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Consultation on monitoring of water-miscible metalworking fluid (MWF) mists

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Consultation on monitoring of water-miscible metalworking fluid (MWF) mists

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The aim of this research was to examine metal working fluid (MWF) exposure limits and guidance set by other countries, summarise studies and investigations that examined water-miscible MWF mist as well as new techniques to monitor mist. The following conclusions were drawn:

- The majority of guidance levels or exposure limits for MWF mist relate to mineral oil and not water-miscible fluids. Certain recommended exposure limits (RELs) such as those set by NIOSH (USA) and INRS (France) relate to all MWFs.
- European countries, with the exception of the UK, and the USA monitor all forms of MWF mist by capture onto filters (with or without subsequent chemical extraction steps), followed by gravimetric analysis or the use of infra-red spectroscopy.
- Historically, average mist levels have not changed over time; the majority were below the previous UK guidance value of 1.0 mg/m3 with a large proportion below the NIOSH REL of 0.5 mg/m3. This suggests that as ill health was reported at these low levels of mist, the exposure limits have no relevance to health risk.
- A different approach to MWF mist monitoring may be required based on good practice. The question is whether the use of monitoring devices or internationally recognised methods (eg gravimetric analysis) might help to determine the effectiveness of this control strategy.

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HSE Books

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ABBREVIATIONS

ACGIH	American Council of Governmental Industrial Hygienists
ACTS	Advisory Committee on Toxic Substances
ASTM	American Standard for Testing & Materials
BGIA	Berufsgenossenschaftliches Institut für Arbeitssicherheit
COSHH	Control of Substances Hazardous to Health
DECOS	Dutch Expert Committee on Occupational Safety
EAA	Extrinsic allergic alveolitis
FIOH	Finnish Institute of Occupational Health
GC-FID	Gas chromatography with flame ionisation detector
HBROEL	Health-based recommended occupational exposure limit
HSE	Health & Safety Executive
HSL	Health & Safety Laboratory
INRS	Institut National de Recherche et de Sécurité
ILMA	Independent Lubricant Manufacturers Association
m^3	Cubic metre
mg	Milligram
ml	Millilitre
MAC	Maximum workplace concentration
MWF	Metalworking fluid
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OEG	Occupational exposure guidelines
OES	Occupational exposure standard
OSHA	Occupational Safety and Health Administration
OTDS	Organic toxic dust syndrome
PEL	Permissible exposure limit
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
REL	Recommended exposure limit
SVHC	Substance of very high concern
STLE	Society of Tribologists and Lubrication Engineers
TDS	Technical development survey
TNO	Netherlands Organisation for Applied Scientific Research
TWA	Time-weighted average
UAW	United Auto Workers
UEIL	Independent Union of the European Lubricants Industry
UKLA	UK Lubricants Association
VOC	Volatile organic compound
WATCH	Working Group on Action to Control Chemicals

EXECUTIVE SUMMARY

Outbreaks of ill health have occurred across the world in machining plants using water-based metalworking fluids (MWFs) despite apparent compliance with national exposure or guidance limits designed to protect worker health. An example of this is the large number of occupational asthma and extrinsic allergic alveolitis (EAA) cases observed at the Powertrain engine manufacturing plant in Birmingham, UK. Following this outbreak of ill health in 2005, the Health and Safety Executive (HSE) withdrew all guidance limits relating to MWFs but this has left UK industry without a benchmark to demonstrate adequate control of mist. Equally, there is uncertainty within the UK as to the continued relevance of the HSE-recommended boron marker method of monitoring water-miscible MWFs (MDHS 95/2) as boron and its derivatives are being less widely included in MWF formulations following the possibility of imposed restrictions on its use in Europe. The aims of this project were to identify methods of monitoring water-miscible MWF mist and examine national guidance and exposure limits based on a consultation with industry and academic experts. The relevance of set mist guidance limits reported in workplaces and their role in preventing ill health was examined by reviewing studies that had measured water-miscible MWF mist.

Health and Safety Laboratory (HSL) staff has interacted with UK industry by attending the quarterly meetings of the UK Lubricants Association (UKLA) MWF product stewardship group that discuss health and safety and regulatory issues associated with MWFs and their components. This led to invitations to present our research at a symposium on MWFs organised by the Independent Union of the European Lubricants Industry (UEIL) in Barcelona and to attend a workshop held at the UEIL headquarters in Brussels to discuss air quality in engineering plants. The aim of the latter was to establish consensus as to whether a guidance limit for water-miscible MWF mist could be set for European industry.

Further to this, a search of peer-reviewed publications and National Institute for Occupational Safety & Health (NIOSH) Health Hazard Evaluation (HHE) Reports that included the measurement of mist derived from water-miscible MWFs was undertaken. Principles applied in systematic reviews were used to determine the relevance of the published studies and to assess the robustness of the findings. Twenty-four relevant studies that included data following the assessment of airborne MWF mist were found. These studies included investigations of outbreaks of respiratory ill health where exposure to MWF mist had been monitored, workplace studies that assessed occupational hygiene including exposure to MWF mist and aerosol mapping studies that tried to relate peaks of airborne mist levels with workplace activities. Pertinent data such as type of MWF process, air monitoring (personal or area), method of quantification and exposure limit or guidance value that applied at the time were recorded for each study. Certain studies used particle counters as a means of monitoring MWF mist and their role in mist monitoring has been briefly discussed.

Despite the relatively low number of qualifying papers in the study, their variable quality and the relatively few ill health investigations, the mist measurement data suggests a potential respiratory ill health risk even if levels are maintained to the NIOSH recommended exposure level (REL) of 0.5 mg / m^3 or below. The NIOSH REL is intended to prevent or greatly reduce respiratory disorders associated with MWF exposure[1]. The removal of the UK guidance limit of 1.0 mg / m^3 by HSE in 2005 was necessary given that ill health occurred at the Powertrain plant despite mist exposures generally being controlled beneath this level.

This study was undertaken to examine MWF exposure limits and guidance values set by other countries, summarise studies and investigations that examined water-miscible MWF mist as well as new techniques to monitor mist. The following conclusions were drawn:

- The majority of guidance levels or exposure limits for MWF mist relate to mineral oil and not water-miscible fluids. Certain RELs such as those set by NIOSH and Institut National de Recherche et de Sécurité (INRS), France relate to all MWFs.
- European countries, with the exception of the UK, and the USA monitor all forms of MWF mist by capture onto filters (with or without subsequent chemical extraction steps), followed by gravimetric analysis or the use of infra-red spectroscopy.
- The number of papers meeting the criteria of summary of water-miscible mist data was small and revealed inconsistencies in the determination of exposure.
- Historically, average mist levels have not changed over time; the majority were below the previous UK guidance value of 1.0 mg / m^3 with a large proportion below the NIOSH REL of 0.5 mg / m^3. This suggests that as ill health was reported at these low levels of mist, the exposure limits have no relevance to health risk.
- A different approach to MWF mist monitoring may be required based on good practice. The question is whether the use of monitoring devices or internationally recognised methods (e.g., gravimetric analysis) might help to determine the effectiveness of this control strategy.

[1] *http://www.cdc.gov/niosh/topics/metalworking/*

1.0 INTRODUCTION

1.1 Background

Outbreaks of ill health have occurred across the world in machining plants using water based metal working fluids despite apparent compliance with national exposure or guidance limits designed to protect worker health. An example of this is the large number of occupational asthma and extrinsic allergic alveolitis (EAA) cases observed at the Powertrain engine manufacturing plant in Birmingham, UK. This was despite levels of MWF mist being controlled by the company, typically below those required by the then current HSE guidance value of 1.0 mg / m^3 time-weighted average (TWA) over an 8 hour shift for water-miscible fluids and based on analysis of boron as a marker element (MDHS 95/2) (HSE, 2003). The guidance value was not health-based but was agreed with industry according to what was deemed achievable, following a survey of UK engineering premises providing good practice was adopted (Simpson *et al*, 2003). Following this outbreak of ill health in 2005, HSE withdrew all guidance limits relating to MWFs (including those for mineral oil-based fluids), but this left UK industry without a benchmark to demonstrate adequate control of mist. In its revised guidance issued after the Powertrain investigation, HSE emphasised the importance of controlling worker exposure to mists of used MWFs, supporting this statement with general concerns that contamination of MWFs with micro-organisms (and their 'by products') was likely to contribute to the risk of respiratory disease and specifically respiratory allergy. HSE, in collaboration with international MWF manufacturers, have continued to develop this guidance based on good industry practice in the safe use of MWFs. The timeline of MWF mist exposure limits and guidance values is shown in Table 1.

The HSE recommended method of monitoring water-miscible MWF (MDHS 95/2) is novel and is only used in the UK. It was developed by HSL staff, in collaboration with a large engineering company, to allow measurement of mist from water-miscible MWF to the guidance limit of 1.0 mg / m^3; it was published in August 2003. It utilises a marker within the MWF, usually boron but can be sodium or potassium. Mist samples are collected on air filters and the concentration of marker in the air compared with that determined in the bulk MWF. Historically, potassium and sodium have never been adopted as markers as inaccuracies in the method often occur due to the high levels of these salts in the environment. It is important to note, however, that there is uncertainty within the UK as to the continued relevance of this method because boron and its derivatives are being less widely included in MWF formulations, following the possibility of imposed restrictions on its use in Europe. It is understood that boric acid and sodium borates used in the production of corrosion inhibitors and buffer systems, will have their hazard-based classification changed from category 2 to a category 1B reproductive toxin due to their considered effects on fertility and development. Boric acid and borates have been added to the Candidate List of Substances of Very High Concern (SVHC) under Annex XIV of Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) which may lead to their exemption or removal from the European market.

1.2 Overview of national MWF mist limits in Europe and USA

Traditionally, MWFs consisted of neat mineral oils and the majority of national occupational exposure limits relate to the measurement of mineral oil mist and do not relate to water-miscible MWFs. The American-based Occupational Safety & Health Association (OSHA) set the first exposure limit in the USA; a permissible exposure limit (PEL) of 5.0 mg / m^3 for mineral oil mist in air, averaged over an 8-hour period. The American Council of Governmental Industrial Hygienists (ACGIH) originally set a guidance value of 5.0 mg / m^3 in 1964 and proposed lowering this level to 0.2 mg / m^3 for mineral oils with carcinogenicity designations. In 2005, MWF was removed from their "under study" list (Cohen & White, 2006), and so this was never recognised as a threshold level through a lack of supporting data. An occupational exposure standard (OES) of 5.0 mg / m^3 was also considered by HSE and following a survey of UK engineering premises, a guidance value of 3.0 mg / m^3 was recommended in 2002 albeit based achievable good practice, not health outcome. This recommended value was withdrawn in 2005 following an outbreak of ill health where levels of mist were below guidance values.

There is also wide variation in exposure limits to mineral oil mist across Europe. The German limit for mineral oil mist is 10.0 mg / m^3 of oil aerosol and vapour (BGIA, 1997). However in Switzerland, there is an optional limit of 20.0 mg / m^3 for oil aerosol and vapour of medium or light oil, yet both are measured using the same method (BGIA, 1997). Also, since 2003, Swiss authorities have recommended a PEL of 0.2 mg / m^3 for heavy oil with a boiling point of over 350°C of aerosol similar to that of the ACGIH.

In 1993, following the advent of water-miscible MWFs, the United Auto Workers (UAW) in the USA petitioned OSHA to set a limit for exposure to MWFs regardless of mineral oil content. In response to this petition, the NIOSH issued a 'Criteria for a Recommended Standard: Occupational Exposure to Metalworking Fluids' in 1998, which included a recommended exposure level (REL) of 0.5 mg / m^3 of total inhalable particulates or 0.4 mg / m^3 of MWF aerosol meeting the thoracic particulate size definition; these related to all types of MWF. To date, OSHA has not set any further PELs in relation to water-miscible MWFs, issuing a response to the UAW in 2004 stating that there was insufficient evidence to justify a separate MWF standard for water-miscible fluids at this time. This was also the case in many European countries, yet the Institut National de Recherche et de Sécurité (INRS) in France has a recommended value of 1.0 mg / m^3 of aerosol only (INRS, 2003) for both mineral oil-based and water-miscible fluids. As stated above, the same guidance value was adopted in the UK in 2002 for water-miscible MWF but based on the outcome of analysis by the boron marker method. The guidance value was subsequently withdrawn in the UK in 2005 following the outbreak of ill health at Powertrain. The different limits and the principles behind the different methodologies are summarised in Table 2.

New methods for monitoring MWF mist exposure have been investigated including direct reading instruments which may be used to quantify airborne particulates (e.g., solids and liquids). Some of the instruments can quantify the size distribution of particles, the mass of particles within a given size range (e.g., the respirable fraction), as well as other properties (e.g., surface area). The use of these instruments is being explored by researchers as rapid monitoring tools to assess exposure to MWF mists.

This report sets out some of the current evidence about the value of monitoring water-miscible MWF mist, what current research is pointing to the value of limits for mist, and what other international experts and organisations in this industry consider as the significant knowledge gaps that need to be addressed about water-miscible MWF mists.

Table 1: Summary of actions taken to approve and set limits for exposure to MWF mist in the UK.

Date	**Action**
1960s	Exposure limit for oil mist at OES values of 5.0 mg / m^3 (8hr TWA) in place since ACGIH threshold values (TLVs) were adopted as guidance values.
1994-2000	OES of 5.0 mg / m^3 for mineral oil mists on programme of reviews for consideration by WATCH.
1995	Technical Development Survey (TDS) criteria agreed with WATCH to determine extent of MWF use and levels of mist in the workplace derived from both mineral oil-based and water-miscible MWFs, as well as other technical issues.
July 1999	Following reporting of findings from TDS (summarised in Simpson *et al* (2003)), Advisory Committee on Toxic Substances (ACTS) agreed the best strategy was to produce guidance on how to improve control measures and maintenance of MWFs. It was suggested at the meeting that the guidance could include an indicative mist concentration that was achievable by good practice but outside the Occupational Exposure Limit (OEL) framework. It was also concluded that maintaining the mineral oil mist OES was valid. This limit was not, however, helpful in the context of MWFs because of their complex formulation and lack of measurement methods to assess compliance.
March 2000	ACTS considered draft guidance for mineral oil-based and water-miscible MWFs separately, which included separate guidance limits for the respective mist.
July 2000	ACTS agreed a revised definition of mineral oils and mist, effectively excluding MWF from inclusion EH40, the HSE list of Workplace Exposure Limits (HSE, 2011).
October 2002	The guidance values of 3.0 mg / m^3 (10hr TWA) for straight oil MWF mist and 1.0 mg / m^3 (10hr TWA) for water-miscible MWF, based on boron marker analysis, were published in the HSE guidance document 'Working Safely with metalworking fluids; ISBN 0-7176-2561-3'.

Table 2: Summary of different national guidance and exposure limits applied to mist derived from mineral oil-based and water-miscible MWFs.

Country	PEL/ REL/MAK	Fluid	Size Fraction	Methodology
USA: OSHA	PEL 5.0 mg / m^3 (10hr TWA)	Mineral Oil	Total	Gravimetric
USA: NIOSH	REL 0.5 mg / m^3 (10hr TWA)	All types	Total	Gravimetric
	REL 0.4 mg/ m^3 (10hr TWA)*	All types	Thoracic	Extraction following gravimetric
Finland	5.0 mg / m^3 (8h TWA)	Mineral oil	Total	Extraction following gravimetric
Germany	10.0 mg / m^3	Mineral oil	Total including vapour	Infra-red absorbance + GC-FID for vapour fraction
Netherlands: DECOS	5.0 mg / m^3 (8hr TWA)	Mineral oil	Total	Extraction following gravimetric
	REL 0.1 mg / m^3 (8hr TWA)	HBROEL (*particulate mass)	Total	
Sweden/ Denmark	1.0 mg / m^3 (8hr TWA)	All types (*particulate mass)	Total	Extraction following gravimetric
France	1.0 mg / m^3	All types	Total	Extraction following gravimetric
Switzerland	PEL (MAK) 0.2 mg / m^3	Heavy mineral oil	Total	Gravimetric
Withdrawn guidance values				
UK: HSE	3.0 mg / m^3 (10hr TWA)	Mineral oil	Total	Gravimetric
UK: HSE	1.0 mg / m^3 (10hr TWA)	Water-miscible	Total	Boron marker

PEL = Permissive Exposure Limit REL = Recommended Exposure Limit

TWA = Time-Weighted Average MAK = Maximum Workplace Concentration (German)

1.3 Aims

To identify which methods of monitoring the industry should be advised to use when quantifying exposure to water-miscible MWFs, based on the outcomes from a consultation with industry and academic experts.

1.4 Objectives

1. To consult a small group of experts (analysts, British Occupational Health Society (BOHS) members) and relevant trade associations to identify key questions.
2. To consult with national and international experts about the use of methods to monitor exposure to MWF mist.
3. To summarise the findings from experts about the guidance and exposure limits for MWFs and about methods to monitor mist.

2.0 METHODOLOGY

2.1. Interactions with Industry Experts

2.1.1 MACH 2012 & 2014 trade exhibitions

HSL staff met various manufacturers of mist extraction devices at the MACH trade exhibition which is held every 2 years at the NEC, Birmingham. It is organised by the Manufacturing Technologies Association and gives manufacturers an opportunity to showcase new engineering-based manufacturing technologies. Attendance at the exhibition enabled HSL staff to discuss various issues in respect to mist with manufacturers of mist control devices. These included large scale mist extraction devices that could be retrofitted to machinery, in addition to smaller scale devices such as the use of guards and blast boxes to reduce mist associated with compressed air use. Opinion on the need for mist monitoring and the reintroduction of a guidance value was canvassed, as well as support for the proposed HSL consultation on mist. Through an HSE inspector, a demonstration of a particular mist extraction system was also attended; this was a large scale device that filtered the air in order to capture the mist particles.

2.1.2. United Kingdom Lubricants Association MWF Product Stewardship Group (UKLA PSG)

The UKLA is the lead trade association for the UK's lubricant industry. It was formed by a merger between the British Lubricants Federation (BLF), the long standing UK Lubricants Industry Trade Association and the UK Delegation to the European Lubricants Industry Organisation (UEIL) in 2005. It represents 103 companies who produce the majority of the UK's £2 billion, 800,000+ tonne output of lubricants and their components. Members include major multi-national oil companies, independently-owned lubricant manufacturers and marketers, and the sector's raw material suppliers. The UKLA consists of various PSGs that focus on different lubricant categories. Since January 2010, HSL staff have attended the quarterly meetings of the MWF PSG. These meetings are convened to discuss health and safety and regulatory issues associated with MWFs and their components and guest speakers are invited to discuss various related topics. HSL staff were initially invited to give an overview of the three year programme of research HSE had funded on MWFs. However, interest was so great that HSL staff were asked to become a regular participant and has given updates on the research programme at subsequent meetings; resulting in an invitation to present the research at a UEIL symposium on MWFs in Barcelona.

2.1.3 UEIL Symposium on MWFs, Barcelona

In September 2011, an international UEIL symposium entitled “Metal Removal Fluids: Global challenges” was attended. The symposium was organised in partnership with the Independent Lubricant Manufacturers Association (ILMA) and the Society of Tribologists and Lubrication Engineers (STLE), which are both American trade associations. Presentations were given on a wide range of issues relating to MWFs that were categorised into three themes: innovation, application or regulation. Several presentations examined mist with two specific investigations carried out in Sweden and Germany that had a direct bearing on the HSL study of mist. Networking opportunities also allowed the importance of mist measurement to be discussed with key experts and respected members of UEIL, ILMA and STLE.

2.1.4 UEIL Health and Safety Committee Workshop

The link between control of MWF mist and reduction of respiratory ill health in machining workers has been a key concern of MWF manufacturers and associated industries, with regards to either the incorporation of low misting additives or use of enhanced local exhaust ventilation systems. As outlined above, guidance limits for the acceptable level of mist vary greatly between European countries, and within the UK have been withdrawn. The importance of controlling mist and the possible need to investigate alternative methods of monitoring has been conveyed to the UKLA by HSL and in turn the UKLA have raised awareness of the potential harmful effects of inhaling MWF mist at the European level through discussions at the UEIL Health & Safety Committee. A sub-group of the UEIL Health & Safety Committee has formed to investigate air quality within machining workshops with the objective of determining the best way forward in the control of MWF mist. In order to determine European opinion, UEIL held discussions at their headquarters in Brussels in January 2013. Presentations were made by representatives from the Netherlands (Netherlands Organisation for Applied Scientific Research (TNO)), Sweden (Swedish Environmental Research Institute and University of Gothenburg), Finland (Finnish Institute of Occupational Health, (FIOH)), Germany (Deutsche Gesetzliche Unfallversicherung (DGUV)) and the UK (HSL). These covered the topics of nanoparticle measurement in the Netherlands, airborne volatile organic compound (VOC)s in German machining workshops, the findings of a large scale occupational hygiene survey of conditions in Swedish machining workshops, variations in the microbial flora of different fluids collected in Sweden, ill health effects of MWF exposure as observed in Finland, and an overview of some aspects of the HSE programme of research relating to airborne exposure. Presentation titles have been listed in Appendix 1.

2.1.5 Intelligence Gathering

A variety of industrial experts have been consulted for their knowledge about methods for monitoring mist through attendance of the UKLA MWF PSG, the international symposium and workshop arranged by UEIL. These have included key players within the MWF industry who are highly regarded by members of UEIL, STLE and ILMA. Several have been involved in the preparation of an American Standard for Testing & Materials (ASTM) for water-miscible MWF mist measurement (Version D7049-04: ASTM, 2010).

Initially, a series of questions regarding the availability of mist measurement techniques, their efficacy and accuracy, and new emerging methods was prepared with the intention of circulating the set of questions to a variety of experts. These are outlined in Appendix 2 with the reasoning behind each question. Following consultation with the UKLA MWF PSG, it was concluded that due to a forthcoming gathering of experts at a UEIL workshop on machining workshop air quality, circulation of the questions was essentially repetition. Therefore it was felt that representation by HSL staff at the UEIL workshop was a better way forward.

2.2 Summary of published evidence

A search of peer-reviewed papers and reviews published from 1990 to 2013 was undertaken using the search engines Google Scholar, Pubmed and Web of Science. Only studies including the measurement of mist derived from water-miscible MWF were included. Those focussing on straight oil mists were excluded from the literature summary. Details of the search terms employed are given in Table 3.

Table 3: Search terms employed during summary of published evidence

Key search terms (*wild card character)						
air*	aerosol	exposure	machin*	Metalworking	mist	partic*

A search of the NIOSH Health Hazard Evaluation Report database was also undertaken to find any publications relating to MWF mist investigations in American machining plants. Employees can report their health concerns to NIOSH who will visit premises and undergo an occupational hygiene assessment which, if appropriate, will involve measurement of MWF mist.

2.3 Data extraction from relevant studies

Principles applied in systematic reviews were used to determine the relevance of the published studies and to assess the robustness of the findings. The first stage of this involved data extraction forms (Appendix 3). This form contains a series of questions that were applied to each published study. These are summarised in Table 4.

2.4 Summary of data

Due to the small number of studies containing evidence about the concentrations of MWF mist (and their variable quality), it was decided not to pool the data for further analysis. The results therefore were summarised as provided by the source papers without further modification. For some studies, this included single measurements or for multiple pooled measurements central estimates (arithmetic and geometric means, medians), others provided further analyses with estimates of uncertainty (e.g., confidence intervals or estimated error values).

Table 4: Criteria used to assess the quality of the published studies.

Questions that were applied to the published studies
Primary purpose of study
Is the main focus on measurement of mist?
Was the study in response to ill health, an epidemiological study or mapping of aerosol formation?
Type of exposure sampling
Were samples personal or fixed area?
Was airborne exposure assessed by total mass, a marker (e.g., boron) or particle counting?
Was the method of determining airborne exposure based on inhalable, thoracic or respirable fractions
Was the duration of sampling time short (minutes) or long (hours)?
Methodology and data analysis
Is enough detail provided to understand the study design, sampling methods, and data analysis?
Was the mist measured by gravimetric analysis or particle counter?
How is the data summarised (are individuals data provided or only summary statistics)
Was the study of sufficient size to provide a robust assessment of exposure (e.g., numbers of samples and variables)?
Were samples taken in replicate?
Other supporting questions
Were the levels of mist compared to a guidance limit?
Was the study longitudinal (repeated sampling along a time line)?
Was it focused on a particular type of machining?
Were multiples types of MWF fluid in use where the samples were collected?

3.0 RESULTS

3.1 Outcomes of Interaction with Industry Experts

3.1.1 MACH 2012 & 2014 trade exhibitions

Attendance at the MACH 2012 Trade Exhibition enabled HSL staff to engage with a variety of manufacturers of MWF and suppliers of mist control devices. It also meant that large pieces of machinery that create mist such as CNC machines and high speed grinding machines could be observed in operation. The majority of the MWF manufacturers spoken with were aware of the potential ill health effects of working with MWF and inhaling mist. Many were also aware of the HSE COSHH essential fact sheets and were actively promoting their use to end users. The difficulties in accurately monitoring mist were known and the general consensus was that a benchmark against which mist was effectively controlled was required. Several manufacturers of mist extraction devices were interested in the proposed HSL consultation on mist and were happy to provide information as to how their devices operated and discuss levels of mist found in the workplace. It became apparent that certain devices could be retrofitted to existing machinery but the majority of large scale machines were enclosed and had mist extraction incorporated as well as time delay locks to prevent doors being opened prior to completion of machining. Several smaller devices for the reduction of mist produced by the use of compressed air for the removal of waste MWF were also viewed. These included guards produced by a manufacturer of compressed air guns which deflected airborne droplets away from the worker and a blast box. The latter, produced by a different manufacturer was essentially a glove box in which compressed air could be used to clean small components whilst the mist was extracted through a filter system.

3.1.2 UKLA MWF PSG

Useful knowledge regarding MWFs has been gained from attendance at the quarterly UKLA MWF PSG meetings. This has included a greater understanding of how different types of MWFs are formulated and the changes they undergo in use. This has been invaluable in the planning of experimental work, as it has become apparent that each fluid behaves differently as its composition changes according to the environment in which it is being used; this includes the ability to form mist.

Discussions with members of the PSG has enabled the design of projects, as part of the three year HSE-funded programme, to be greatly improved as well as the outcomes of the research to be discussed with industry. The advice of members of the PSG and the donation of various samples of MWFs has been invaluable to the progress of the research. In respect to the study of mist and methods of monitoring, the direction this particular piece of work has taken has been, in some respects, influenced by the opinions of members of the product stewardship group. Interaction with UKLA has also enabled HSE and HSL to publicise the research activities regarding MWF with updates on the progress of the research being published in the UKLA trade magazine, “Lube”, and the presentation of data at an international symposium on MWF organised by the UEIL.

The PSG of UKLA have agreed to focus some of their resources on commissioning research with HSL to investigate how mist generation devices and real time particle monitors can be used to check the effectiveness of machine containment.

3.1.3 UEIL Symposium on MWFs, Barcelona

The UKLA MWF PSG kindly invited HSL staff to attend and present aspects of the MWF research at an UEIL-organised symposium on MWFs in September 2011. As part of the application theme, experimental data from a study of the influence of compressed air use on mist formation was presented by HSL staff. Presentations covered a wide range of aspects of MWF management including the impact of new regulations such as REACH and the growing need to improve management of fluids and their disposal. The impact of the removal of borates from MWFs, as well as the measurement of possible components of mist such as VOCs and pyrogens were discussed. Two presentations were of particular relevance to the HSL mist study. A workplace study using various air sampling techniques was conducted in Sweden to examine exposure to airborne bacteria, endotoxin and ultra-fines was presented by a team of university-based occupational hygienists. A novel cascade impactor that separated coarse, fine and ultra-fine particles was operated alongside IOM air samplers within the breathing zone of machine workers and was supported by the collection of data using a DataRam particle counter. This particle counter showed mean mist concentrations to be below 1.0 mg / m^3 with peaks of thoracic particles occurring during cleaning of machinery. Background levels in clean environments were shown to be < 0.1 mg/m^3. A representative from the DGUV gave an overview of new German guidance on the management of risks from MWF use. This included airborne concentrations of MWF mist and how reductions in levels of mist can be achieved. The approach of good management practice to reduce MWF mist was advocated in preference to actual mist measurement.

Networking opportunities allowed HSL staff to discuss methods of mist monitoring with members of STLE and ILMA and led to an appreciation of the American viewpoint on mist monitoring and measurement methods. On the whole, in the opinion of the American delegates their gravimetric method was best and could achieve measurement to levels of 0.2 mg / m^3. Given that the sensitivity limits for the existing American methods are between 0.05 to 0.1 mg / m^3, (NIOSH Method 500: 0.1 to 2 mg / m^3; ASTM D7049-04/NIOSH 5524: 0.05 to 2 mg / m^3), it was concluded that personnel would find it difficult to quantify mist levels < 0.1 mg / m^3.

Following discussions at this conference, it was decided that a survey of peer-reviewed publications and technical reports would provide an overview of MWF mist levels in workplaces and the monitoring methods being employed.

3.1.4 UEIL Health and Safety Committee Workshop

Involvement in the UEIL workshop on air quality in machining plants enabled discussions between various European research establishments in respect to airborne health issues linked to machining practices. Presentations covered a broad range of issues highlighting the diversity of knowledge and perspectives as to the key issues regarding air quality in machining workshops. Representatives from Finland and Sweden gave overviews of workplace studies. The Swedish group identified four machining workshops where workers had symptoms of respiratory ill health. They undertook occupational hygiene surveys as well as collecting mist samples and bulk fluid samples. Their findings suggest that ill health can occur even at low concentrations of mist equivalent to the RELs set by NIOSH of 0.4 mg / m^3 for thoracic particulates and 0.5 mg / m^3 for total inhalable particulates but levels of > 1.0 mg / m^3 can occur. The use of particle counters for the monitoring of mist was proposed as a good tool for the identification of mist sources and work tasks that lead to temporary high exposures. A focus on local exhaust ventilation led to the demonstration of mist when these systems were not adequate or not maintained. The Finnish researchers looked more in depth at the constituents of mist, both chemical and biological, including levels of total VOCs, formaldehyde and ethanolamines, as well as bacteria and endotoxin.

The use of particle counters for the monitoring of mist was again advocated and levels of chemical and bacteria were well below Finnish and OELs. The Finnish group suggested a revision of the target levels to account for water-miscible MWFs as the present limits are uninformative. They commented that generally aerosols stay close to their source or travel with air currents but VOCs spread easily by themselves. They also reported that VOCs were the most predominant impurity in the sampled air but levels were lower than found in the Netherlands and Sweden. One possible reason provided for the levels of VOCs in the air was that they were not retained by oil mist separators and may thus accumulate in the air. A presentation on the German environmental regulations for VOCs in workplace air was given by the same representative of the DGUV who spoke at the UEIL symposium on MWFs. It was suggested that approximately 90% of the mass of airborne particulates were found in the vapour phase not the actual mist and this also needs to be assessed. The presentations emphasised the need for good management of MWFs and the implementation of engineering controls as a means to control mist. In particular, the German representative suggested this was the way forward and not the measurement of the mist. The general conclusion from the meeting was that more gathering of field data and discussions were required before a European mist guidance limit could be set and this was outside the remit of UEIL.

3.2 Summary of published evidence

3.2.1 Types of studies included in this summary

Twenty-four relevant studies that included data following the assessment of airborne MWF mist were found after conducting a literature search. These studies included investigations of outbreaks of respiratory ill health where exposure to MWF mist had been monitored, workplace studies that assessed occupational hygiene including exposure to MWF mist, and aerosol mapping studies that tried to relate peaks of airborne mist levels with workplace activities. Pertinent data such as type of MWF process, air monitoring (personal or area), method of quantification and exposure limit or guidance value that applied at the time were recorded for each study. This is summarised in Table 5. The quality of the reported studies varied considerably, with most giving some description of the methodologies used. However, precise details of sampling point, sampling time, volume of air and whether multiple samples were taken was often lacking.

Table 5: Overview of studies included in summary of published evidence

		Number of papers	Comment
Study type	Ill health investigation	7	Mainly NIOSH HHE
	Mist exposure assessment	12	
	Aerosol mapping	5	
Type of sampling	Personal breathing zone (PBZ)	9	
	Static area	6	
	Both static and PBZ	9	
Method of sampling	Gravimetric	19	Different types of filter, sampling apparatus & analysis
	Particle counter	9	Various models
Comparison to Guidance limit	NIOSH REL (thoracic)	8	
	NIOSH REL (total)	6	
	ACGIH	2	
	OSHA PEL	1	
Identified Variables	MWF type	6	Soluble, semi-synthetic or synthetic
	Machinery type	4	
	Enclosure of machinery	2	Fully, partial or non-enclosed

3.3 How comparable are studies that have monitored MWF mist?

Due to the wide variation in the methods of determining water-miscible MWF mist, a true comparison between the reported measurements is difficult. This is often not only due to differences in the collection of air samples, whether be it the type of sampler used or the type of filter used, but also the method of analysis. The majority of MWF mist sampling analysis is gravimetric but the particle size class collected and the efficiency of collection is often determined by the type of sampler used (i.e., total inhalable fraction, thoracic fraction or respirable fraction). However, certain analytical techniques such as the NIOSH method will allow the thoracic particle fraction to be extracted from filters used to collect total inhalable particulates. The validation of many mist measurement techniques has been limited and this is particularly the case for the use of particle counters. Generally, particle counters are used to measure dust particles but several of the studies included in the literature survey have used such devices to measure mist. The viscosity and type of MWF, as well as the presence of fine metal particles, can influence the outcome of mist measurement.

A summary of the studies in peer-reviewed publications involving mist measurement found that mist levels in workplaces were always reported as a mass (milligram of mist per cubic metre of air (mg / m^3)), but a certain level of repetition within the experimental design meant the data was often expressed as an arithmetic mean or geometric mean, median or just maximum concentration. Along with wide variation in the methods of data gathering between studies and varying factors such as machining task or MWF type, this led to the decision that the mist concentration data extracted from the publications would not be altered in an endeavour to analyse pooled data.

3.4 What, in general terms, does the literature survey data demonstrate?

To allow a level of comparison, it was decided to separate personal breathing zone data from that collected at fixed or static area samples. To determine whether mist levels declined historically, data from publications were plotted against a timeline (Figure 1: Personal air samples, Figure 2: Static area air samples). The paper relating to an individual study number is shown in Table 6.

The data suggest that no general reduction in mist has occurred over the time period the studies were published. Measurement of mist reported as an arithmetic mean clearly shows that for both personal samples and static air samples, the levels are generally below 1.0 mg / m^3. The occasional data point above this value was associated with an outbreak investigation as determined by gravimetric analysis for total particulates or was detected using a particle counter. A similar scenario was observed for data reported as geometric mean with the majority of mist levels being below the NIOSH REL of 0.5 mg / m^3, with the occasional high value again being determined using a particle counter or related to an outbreak investigation. Median values were reported by two studies but the values were generally below the NIOSH REL as were minimum levels reported in several papers. However, maximum data points often greatly exceeded all guidance limits.

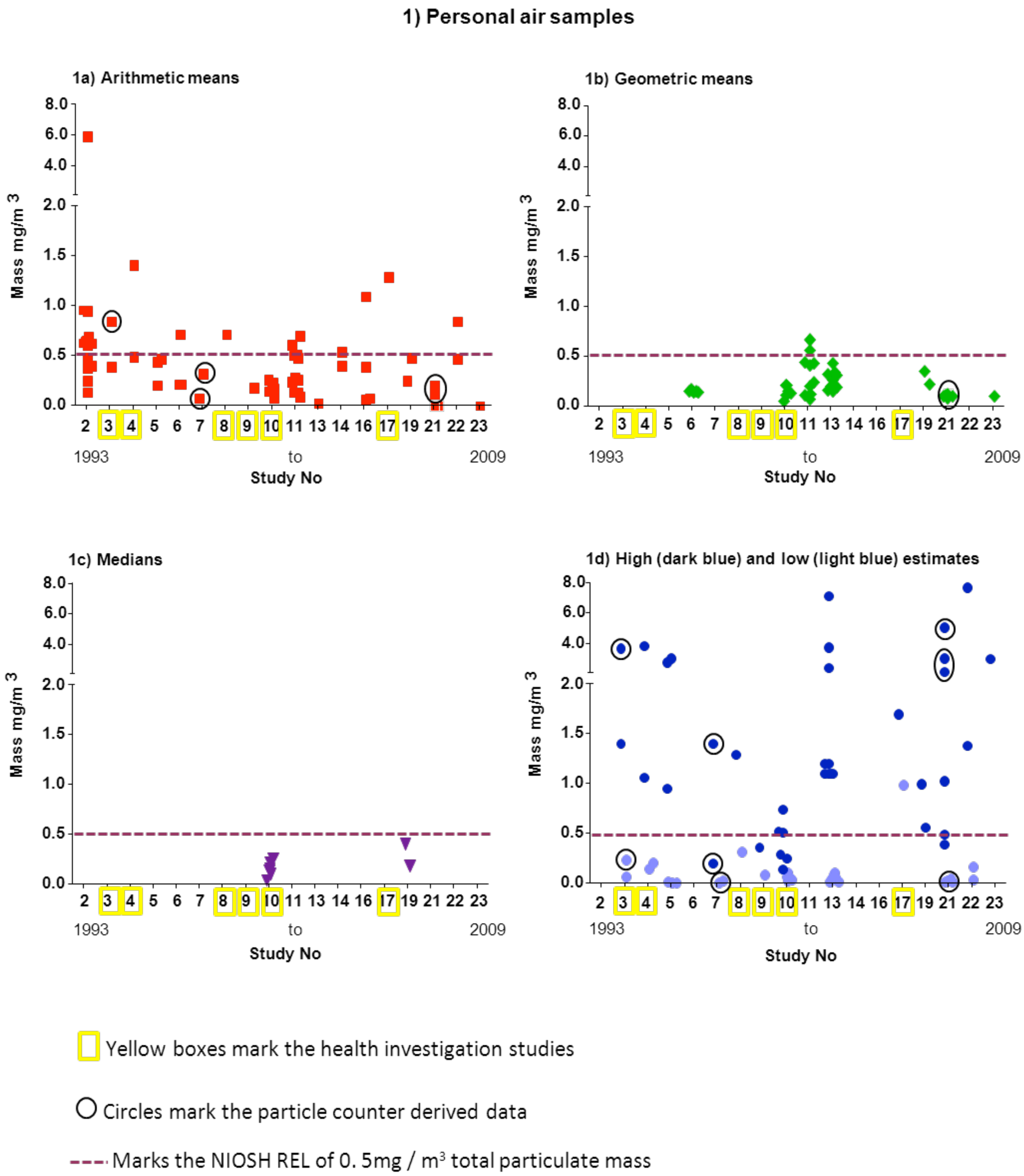

Figure 1: Graphical summary of personal exposure monitoring data from MWF mist based on mass (mg / m^3) obtained from literature over 16 years. Figure 1a) shows the arithmetic means; 1b) the geometric means, 1c) the median values and 1d) the low and high estimates. The dotted line marks the recommended NIOSH REL of 0.5 mg / m^3 total particulate mass up to 10 hours per day time-weighted average during a 40-hour work week.

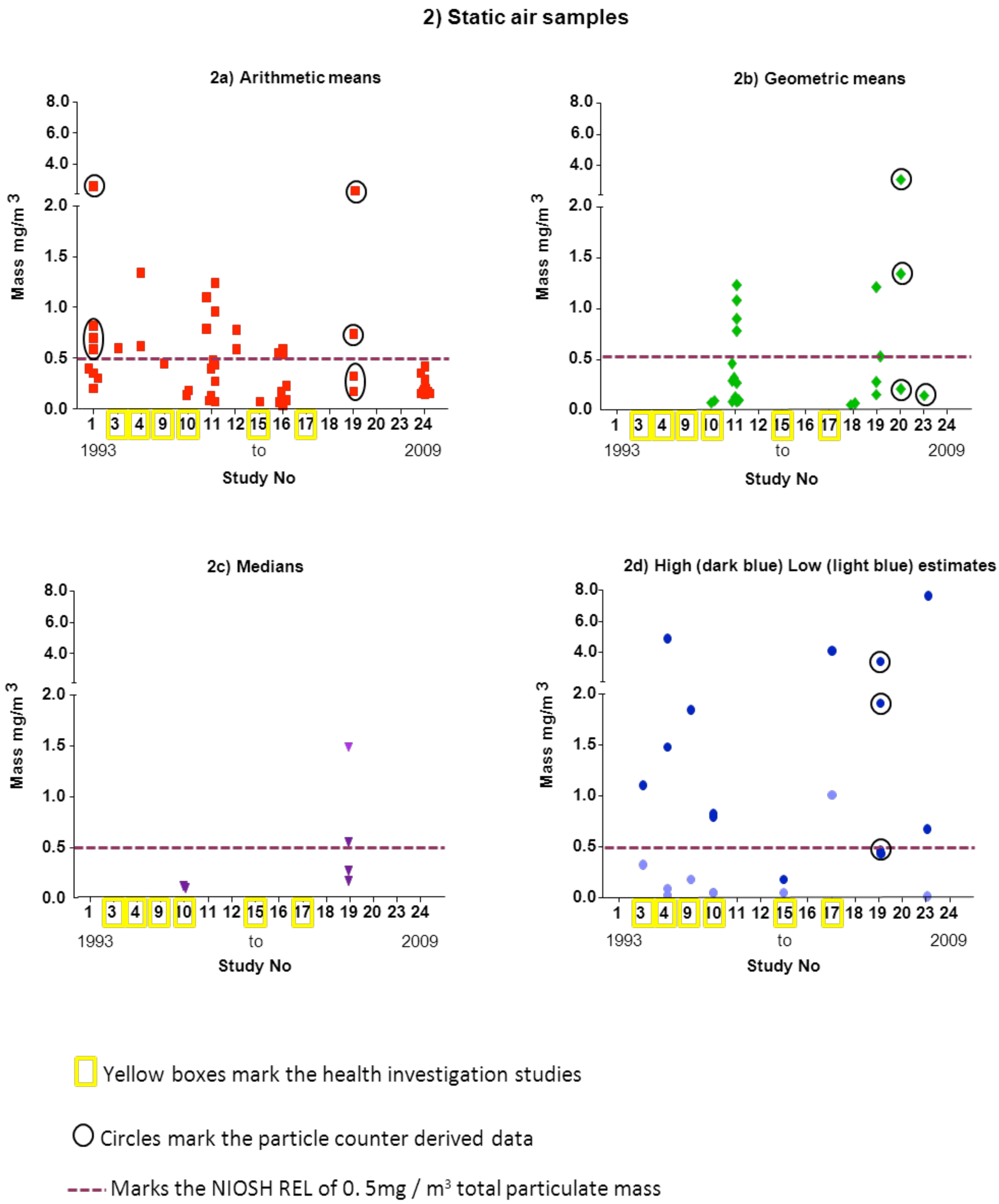

Figure 2: Graphical summary of static air monitoring data for MWF mist based on mass (mg / m^3) obtained from literature over 16 years. Figure 2a) show the arithmetic means; 2b) the geometric means 2c) the median values and 2d) the low and high estimates. The dotted line marks the recommended NIOSH REL of 0.5 mg / m^3 total particulate mass up to 10 hours per day time-weighted average during a 40-hour work week.

Table 6: Studies included in summary of mist measurement

Study No.	Reference
1	Chan *et al* (1990)
2	Kenyon *et al* (1993)
3	Trout *et al* (1996)
4	Piacitelli & Washko (1996)
5	Hands *et al* (1996)
6	Woskie *et al* (1996)
7	Sprince *et al* (1997)
8	Trout & Decker (1998)
9	Kiefer & Trout (1998)
10	Trout *et al* (1999)
11	Abrams *et al* (2000)
12	Rosenthal & Yeagy (2000)
13	Piacitelli *et al* (2000)
14	Eisen *et al* (2001)
15	Bracker *et al* (2003)
16	Dasch *et al* (2005)
17	Robertson *et al* (2006)
18	Peters *et al* (2006)
19	Sheehan & Hands (2007)
20	Heitbrink *et al* (2007)
21	Lillienberg *et al* (2008)
22	Park *et al* (2008)
23	Jaakkola *et al* (2009)
24	Gilbert *et al* (2010)

Examination of the data from the seven ill health investigations (studies highlighted on the timelines in Figures 1 and 2), in particular, shows that despite cases of respiratory ill health, mist levels were predominantly below the previous UK guidance limit of 1.0 mg / m^3 and in many cases the arithmetic means were below the NIOSH REL for inhalable particulates of 0.5 mg / m^3. However, in four investigations maximum values greater than 1.0 mg / m^3 were reported of which two studies had high data for both personal and static sampling.

3.5 Current position on national exposure limits for MWFs

Despite the relatively low number of qualifying papers in the study, their variable quality and the relatively few ill health investigations, the mist measurement data suggests a potential respiratory ill health risk even if levels are maintained to the NIOSH REL of 0.5 mg / m^3 or below. Much of the reported data in the study represents levels that are achievable more than levels that prevent ill health. The removal of the UK guidance limit of 1.0 mg / m^3 by HSE in 2005 following the outbreak of ill health at Powertrain is therefore justified; the cautious introduction of a new health-based guidance limit as the level at which respiratory health is protected is also vindicated.

3.6 Potential role for particle counters

Particle counters are being increasingly used in conjunction with the determination of mist by gravimetric analysis. However, only Volckens *et al* (2000) one paper compared the two methods of mist measurement. The majority of particle counters used for occupational hygiene assessment are portable devices designed for determining the concentration of dry dust particles. Models can vary greatly in respect to the particle size classes measured and the ease at which they become blocked when used for liquid particle measurement. It is still too early in the development of aerosol monitoring particle counters to ascertain whether they could be used to measure MWF mist against guidance limits. However, indications from the present summary of mist data suggest that in certain studies similar mist concentrations are reported when a particle counter is used compared to gravimetric analysis. Data points that have been derived using particle counters are shown in Figures 1 and 2. In some respects, particle counters may give a more accurate measurement of MWF mist as any loss of MWF particles due to poor recovery from the sampler or during analytical stages are negated. Therefore, it could be concluded that with further evaluation, there is a potential role for particle counters in the measurement of MWF mist and in particular the rapid assessment of high concentrations possibly due to poor extraction.

4.0 DISCUSSION

4.1 International and national exposure limits and guidance values for MWFs

Outbreaks of respiratory disease in machining workers in recent history have driven occupational health researchers and MWF products manufacturers to seek more evidence about 'candidate hazards' and risk factors that may be causing this disease. Following the UK Powertrain outbreak in 2005, there has been a focus on the biological hazards associated with the breathing in of mist and vapour formed during machining with water-miscible MWF. Discussions with international experts and the undertaking of a survey of peer-reviewed studies of mist have clearly highlighted that respiratory ill health is currently still occurring despite compliance with national exposure guidance limits. It was for this reason HSE removed the previous guidance limits for water-miscible MWF of 1.0 mg / m^3 in 2005.

Discussions between HSL and UK and European industry experts have highlighted a growing recognition that industry needs guidance and practical methods to monitor mist emissions from water-miscible MWFs. Concerns were expressed in the UK that it is difficult to persuade the industry in general to take further action to control mist emissions without a benchmark to aim for (recognising that this does not need to be health-based) and appropriate measurement methods to use. The situation internationally is that in some European countries changes have been introduced to lower national limit and guidance levels for water-miscible MWFs. Whilst HSL staff has consulted the European industry about monitoring mist exposures, new evidence has emerged that more cases of respiratory ill health are occurring in other countries; these are occurring despite exposure levels being low in relation to any historical guidance values that applied. For example, studies have been published from Finland (Jaakkola *et al*, 2009, Fornander *et al*, 2013) and France (Tillie-Leblond *et al,* 2011, Murat *et al*, 2012) and unpublished studies are on-going in Sweden (Personal Communication, Ann-Beth Antonsson, IVL Swedish Environmental Research Institute).

To address concerns about monitoring exposure to MWF mists, the UKLA and the UEIL Health and Safety Committee organised a workshop of European experts at the UEIL headquarters in Brussels. The aim was to establish an industry guidance exposure limit for water-miscible MWF mist that could be used across Europe. However, after lengthy discussions it was agreed that the setting of such a limit was highly complex and outside of their remit. The emerging view is that ill health occurs when MWFs are poorly managed and where there is a 'build up' of chemical and biological contaminants (i.e., micro-organisms and their by-products). No single factor has been identified as the cause of ill health although some researchers continue to argue that *Mycobacterium sp.* is important for the development of delayed respiratory hypersensitivity disease (Tillie-Leblond *et al,* 2011).

Setting enforceable health-based exposure limits for water-miscible MWFs has not been possible because of their complexity of formulation, and the lack of clear evidence pointing to specific hazards causing respiratory disease. However, hygiene-based limits set on good practice might present a more practical route to inform control strategies. Limits for straight mineral oil MWFs have remained in most European countries and the USA. The removal of guidance values for both straight oils and water-miscible MWFs has left the UK industry in a position where they have no benchmark to address standards, or the effectiveness of controls such as exhaust ventilation or mist suppression.

Although some expert bodies recognised many years ago the need to lower exposure guidance levels, such as NIOSH in 1998, and measure the thoracic and not total inhalable fraction of mist, these recommendations have not been adopted by certain regulators (i.e. OSHA in the US). More recently, initiatives have been implemented to improve standards and guidance about limiting exposure to water-miscible MWF mist in the USA; this has not included specific occupational exposure guidelines (OEGs). For example, the ASTM have been considering the incorporation of an OEG within a new standard for more than 5 years (ASTM E2889-12 'Control of respiratory hazards in the metal removal fluid environment'), which includes the monitoring of mist by ASTM method D7049. However, it was decided to adopt an approach where end users are required to set their own OEGs for the purpose of triggering various elements of the new standard, but not specify any values in the standard itself. Guidance is given to appropriate OEGs in an appendix to the standard which includes OEGs already set by the US Government and non-governmental organisations; some European countries have taken a similar line in seeking to set lower values. Based on a substantial review of the literature on exposure and risks to health, the Health Council of the Netherlands (DECOS) (2011) have proposed a health-based OEL of 0.1 mg / m^3 (8hr TWA) inhalable particulate mass for "working with MWF". This way of defining exposure is controversial since it suggests that any work where there is exposure to MWFs is relevant. A further concern is how compliance with such a limit could be established, since 0.1 mg / m^3 is already the limit of detection for gravimetric methods. Other European countries that have lowered their guidance values or exposure limits include Sweden, Denmark, and France for which 1.0 mg / m^3 (8hr TWA) (*particulate mass) is applied to all types of MWF.

4.2 Findings from summary of published studies on exposure to mist from water-miscible MWFs

The study carried out was not a complete review of the published literature reporting measurement of MWF mist as other authors have attempted more complete narrative reviews of hygiene investigations of airborne exposure to MWFs (Park, 2012). It has been observed that outbreaks of respiratory ill health have occurred despite at the time of the outbreak levels of mist were below those set out in national guidance. One aspect of this work concentrated on studies reporting respiratory ill health investigations but also where exposure to MWF mist had been measured. There has also been growing concern that measurement of exposure to mist in terms of inhalable mass, for example, is unrepresentative of the risk for respiratory disease. Therefore, findings from studies in which novel particle counting equipment was used were also summarised.

When selection criteria were applied to the published literature, only a small number of studies were left in which ill health and respiratory exposure to MWF mist had been assessed jointly; an even smaller number of studies had investigated the use of particle counting devices to assess exposure to MWF mist. Of the studies included in the summary there was a lot of variation in the study design, in particular the means by which exposure to mist had been quantified and presented (Table 5). No reports had solely focussed on studying ill health and exposure with the health investigations undertaking a limited exposure assessment, and the more detailed hygiene surveys not including investigations of ill health. There is therefore a considerable knowledge gap about the relationship between exposure to MWF mist, both in terms of duration and intensity (i.e., dose) in relation to the prevalence or incidence of respiratory symptoms. This is a general limitation for many occupational health and exposure studies.

Given the variability in the methodology of MWF mist measurement and the circumstances of each investigation, it was considered appropriate to leave the data as reported in each study rather than to seek to standardise or undertake a meta-analysis of these results. The summarised data should therefore be considered as a collection of separate estimates (means, medians and high and low values) of exposure reflecting the bias and uncertainties for these separate investigations. The trends in the data were considered in terms of the overall distributions of these estimates with respect to the NIOSH REL of 0.5 mg / m^3 for inhalable fraction, as this directly concerned water-miscible MWF mist levels).

With respect to the central estimates of exposure (Figure 1a, b, and c), these were less than 1.0 mg / m^3 irrespective of when the study was undertaken and closer in value to the NIOSH REL of 0.5 mg / m^3. Concern has been expressed about the practicality of reducing exposures as low as 0.5 mg / m^3, but these data suggest that exposures have historically been controlled to this level. Single high values up to 8.0 mg / m^3 were reported in some cases, even in recent studies, but the significance of these values is not clear in terms of additional risk of respiratory disease.

Examining those studies where mist levels had been monitored as part of an investigation of ill health, it does not appear that mist levels were greatly in excess of those reported by other studies. Individual high values were reported in four of the health investigation studies but the overall central estimates of exposure did not suggest consistently higher exposures. Despite the central estimates of exposure being lower than the guidance limit levels (Figure 1a, b, and c), outbreaks of ill health still occurred (Burton *et al*, 2012). This apparent discrepancy suggests that previous guidance limits for MWF mist do not protect against the risk for respiratory ill health and either the mist is not responsible, or the way that mist is quantified is not relevant to understanding the risk for respiratory disease.

Most measurement methods for water-miscible MWF mist have been based on quantification of collected mass using different devices to collect the samples, and different analytical methods to quantify the mass. Traditionally, most sampling methods have collected the inhalable fraction (i.e., mist particles up to 100 μm diameter) either based on sampling in the breathing zone or as static samples. The collected mass of the mist has been quantified either gravimetrically or using optical absorption techniques. Modifications have also been introduced to account for the mass of the total fluid collected, the volatile fraction, and insoluble particulate fines (Huynh *et al*, 2009). The lower limit of detection based on these methods is generally close to 0.1 mg / m^3. Concern has been expressed by some expert bodies that the inhalable mass is not the relevant measure needed to quantify risk for respirable disease. This underlines the reasoning behind the REL of 0.4 mg / m^3 for a thoracic fraction as proposed by NIOSH.

4.3 Use of particle counters

Evidence has been presented in peer-reviewed papers that the use of particle counters has being investigated alongside conventional gravimetric measures (Volckens *et al*, 2000, Verma *et al*, 2006, Lillienberg *et al*, 2008, Jaakkola *et al,* 2009) to assess the general air quality as well as MWF mist. The shortcomings of the gravimetric samplers have been reported as underestimation of mist concentrations due to evaporative losses of the semi volatile content of MWFs. Volckens *et al,* (2000) reported that such losses depend on factors such as fluid type, temperature and level of vapour saturation of sampled air, as well as levels of contamination with tramp oil.

Certain exposure mapping studies (O'Brien, 2003, Heitbrink *et a*l, 2007, Heitbrink *et al*, 2008) as well as some health investigation studies (Dasch *et al,* 2005, Jaakkola *et al*, 2009) have explored the use of particle counting devices which are capable of quantifying the numbers and size classes of mist particles, or assessing the mass of particles within specific size ranges (e.g., the thoracic fraction). In particular, Volckens *et al,* (2000) undertook a direct comparison of mist measurement performed using four different gravimetric samplers with the use of two different particle counters. This study was undertaken both in the laboratory and workplace, comparing mist associated with water-miscible MWF, synthetic MWF and straight oil. The conclusions were that although both methods of mist sampling had their shortcomings, particle counters were not an accurate means of MWF mist measurement. Two main reasons were given: particle counters have been developed to analyse solid particles not liquid droplets. Therefore, they are calibrated with manufacturer-derived aerosols with properties differing from those of MWFs. This may lead to bias in the response of the instrument and due to the high variability in MWFs; calibration to one mist species is not practical. Secondly, the results of the laboratory study undertaken by Volckens *et al,* (2000) suggested mist concentrations measured using particle counters may vary with the size distribution of the sampled mist. As this is influenced by the type of fluid, its initial formulation and changes in use, it was concluded that particle counters cannot accurately quantify MWF mist concentrations. Evaporation during the sampling process may also occur altering the dimensions of the smaller droplets and for methods based on light scattering the reflective properties of liquid differs from that of solid particles.

Volckens *et al,* (2000) found that particle counters tended to overestimate actual mist concentrations, yet in the workplace underestimated the levels of mist produced by water-miscible MWF when compared to mist measured using gravimetric samplers. The author suggested that errors associated with light scattering particle counters may be due to variations in mist particle size. It was found that when particle sizes were less than 2 µm, both the DataRam and the DustTrak samplers tended to overestimate mist concentrations. However, workplace measurements involving water-miscible MWF where the median particle sizes were 2.3 µm and 6 µm, respectively, the particle counters underestimated mist concentrations compared to the gravimetric samplers.

Volckens *et al,* (2000) suggested that particle counters may have a role as a survey instrument to locate areas of high mist concentrations. This is consistent with the findings of more recent investigations that have utilised particle counters. The results of these studies suggest that particle counters provide information that is not obtained using conventional measures of the total mass of the sample. It has also been suggested that the portable particle counters are practical in use and offer a quicker 'on site' assessment of exposure to assess the effectiveness of controls, e.g., whether machine enclosures are offering protection (Personal Communication, Simon Tebb, TSI, UK). Experts that attended the UEIL workshop on air quality in machining workshops presented some of the most recent evidence (although most of this work was being carried out in small enterprises) which included their use of particle counting devices in addition to the use of conventional gravimetric analysis methods.

The number of ultra-fine particles is usually increased in environments where exhausts and combustion processes take place. Previous HSL work on compressed airguns showed that in a well-managed machining plant, the numbers of respirable particles often exceeded 10^7 / m^3. These high backgrounds may originate from other processes such as engine exhausts and general environmental dusts. However, they may interfere with the practical use of particle counters to assess operator exposure to MWF mist. It is also likely that numbers of particles in a MWF mist will vary considerably from machine to machine in relation to many contributing factors (e.g., types of fluid used, rotational speed of the machines, whether enclosures and ventilation systems are working effectively, and the presence of mist suppression technology).

The UEIL workshop agreed that it is helpful to monitor mist emissions using particle counters as the most practical means to identify control solutions that are not working correctly, or where more controls on mist need to be applied. However, it should be noted that a large initiative funded by DGUV has carried out substantial exposure surveys to monitor mist from use of water-miscible MWFs (in addition to others) but is recommending the use of this data to define 'good practice'. Their aim was to encourage duty holders to follow good practice but without monitoring exposure.

The value of UEIL's approach is now being supported by a research initiative being developed by the UKLA MWF PSG. This initiative aims to assess the best and most practical means to use particle counters to monitor mist emissions and how these methods compare with boron-based marker method still used in the UK and gravimetric methods used elsewhere. It should also be noted that UEIL have identified air quality (and contribution from MWF mist) as a critical knowledge gap for which they are seeking to develop better guidance for industry as to how this may be achieved. Amongst the issues discussed by the experts at the UEIL workshop, apart from MWF constituents and biohazards, the contribution of VOCs to poor air quality was highlighted.

5.0 SUMMARY AND KNOWLEDGE GAPS

5.1 Conclusions

Despite more than twenty years of studies, a true understanding of the cause of respiratory ill health due to MWF mist inhalation has not been established. This lack of knowledge and the complexity of water-miscible MWFs, due to their change in constituents when in use, have made setting a health-based exposure limit impractical. However, this has led to problems for industry as MWF end-users consider it important to monitor mist levels to a benchmark value. A set value encourages end users to control levels of mist effectively. Equally, there have been questions over the future of the UK-recommended boron marker method of mist monitoring as opposed to the internationally-favoured gravimetric methods, particularly as boron is being used less frequently in MWF formulation, with the potential for its removal entirely. This study examined MWF exposure limits and guidance values set by other countries, and summarised studies that investigated water-miscible MWF mist and new techniques to monitor mist. The following conclusions were drawn:

- The majority of guidance levels or exposure limits for MWF mist relate to mineral oil and not water-miscible fluids. Certain RELs such as those set by NIOSH and INRS relate to all MWFs.
- European countries, with the exception of the UK, and the USA monitor all forms of MWF mist through capturing mist onto filters (with or without subsequent chemical extraction steps) followed by gravimetric analysis or the use of infra-red spectroscopy.
- The number of papers meeting the criteria of summary of water-miscible mist data was small and revealed inconsistencies in the determination of exposure.
- Historically, average mist levels have not changed over time; the majority were below the previous UK guidance value of 1.0 mg / m^3 with a large proportion below the NIOSH REL of 0.5 mg /m^3. This suggests that as ill health was reported at these low levels of mist, the exposure limits have no relevance to health risk.
- A different approach to MWF mist monitoring is required. This should be based on good practice to demonstrate effective control of mist and could include the use of particle counters. These devices allow a rapid means of monitoring mist but individual products and / or processes will need to be evaluated to ensure they are fit for purpose. The UKLA are presently funding HSL to undertake such an evaluation of particle counters.

5.2 Knowledge gaps

A fundamental knowledge gap that is preventing the setting of health-based exposure limits to water-miscible MWF mist is the relationship between duration and intensity of exposure (i.e., dose) and the prevalence of respiratory symptoms. On what basis then should we be setting guidance values for MWF mist exposure; should these be based on good industry practice?

- Further research is required into practical means of mist monitoring, such as the use of particle counters in order to demonstrate effective control. Can the devices be more accurately calibrated? Will exposure to MWF mist cause damage to the device as many are designed for solid particles not liquid droplets?
- For duty holders, what is the practicality for using particle counters and interpreting the data?
- Many previous studies focussed on personal exposure measurements since this is more informative about the risk to the individual. Should data be gathered about general air quality within workshops?
- Further investigations are required to examine the levels of MWF mist exposure including aerosol mapping to determine areas of high mist concentration and possible links to particular machinery or practices. This work might also include the use of particle counters to identify sources of MWF mist or the use of 'dust lamps' and smoke pencils to visualise movement of mist. This latter method is specified for use with spray booths use in motor vehicle repair (e.g., to prevent exposure to isocyanates) to identify leaks in enclosures, and to determine clearance times.[23]

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[2] HSG261 http://www.hse.gov.uk/pubns/books/hsg261.htm

[3] HSG276 http://www.hse.gov.uk/pubns/books/hsg276.htm

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7.0 APPENDICES

Appendix 1: UEIL Workshop Presentations

Ann-Beth Antonsson and Bengt Christensson (IVL Swedish Environmental Research Institute, Sweden): "Experiences from studies of workplaces with respiratory problems due to MWF."

Maikel van Niftrik, Wouter Fransman, Peter Tromp and Dinant Kroese (TNO, the Netherlands): "Measuring exposure to nanomaterials at workplaces across the lifecycle."

Inger Mattsby-Baltzer, PhD (University of Gothenburg, Sweden): "Microbiology of MWFs Why are there differences between products and workshops?"

Katri Suuronen, PhD (FIOH, Finland): "Exposure to MWF's - What are the risks for the workers?"

Helena Senior, PhD & Gareth Evans, PhD (HSL, UK): "Monitoring mist exposure."

Michael Rocker (DGUV, Germany): "The German regulation for VOC in workshops."

Appendix 2: HSL and HSE questions developed for industry consultation

- What experience do you have in using methods to quantify exposure to MWF mists?

  This was asked to determine whether people had a technical knowledge in mist monitoring techniques.

- Which method(s) do you use and what do you see as the advantages and limitations of these methods?

  This was asked to assess the range of different methods or modifications of methods and their strengths or limitations.

- Do you use these methods to monitor the performance of systems designed to control mists, or as a measure of adverse risk to respiratory health?

  This was asked to determine the aim of MWF mist monitoring in different countries.

- Do you have knowledge about other methods and how do these methods compare with the one that you use?

  This was asked to establish whether any comparative studies had already been undertaken.

- How comparable are the results you obtain with those obtained using other methods?

  This was asked to determine participant's opinion of the effectiveness of alternative methods.

- Do you think the method you use accurately reflects personal exposure?

  This was asked to determine whether monitoring focussed on personal or static sampling and whether as part of health-based investigation or measurement of control.

- Are you aware of any development in MWF technology that will require you to change the method you use to quantify mist?

  This was asked to determine awareness of low misting additives, mist collectors and identify any other technologies outside the UK.

- Do you think there is a need for new methods?

  This was asked to determine the level of satisfaction with methods presently available.

- What evidence is driving the use of new methods?

  This was asked to determine the reasons for the requirement of new methods.

- Do you think these new methods are likely to be practical and reliable for use by duty holders?

  This was asked to establish opinion of the validity of new methods.

Appendix 3: Data Extraction Form template

	Data extraction form		
Study identification (*Include author, title, year of publication, journal title, pages*)			
			Completed by:
1	**No of workers exposed?**		
2	**No of workers with resp ill health?**		
3	**Predominant symptoms / defined cases**		
4	**Method of mist measurement?** **What was the duration of air sampling or volume of air sampled?** Give information eg flow rate & time		
5	**Mist data?**		
6	**Data related to a limit?** **Which limit?**		
7	**Proportion of mist data below limits?**		
8	**What statistics were performed on the data?**		

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Consultation on monitoring of water-miscible metalworking fluid (MWF) mists

The aim of this research was to examine metal working fluid (MWF) exposure limits and guidance set by other countries, summarise studies and investigations that examined water-miscible MWF mist as well as new techniques to monitor mist. The following conclusions were drawn:

- The majority of guidance levels or exposure limits for MWF mist relate to mineral oil and not water-miscible fluids. Certain recommended exposure limits (RELs) such as those set by NIOSH (USA) and INRS (France) relate to all MWFs.
- European countries, with the exception of the UK, and the USA monitor all forms of MWF mist by capture onto filters (with or without subsequent chemical extraction steps), followed by gravimetric analysis or the use of infra-red spectroscopy.
- Historically, average mist levels have not changed over time; the majority were below the previous UK guidance value of 1.0 mg/m3 with a large proportion below the NIOSH REL of 0.5 mg/m3. This suggests that as ill health was reported at these low levels of mist, the exposure limits have no relevance to health risk.
- A different approach to MWF mist monitoring may be required based on good practice. The question is whether the use of monitoring devices or internationally recognised methods (eg gravimetric analysis) might help to determine the effectiveness of this control strategy.

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