSA (BRITAIN) Ltd.** East Shawhead Coatbridge Scotland ML5 4TD Tel: 01236 424966 Fax: 01236 440881
Personal Sampling Pump Capable of 2.0 litres/minute **(a,b,c)** **Glass Rotameter** To measure up to 2.5 litres/min **(a,b)**	**a) SKC Ltd.** Unit 11, Sunrise Park, Higher Shaftesbury Road Blandford Forum Dorset, DT11 8ST. Tel: 01258 480 188 Fax: 01258 480 184 **b) Casella CEL** Regent House, Wolseley Road Kempston Bedford, MK42 7JY. Tel: 01234 844100 Fax: 01234 841490 **c) Shawcity Ltd.** Pioneer Road, Faringdon Oxfordshire, SN7 7BU. Tel: 01367 241675 Fax: 01367 242491

Appendix F - Result sheet with a worked example

Date/Location	DPM Cassette Number	Flow Rate (l/min) Initial	Final	Mean (A)	Sampling Time	Total Time (B) (mins)	Sample Vol. (A) x (B) = (C) litres	Sample Vol. (C) / 1000 = (D) m^3	BOSCH No.	EC (From look up table) (E) µg	EC Conc. (E) / (D) $\mu g/m^3$
30/10/04 FSV Garage	CY1	2.0	2.1	2.05	**Start:** 10.00 **End:** 11.30	90	184.5	0.184	5.1	19.7	**107.1**
					Start: **End:**						
					Start: **End:**						
					Start: **End:**						
					Start: **End:**						
					Start: **End:**						
					Start: **End:**						
					Start: **End:**						

Note: For the sake of the worked example here the EC mass has been determined using the look up table in Appendix B. In normal use the EC mass will be determined from a look up table which is specific to each mine.