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DIESEL PARTICULATE MATTER & OCCUPATIONAL HEALTH ISSUES

Position Paper





PREPARED BY
AIOH Exposure Standards Committee
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AUTHORISATION
This position paper has been prepared by the AIOH Exposure Standards Committee and authorised by the AIOH Council.

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Australian Institute of Occupational Hygienists Inc (AIOH)

The Australian Institute of Occupational Hygienists Inc. (AIOH) is the association that represents professional occupational hygienists in Australia. Occupational hygiene is the science and art of anticipation, recognition, evaluation and control of hazards in the workplace and the environment.

Occupational hygienists specialise in the assessment and control of:

- Chemical hazards (including dusts such as silica, carcinogens such as arsenic, fibrous dusts such as asbestos, gases such as chlorine, irritants such as ammonia and organic vapours such as petroleum hydrocarbons);
- Physical hazards (heat and cold, noise, vibration, ionising radiation, lasers, microwave radiation, radiofrequency radiation, ultra-violet light, visible light); and
- Biological hazards (bacteria, endotoxins, fungi, viruses, zoonoses).

Therefore the AIOH has a keen interest in the potential for workplace exposures to Diesel Particulate Matter (DPM), as its members are the professionals most likely to be asked to identify associated hazards and assess any exposure risks.

The Institute was formed in 1979 and incorporated in 1988. An elected governing Council, comprising the President, President Elect, Secretary, Treasurer and three Councillors, manages the affairs of the Institute. The AIOH is a member of the International Occupational Hygiene Association (IOHA).

The overall objective of the Institute is to help ensure that workplace health hazards are eliminated or controlled such that worker exposures are minimised. It seeks to achieve this by:

- Promoting the profession and principles of occupational hygiene in industry, government and the general community.
- Improving the practice of occupational hygiene and the knowledge, competence and standing of its practitioners.
- Providing a forum for the exchange of occupational hygiene information and ideas.
- Promoting the application of occupational hygiene principles to improve and maintain a safe and healthy working environment for all.
- Representing the profession nationally and internationally.

More information is available at our website – http://www.aioh.org.au

Consultation with AIOH Members

AIOH activities are managed through committees drawn from hygienists nationally. This position paper has been prepared by the Exposure Standards Committee, with comments sought from AIOH members generally and active consultation with particular members selected for their known interest and/or expertise in this area. Various AIOH members were contributors in the development of this position paper. Key contributors included: Brian Davies and Alan Rogers.

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List of Abbreviations and Acronyms

ACES	Advanced Collaborative Emissions Study
AIOH	Australian Institute of Occupational Hygienists
CO	carbon monoxide
DE	diesel exhaust
DEEP	Diesel Emissions Evaluation Program
DNA	Deoxyribonucleic acid
DPM	diesel particulate matter
EC	elemental carbon
EPA	Environmental Protection Agency (USA)
HEI	Health Effects Institute
HSE	Health and Safety Executive (United Kingdom)
IARC	International Agency for Research on Cancer
ISBN	International Standard Book Number
mg/m^3	milligrams (10-3 grams) per cubic metre
µm	micrometer (10-6metres)
MDG	Mine Design Guide
MSHA	Mines Safety and Health Administration (USA)
NCI	National Cancer Institute
NIOSH	National Institute for Occupational Safety and Health
NSW	New South Wales
OH&S	Occupational Health & Safety
PEL	permissible exposure limit
$PM_{2.5}$	particulate matter with a diameter of 2.5 micrometres or less
REC	respirable elemental carbon
RR	Relative Risk
R2	Coefficient of Determination
SIMTARS	Safety in Mines Testing and Research Station
SMR	standard mortality ratio (observed deaths / expected deaths)
TWA	time weighted average
UK	United Kingdom
US / USA	United States of America
WA	Western Australia

AIOH Position on Diesel Particulate Matter and its Potential for Occupational Health Issues

Summary

This is an update of the previous Position Paper on diesel particulate matter (DPM) issued by the AIOH (2007) and reflects the AIOH review of the recent National Cancer Institute (NCI) epidemiological study and the International Agency for Research on Cancer (IARC, 2012) reclassification.

Although the adverse health effects of the gaseous fraction of diesel emissions have been known for some time, only in the last two decades has research indicated that the particulate component (DPM) of the diesel exhaust has the potential to induce various health effects. In addition, diesel exhaust emissions are known to be associated with non-health aspects such as malodour, visual and nuisance pollution.

Methods to monitor workplace exposures to diesel particulate (capture of the submicron aerosol fraction and analysis as elemental carbon; EC) are now readily available and control technologies have been developed for industries of known elevated exposure (eg underground mining).

Based on some of the animal and epidemiological studies, it has been apparent for a number of years that DPM is a potential carcinogen. The recent 2012 IARC classification of DPM as a Group 1 carcinogen (without indicating the degree of potency) is simply a continued progression of toxicological and epidemiological information that has been accumulating in the literature over the past 30 years. However, due to information deficiencies in the literature, particularly regarding lack of data on past exposure conditions, including the multistage surrogate data used in the recent 2010 NCI/NIOSH study, the AIOH has serious concerns as to the degree of potency being assigned to diesel particulates by some regulatory authorities. It is most likely that as with many low potency substances the issue may never be completely defined.

There is little doubt that this area of the health debate will continue for some time within the scientific and regulatory community, due in part to limitations in the epidemiological studies. Limitations are imposed by the requirements for suitable large sized study populations necessary to study common cancers such as lung cancer; the issues in dealing with a 30 to 40 year latency; the absence of actual exposure data over the long latency period; and the control of confounders, particularly due to the overwhelming effects of tobacco smoking on lung cancer outcome in the population. Given the difficulties of finding rigorous and statistically valid historical exposure data, particularly in regard to potency, the issues may never be completely or adequately resolved. 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.

There is an emerging trend within the occupational hygiene community to take a pragmatic approach to measure and control exposures of the noxious, irritant and malodorous emissions without attempting to define a dose response based exposure standard.

Notwithstanding the lack of a defined universal dose response relationship, experience has shown that when workplace exposures are controlled below 0.1 mg/m^3 DPM (measured as submicron elemental carbon), irritant effect decreases markedly. AIOH believe that such a level should result in a reduced lung cancer outcome if such a carcinogenic effect is attributable to DPM exposure.

In the absence of any more definitive data, the AIOH supports the use of an exposure standard of 0.1 mg/m^3 DPM (measured as submicron elemental carbon) as being a balance between the factors of primarily minimising irritation, secondarily minimising any potential for risk of lung cancer to a level that is not detectable in a practical sense in the work force, and finally on the basis of setting a level achievable as best practice by industry and government.

What is Diesel Particulate Matter (DPM)?

Over the past 115 years the invention of a compression ignition engine by Rudolph Diesel in the 1890's has contributed significantly to the productivity of many nations, owing to the widespread use of larger diesel powered equipment in most industrial activities. The down side in terms of occupational health has been the exposure of a large number of workers to the complex mixture of toxic gaseous, adsorbed organics and particulate components found in the raw exhaust emissions.

The gaseous phase of diesel exhaust consists largely of the same gases found in air, such as nitrogen, oxygen, carbon dioxide and water vapour.

The particulate fraction of the diesel exhaust aerosol consists of a solid carbon phase and ultra-fine droplets of a complex mix of semi-volatile organic compounds. The solid particulate fraction consists mainly of very small particles (typically 15 30 nm diameter) that rapidly agglomerate together to form "chains" or clumps of particles, which are themselves typically <1 μm aerodynamic size. High resolution electron microscopy has demonstrated that the basic diesel particle consists of an irregular stacked graphitic structure, nominally called elemental carbon.

The graphitic nature and high surface area of these very fine carbon particles means they have the ability to absorb significant quantities of hydrocarbons (the semi-volatile organic carbon droplets and vapours) originating from the unburnt fuel, lubricating oils and the compounds formed in the complex chemical reaction during the combustion cycle.

In terms of health outcome, the very small particle size of DPM is important as this means it can reach the deep parts of the lungs. Particulate overload rather than chemical composition is thought to be the major mechanism leading to toxic effect.

Regulatory trends in emission controls and fuel quality have led to alterations in the chemical fingerprint of diesel exhaust (DE), such that modern engines, particularly those post 2007, now emit much lesser quantities of carbon particulates (EC), less sulphur (as sulphates) and as a consequence there are more detectable numbers of ultrafine droplets of semi-volatile organic compounds (as these are less readily adsorbed onto the surface of the fewer quantities of carbon particulates).

How do we Measure it?

Methods for the quantification of employee exposure to diesel particulate have been developing over approximately 30 years. The most advanced and specific method involves capturing the submicron fraction of the workplace aerosol and then determining the amount of the core component of diesel particulate (elemental carbon; EC). EC is used as a surrogate for DPM as it provides the best fingerprint of diesel particulate emissions, is relatively free of interferences and is chemically stable, unlike the adsorbed organic carbon fraction.

Recent commercial developments provide ease in routine submicron sampling using a single use impactor cassette, fitted into a respirable aerosol cyclone, which is necessary when sampling in dusty atmospheres to prevent clogging of the cassette impactor holes. The impactor plate in the DPM cassette may not be required when sampling in environments when other mechanically generated aerosols are at a very low level and or when these aerosols are known not to contain organic carbon such as that found in coal dust. Sample analysis on the captured aerosol is best conducted using NIOSH method 5040 (NIOSH, 2003) for determination of carbon species (especially elemental carbon), however care needs to be exercised to minimise errors due to sampling, blank filter interpretation and instrument operating parameters (Davies & Rogers, 2004).

The latest DE chemical fingerprint may have contrary implications for our current understanding of the toxicological, carcinogenic and non-malignant effects from exposure to DPM as they are based on historic engine emission fingerprints.

At this stage there is no evidence that unproven methods, which rely on measuring the number of ultrafine droplets of semi-volatile organic compounds based on insufficient primary calibration methods, provide a suitable alternative or better method of defining exposures for health assessment purposes.

Real-time monitoring instruments currently on the market can be used as very useful indicative instruments, in helping identify DPM sources and manage and reduce DPM levels. However, these need to be adequately calibrated against traceable primary standards such as for total carbon (TC) or EC.

Hazards Associated with DPM

In 1988 the US National Institute of Occupational Safety and Health (NIOSH) published Criteria Bulletin No.50 (NIOSH, 1988) which proposed a potential link between occupational exposure to diesel exhaust and lung cancer. The NIOSH finding was based on the consistency of toxicological studies in rats and mice and limited epidemiological evidence, mainly from railroad workers.

The IARC evaluation 2A (probable human carcinogen) was based on limited evidence in humans and sufficient evidence of carcinogenic risk in animal studies (IARC, 1989).

The Health Effects Institute (HEI, 1995) undertook a review of the toxicological studies including acute and chronic effects (such as risk of lung and other cancers). It also included the 30 epidemiological studies of workers exposed to diesel emissions in occupational settings for the period 1950 to 1980. About half of these epidemiological studies indicated an increase risk of lung cancer and the remainder showed no increase in lung cancer risk. HEI after examining the positive outcome studies concluded that the epidemiological data indicated weak associations between exposure to diesel exhaust and lung cancer with a relative risk of 1.2 to 1.5. They issued a note of caution indicating that all of the studies lacked definitive exposure data for the populations studied and most had an inability to determine the influence of confounding factors, such as tobacco smoking.

Mines Safety and Health Administration (MSHA, 2001) reviewed 47 epidemiological studies and determined that in 41 studies there was some degree of association between occupational exposure to diesel particulate matter and an excess prevalence of lung cancer. However, some of these studies had limited statistical power either because they included relatively few workers or had an inadequate allowance for latency or follow up period. MSHA then concluded, based on the studies with positive lung cancer outcomes and implied estimates of historical exposure levels, that exposure at a mean concentration of 0.64 mg/m^3 DPM for a period of 45 years would result in a relative risk of 2.0 for lung cancer.

The United States Environmental Protection Agency (US EPA) conducted a health assessment for diesel engine exhaust (US EPA, 2002). They concluded that acute effects with respect to health, such as eye, throat and bronchial irritation, light headedness, nausea, cough and phlegm were evident. With respect to chronic non cancer respiratory effects they suggested, from animal studies, the potential for chronic respiratory disease in humans. The US EPA also concluded that lung cancer was evident in occupationally exposed groups but could not define sufficient dose response data to produce a quantitative risk assessment.

Based on their interpretation of the toxicological and epidemiological data, regulatory authorities in USA, Europe and Canada have concluded that sufficient evidence exists to indicate that diesel particulate presents an increased risk of lung cancer, although the absolute quantification of potency remains unclear. On the other hand, the UK HSE (2012) believes there is limited evidence that an increased risk of cancer is attributable to exposure to the particulates found in diesel engine exhaust emissions and that although sustained exposure to diesel engine exhaust emissions over many years may produce cancer, there is insufficient evidence overall for diesel engine exhaust emissions to be regarded as "a carcinogenic substance" under UK OH&S legislation. A NSW Coal Industry cancer surveillance study has shown no significant cancer risk for underground workers exposed to high levels of diesel particulate (SMR of 0.85 all cancers, 0.74 for lung cancer) (Brown *et al.,* 1997).

Previous reviews by US EPA and MSHA had flagged an epidemiological study with a potential dose response component that was being conducted by a joint NCI and NIOSH research program. The multi study, published as the 'Diesel Exhaust in Miners Study', consisted of a cohort of 12,315 mine workers from eight underground non-metal hardrock mines with DE, operating from 1946 onward (NCI, 2012). Mortality analysis indicated a lung cancer SMR of 1.21 for ever-underground workers and 1.33 for surface only workers. Using a number of steps and various surrogates of exhaust emission exposure, the researchers made estimates of retrospective exposures to respirable elemental carbon (REC – similar to submicron EC) over the previous 50 years and were able to produce in the mortality and case control analysis a dose response trend between cumulative and average intensity of exposure and relative risk (RR) of lung cancer. The retrospective exposure methodology, which stepwise linked historical carbon monoxide (CO) data, equipment power, ventilation rates and varying mining and haulage methods over time, to contemporary EC exposures, based on log-log transformations, provided very poor correlation co-efficients that were not statistically significant in each step of the analysis (eg CO to REC r^2=0.17, engine power to CO r^2=0.01 (NCI, 2010)). While the NCI study may provide some evidence of a weak dose response relationship with wide confidence intervals for lung cancer for this specific study group, in practice how this relationship applies to other occupational situations and differences in the altered chemical emission profile found with contemporary engines remains unclear at this stage.

The NCI study has been subject to a number of criticisms in the literature and will be the subject of detailed examination by an independent research board from HEI commencing in 2013.

IARC reconvened a working group to review the data available on DPM since its 1989 classification. In June 2012 IARC classified diesel particulate extract as carcinogenic to humans (Group 1), on the basis that on its analysis there was now sufficient evidence from human and animal studies. A summary of the findings indicates the basis was mounting concern due to findings in epidemiological studies across workers exposed in a range of settings and the 2012 NCI 'Diesel Exhaust in Miners Study' re-emphasised evidence on which the decision was made (presumably on the basis of the NCI outcome of a dose response relationship for lung cancer) (IARC, 2012). The detailed review of all data and the reasoning for changes in classification is to be included in IARC Monogram #105 due in late 2013.

While the epidemiological outcomes of cancer associated with exposure to diesel particulate remains unclear, and is unlikely to be conclusively resolved in the near future, there is no doubt as to the irritant nature of diesel emissions (including particulate) in confined atmospheres including that found in mines. On this basis the control of such emissions to minimise irritation in workplaces may in turn reduce the potential for any long term health effects below that which is detectable.

The HEI has produced a detailed review of the epidemiological studies of non-malignant respiratory disease in groups of workers exposed to diesel particulate emissions. HEI (1995) found that diesel exhaust exposures produced chronic changes in lungs of laboratory animals and this may be a problem if the effects were transferable to humans. In reviewing short-term exposure studies little evidence was found for changes in pulmonary function related to diesel exhaust exposure, and it was unclear as to what extent such acute response would indicate the potential for chronic respiratory disease. In long-term exposure studies (six of which addressed effects in miners) some studies suggested a slight decrease in lung function, but overall the studies do not provide strong or consistent evidence for chronic, non-malignant respiratory effects associated with occupational exposure to DPM. In addition HEI found that the published mortality studies to 1995 do not provide consistent evidence of an effect of occupational exposure on mortality from non-malignant respiratory disease. Two recent studies funded and published by HEI examined the pulmonary effects of exposure to DPM on non-smoking asthmatic's (HEI, 2009 & 2012). The studies indicated only minor reductions in lung function and airways inflammation indicating little biological response in these lung sensitised individuals. The studies are in line with those reporting similar effects on workers exposed to break down products from natural polymers, such as proteins and vegetable oils, occurring in the process of cooking some foods.

A number of preliminary toxicological studies have been conducted on diesel emissions from contemporary post 2007 diesel engines. The Advanced Collaborative Emissions Study (ACES) animal toxicological study consisted of long term (16 hour a day, 5 days a week for up to 12 months) sub-chronic exposures of diesel emissions from a 2007 compliant engine. No genotoxic effects (changes in DNA) were found and only mild inflammatory effects were observed in the lungs of the rats and mice so exposed (HEI, 2012).
Emerging review studies on exposures to ultrafine particles in air pollution studies are tending to indicate that mortality and morbidity effects are better explained by PM2.5 fraction of aerosols rather than the ultrafine fraction which is less than 100 nanometer size (HEI, 2013).

Major Uses / Potential for Exposure (in Australia)

Potential for exposure to DPM exists whenever workers are in close proximity to operating diesel equipment. In many cases the fact that the equipment is operating in the open environment significantly reduces the potential for excessive exposures. Exposure assessments conducted aboard diesel locomotives have ranged from <0.001 to 0.045 mg/m^3, with a geometric mean of 0.0037 mg/m^3 (as EC) (Liukonen *et al.,* 2002).

Conversely, where diesel equipment is operating in confined areas (eg underground mines, ships' holds, cool rooms, and large truck loading and unloading depots) there is a significant risk of exposure. Levels in Australian underground coal mines have been measured at 0.01 to 0.37 mg/m^3 (as EC) (Joint Coal Board, 1999; Rogers, 2005), although levels up to 2.2 mg/m^3 have been measured, depending on job type and mining operation (Pratt *et al.,* 1997).

Levels in Australian underground metalliferous mines have been measured at 0.01 to 0.42 mg/m^3 (as EC) (Rogers & Davies, 2001 & 2013). Investigations in 2005 by SIMTARS also found elevated exposures in Queensland underground metalliferous mines (Hedges, 2007). For surface mining operations, forklift operators have been found to be the highest exposed group (Dabill, 2004). Levels for forklift operators have ranged from 0.007 to 0.40 mg/m^3, with a median of 0.075 mg/m^3 (as EC) (Groves & Cain, 2000).

Risk of Health Effects

While there has been (and continues to be) debate as to the carcinogenic potential and potency of DPM, there is sufficient evidence to indicate over exposure will give rise to irritation and potentially other non-malignant adverse health effects.

The quantitative risk of lung cancer is less clear, however some statutory authorities maintain that this is probable and give quantitative estimates based on estimates of past exposures that may have limited application to many work places.

Available Controls

Over the past 15 years considerable research has taken place to develop suitable control technologies, especially for vehicles operating in confined areas (eg underground mining).

Proven control technologies include:

- Low emission engines
- Low emission fuel
- Ventilation
- Engine maintenance
- Exhaust filtration systems
- Air conditioned (filtered) operators' cabins
- Operating practices
- Driver and workforce education
- Personal protective equipment

Experience has shown that no one single simple solution exists and that individual operations need to explore which of the above control technologies best fit their circumstances. The North-American Diesel Emissions Evaluation Program (DEEP), available at http://www.camiro.org/mining_deep.htm, provides good examples of control methods for DPM. Control methods are also provided on the NIOSH, MSHA and UK HSE websites, available at http://www.cdc.gov/niosh/mining/topics/DieselExhaust.html, http://www.msha.gov/S&HINFO/TOOLBOX/DTBFINAL.HTM and http://www.hse.gov.uk/pubns/books/hsg187.htm, respectively.

Overall an integrated approach specific to each exposure situation is necessary to control DPM worker exposures to the recommended exposure limit. The use of real-time monitoring devices that are calibrated against primary standards of EC or TC, both on persons and on vehicles, can facilitate the monitoring, management and reduction of DPM levels.

Current Applicable Legislation and Standards

Legislation for the control of DPM has been around for a number of years but is still in its early stages of development and implementation.

On 2 February 2007 the NSW Department of Primary Industries issued a gazettal notice which picked up sections of their Mine Design Guideline (MDG29) and thus also picked up an 8 hour TWA exposure standard of 0.1 mg/m^3 (as submicron EC) for NSW coal mines on the basis that compliance with such a value 'should provide adequate protection against irritant effects and also minimise any risk of lung cancer'. MDG 29 was later extended to cover other underground non-coal mining operations (NSW Primary Industries, 2008). Initially considered by some to be merely a guide to good practice, recent amendments to include national uniform OH&S regulations mean that it is now considered as mandatory practice in NSW mining operations.

In December 2012 the Queensland Mines Inspectorate, after consideration of the IARC 2012 classification of diesel engine exhaust, issued a Safety Bulletin recommending adoption of the MDG29 limit of 0.1 mg/m^3 (measured as sub-micron EC), shift adjusted (Qld Department of Natural Resources and Mines, 2012).

Around the same time in Western Australia (WA) the Department of Mines and Petroleum issued a Draft Guideline with a recommended exposure limit of 0.1 mg/m^3 (as EC measured as a time weighted average over 8 hours) based on the recommendations of the AIOH (2007) and the use of such a value in other interstate jurisdictions (WA Department of Mines and Petroleum, 2013).

Overseas, legislation is currently in place in the USA, Canada and Europe to control DPM exposures in mining and tunnelling. Effective January 2007, MSHA in the USA reduced their exposure limit (PEL) in mines to 0.35 mg/m^3 (as total carbon, equivalent to 0.31 mg/m^3 as EC). By January 2008, the final PEL in mines became 0.16 mg/m^3 (as total carbon, equivalent to 0.12 mg/m^3 as EC). The basis for the MSHA standard was in part the consideration for potential risk of excess lung cancer (MSHA, 2001). Germany has an exposure standard for underground non-coal mines of 0.3 mg/m^3, and 0.1 mg/m3 for all other activities measured as whole diesel particulate.

AIOH Recommendation

Based on the available information, the AIOH believes that worker exposure to DPM levels should be controlled to below 0.1 mg/m^3 as an 8 hour time weighted average value, measured as submicron elemental carbon. The value has been determined as being a balance of the factors such as primarily minimising eye and respiratory irritation, then secondarily minimising any potential for risk of lung cancer to a level that is not detectable in a practical sense in the work force, and finally on providing a level that is achievable as best practice by industry and government.

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