Outbreak of respiratory disease at Powertrain Ltd, Longbridge, Birmingham

Emerging lessons

Note: Powertrain Limited went into administration in April 2005. The machinery in the factory was subsequently bought by Nanjing Automobile (Group) Corporation and removed to China.

Executive summary

This report outlines emerging lessons, which are for suppliers and users of metalworking and wash fluids, health professionals, and designers of metalworking and washing machines. There are also issues for occupational hygienists and health and safety regulators to consider.

Overview

- 101[1] definite and probable cases of respiratory disease have so far been diagnosed
- The outbreak significantly changes the perception of risk of respiratory disease arising from the use of water – mix metalworking and water – based wash fluids
- A key risk factor is the inhalation of harmful bacteria in metalworking and wash fluids, from mist generated by metalworking and subsequent washing
- Risk assessments for metalworking and wash fluids need to cover how harmful bacterial contamination is to be monitored and controlled
- As a safe level of exposure to mist from water – mix metalworking and wash fluids is not known, exposure has to be better controlled,
- Respiratory health surveillance should be carried out where there is mist from metalworking and wash fluids
- All users of metalworking and wash fluids need to be aware of the risks of serious respiratory disease which may arise from exposure to mist
- Designers of new metalworking and washing machines need to ensure that mist is controlled at source, and that machines are easily cleanable
- Aspects of the outbreak are still under investigation and there may be further findings
- In order to reduce the risk of further outbreaks there is a need to share major lessons as they emerge; this is being done through HSE's web site and contacts with other stakeholders.

1 The number of defined and probable cases can vary with the case definitions used and the dates on which they are applied. 101 is a figure derived from the most inclusive of definitions and dates of application.

Key points

Key point This symbol introduces key points from the investigation, the most significant of which are:

- the investigation did not begin until more than a year after the peak of the outbreak; the conclusions in this report rely both upon information recorded before and during the outbreak as well as scientific and medical investigations carried out afterwards.
- the distribution of the onset of breathlessness points to a widespread, breathable source (or sources) of harmful mist more prevalent in the northern half of the factory;
- the emergence of cases of extrinsic allergic alveolitis at the same time as cases of occupational asthma, and the presence of both diseases in some of those diagnosed suggests one rather than multiple causal agents, and the involvement of bacteria or fungi, although other and multiple causes cannot be ruled out;
- three workers diagnosed with EAA and two with OA demonstrated a serological response to crude metalworking fluid extract, taken from the large Mayfram sump in April 2004;
- three workers diagnosed with EAA demonstrated a serological response to Ochrobactum anthropi and seven workers, also diagnosed with EAA, to Acinetobacter sp, both bacteria present as DNA fragments in samples from the Mayfram sump taken in April 2004;
- in November 2005 the breathing of one worker diagnosed with EAA and another with OA showed significant reactions when challenged with samples of used metalworking fluid taken from the Mayfram sump in September 2004, but no reaction when challenged with samples of unused metalworking fluid of the type used in the same sump;
- the lack of reaction to challenge tests to unused MWF from the large sump in the area where there was most disease indicates that the chemical constituents of this MWF were unlikely to have been causative of disease. Also analysis of the levels of metals in the mist has shown these not to have been at levels which would give cause for concern. Similarly potential asthmagens within unused MWF have not been shown to be at levels in mist where disease may be expected;
- the outbreak appeared to develop and peak while exposures to mist from metalworking and wash fluids were apparently at or near levels, which represented good practice, as set out in HSE guidance, then current.

HSE guidance

HSE Guidance This symbol introduces HSE guidance arising from the investigation and other recent experience. The key parts of this guidance are:

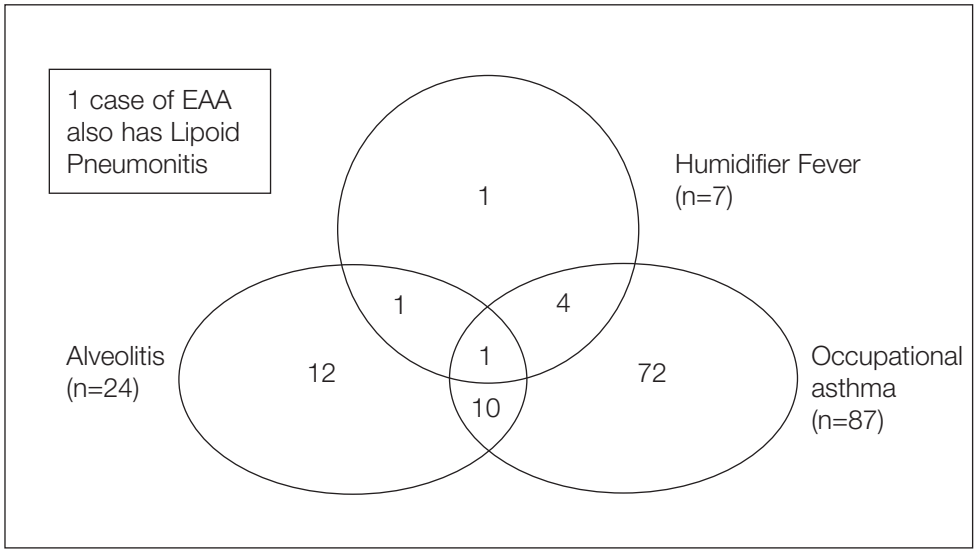
- washing machines linked to metalworking pose a risk of respiratory disease where mist is not controlled; mist from washing machines needs to be assessed and controlled;
- COSHH and other risk assessments must recognise the increased risk of serious respiratory disease, such as EAA and OA arising from metalworking and wash fluid;
- awareness of the risk of serious respiratory disease from metalworking and wash fluids has to be raised among all involved – employees, employers, as well as occupational health and health and safety practitioners;
- that the application of COSHH criteria for respiratory health surveillance to those exposed to metalworking and wash fluid mist should not be dependent upon guidance values, as there is no agreed health-based limit for exposure to mist;

- there are links between harmful bacteria in metalworking and wash fluids and serious respiratory disease, such as OA and EAA, and this risk needs to be assessed and controlled;
- direct means of monitoring bacterial contamination, such as dipslides[2], are essential to check the condition of fluids;
- close attention needs to be paid to cleaning metalworking and washing machines and checking that cleaning has been effective, by, for example, using dipslides, or other direct means of measurement

Introduction

By March 2006, 101 cases of probable and definite work related respiratory disease (excluding occupational bronchitis) had been identified among workers. Among these, there were 87 cases of occupational asthma (OA) and 24 cases of extrinsic allergic alveolitis (EAA). Some workers were diagnosed with more than one disease. It is thought these represent the world's largest recorded outbreak of occupational respiratory disease linked to metalworking and wash fluids.

Figure 1 Cases of definite and probable disease diagnosed by March 2006



Most of those diagnosed recall the onset of breathlessness in 2003, with a huge peak in March of that year.

The HSE investigation has been underway for about a two years and has involved several agencies, notably consultant physicians from the Birmingham Chest Clinic (BCC), a researcher from the University of Warwick Medical School, and the Health and Safety Laboratory (HSL).

The investigation has been aided by the extensive and detailed records kept of fluid management by Powertrain Limited and the fluid supplier.

2 A dip slide consists of a plastic carrier coated with a sterile culture medium, which is dipped into the liquid to be tested. It is then incubated to allow microbial growth and the density of the resulting colonies is compared with reference densities. Results are expressed in terms of colony-forming units per millilitre of fluid (cfu/ml). < (less than) 10^3 cfu/ml are considered to indicate good control of bacteria, between 10^3 – 10^6 reasonable control, and > (more than) 10^6 poor control.

Background to respiratory disease and metalworking

Metalworking fluids and asthma

Metalworking fluids are used to lubricate and cool metal machining processes such as drilling, milling and turning. The most commonly used are mixed with water at high dilution rates.

There is a risk of respiratory disease from breathing in the mist generated during machining and the subsequent washing of components.

Normally only about 5 isolated cases of occupational asthma from **metalworking fluid** exposure are reported to HSE in the UK each year. It is suspected that many cases of respiratory disease in metalworking go unrecognized. No cases from exposure to water-based **wash fluids** used in metalworking have been recorded.

There are thought to be between 1500 and 3000 new cases of occupational asthma each year from all causes. In general, occupationally acquired asthmas account for about 10% of all cases of asthma.

USA outbreaks of respiratory disease

Several large outbreaks of respiratory disease in car component factories using metalworking fluids have been reported in the United States. These outbreaks have shown a spectrum of disease including hypersensitivity pneumonitis (HP) known in the UK as extrinsic allergic alveolitis (EAA), occupational asthma (OA) and work – related bronchitis.

A *Mycobacterium* has been thought to be the causative agent in a number of these outbreaks. The end of outbreaks coincided with improvements in mist control, cleanliness of machines and better management of metalworking fluids.

No *Mycobacteria* were identified in fluid samples taken from Powertrain Limited in 2004.

Generally, the causes of respiratory disease from metalworking and wash fluids are not well understood. Metalworking and wash fluids are complex mixtures, which change in use and no safe level of exposure to mist from such water mix fluids has been identified.

Respiratory disease from metalworking fluids has been linked to:

- the constituents of the fluids themselves, and additives,
- bacteria in the fluids (particularly mycobacteria, which are related to bacteria which cause tuberculosis, but are not infectious in the same way),
- endotoxins (released from dead bacteria, sometimes arising from biocides used to kill bacteria),
- formaldehyde (a by product of some biocides),
- the metals involved, such as cobalt, and
- fungi in the metalworking fluids.

The main diseases diagnosed at Powertrain Limited are occupational asthma (OA) extrinsic allergic alveolitis (EAA) humidifier fever and work-related chronic bronchitis. Several of those affected are suffering from more than one disease.

A common occupational cause of such diseases is the inhalation of bacteria or fungi.

Washing machines

Industrial washing machines are used after machining to remove swarf and to clean components. Metalworking fluids are carried ('dragged out' or 'carried over') on components from metalworking machines into washing machines. Washing machines may contain harmful microorganisms carried over with metalworking fluids on components to be washed, as well as material from the machining process, which may include sensitising metals, such as cobalt, for example.

Wash fluids may also contain constituents, which are harmful to the lungs. Cross contamination by washing machine mist of open metalworking machine sumps may be possible. Washing machines can provide a moist warm environment for the rapid proliferation of microorganisms.

Washing machines can generate mist when in use, from the spraying of fluid and the use of high-pressure air jets to clean and dry components.

✍ **HSE Guidance** in the light of the outbreak is that exposure to mist from washing machines linked to metalworking poses a risk of respiratory disease.

The outbreak

A detailed analysis of the known key variables linked to the outbreak is being carried out. Among the variables are dates and locations of onsets of breathlessness, metalworking and wash fluids in use, and changes to them, fluid concentrations, dip slide readings, dates of cleaning of machines, tramp oil[3] and pH[4] levels, levels of contamination and the micro – organisms found in some machines, immunology results, and machine locations.

Most of those diagnosed could remember the general area where they were working when they first became breathless.

Of those who could recall where they were working when they first became breathless, most were working in the northern half of the factory. Of these, a large proportion was working in assembly areas, away from major sources of mist.

☞ **Key point** This distribution of the onset of breathlessness points to a widespread, breathable source (or sources) of harmful mist more prevalent in the northern half of the factory.

☞ **Key point** The emergence of cases of extrinsic allergic alveolitis at the same time as cases of occupational asthma, and the presence of both diseases in some of those diagnosed suggests one rather than multiple causal agents, and the involvement of bacteria and fungi, although other and multiple causes cannot be ruled out.

3 Tramp oil is machine, lubricating or hydraulic oil, which leaks into the metalworking fluid.
4 This is a measure of alkalinity or acidity, changes in which may be an indication of bacterial activity.

Metalworking at Powertrain Limited

The factory where the outbreak occurred is about 600 metres long and 200 metres wide. Transfer machines performing a number of sequential machining operations dominated the northern half. Metalworking fluids from large sumps of 210,000 (this largest sump was known as the Mayfram sump) 55,000, 35,000 and 19,000 litres capacity were pumped to these machining operations, from where they were drained back to the sumps. Individual metalworking and transfer machines with their own sumps predominated in the southern half of the factory. Components were washed after machining in about 20 dedicated washing machines spread around the factory.

Mist

Mist was more often noticed in the northern area of the factory, particularly near the largest common sump, the Mayfram, and machining associated with it, centring on what was known as 'Prismatic' (non-moving engine parts) operations. This had long been acknowledged by some workers to be a nuisance within the factory with possible, but unspecified, health implications. The perception of mist in the atmosphere varied from time to time. This was linked to whether the automatic roof ventilation louvres were open, the amount of tramp oil in the metalworking fluid and the machining operations being carried out. In autumn 2004, using a Tyndall Beam, mist was also seen to be coming from washing machines in the northern half of the factory.

Risk assessment

Hazard awareness and risk assessment

Over several years, some managers and workers had perceived a problem with mist at various times, particularly in the northern half of the factory, although the company was not aware of any risk of serious respiratory disease from the mist concerned. The risk of OA or EAA from metalworking or wash fluid mist was not specifically considered in the company's COSHH and other risk assessments.

Company risk assessments

Individual cutting, lubricating and wash fluids used in the factory each had separate COSHH assessments, developed by MG – Rover's Occupational Hygiene department, derived from suppliers' safety data sheets. Each data sheet mentioned irritation of the respiratory tract as the respiratory hazard. The data sheets did not address the possible bacterial contamination of fluids. No specific respiratory diseases were mentioned in safety data sheets. Local exhaust ventilation was 'recommended', mostly where there was 'excessive product misting', although 'excessive' was not defined.

This was repeated in Powertrain Limited's COSHH assessments, in which no specific respiratory diseases were recognised either from the handling of neat fluids or the use of diluted fluids in machining or washing. Risks arising from contamination by microorganisms were not addressed.

These COSHH assessments fed into more general risk assessments for work cells or areas, in which the hazards of that cell or area were further assessed and rated. In these, the severity of the potential injury arising from exposure to 'coolants etc' was recognised in Powertrain Limited's scheme of risk assessment as Level 3, meaning 'lost time injury with first aid treatment'. This, together with the risk probability and frequency rating, meant that the overall assessment for 'coolants etc' in use invariably fell below the level for further action, within the formal confines of the recorded risk assessment.

Further action was however taken, including continuous fluid management and monitoring, and, in October 2003, replacement of half the contents of the largest sump, in response to concerns about increased oil in the metalworking fluid in the main sump, leading to increased misting. Continuous fluid management was organised by means of weekly meetings chaired by Powertrain Limited and involved fluid suppliers and machine cleaners. This may therefore be regarded as part of an ongoing risk assessment addressing both fluid quality and risks from biological agents, with significant findings recorded in terms of fluid measurements and changes, and machine cleaning.

HSE guidance in the light of the outbreak is COSHH and other risk assessments must record the increased risk of serious respiratory disease, such as EAA and OA, arising from metalworking and wash fluids. Risk assessments for metalworking must deal with how to:

- develop and maintain management and worker awareness of this risk,
- maintain metalworking and wash fluid quality and minimise bacterial contamination, to be checked by dip slides or similar means,
- minimise risks from mists and aerosols, and
- identify and report respiratory disease symptoms and follow them up.

Where there are occupational health professionals at a company, they should be involved in the assessment process.

Health surveillance

Health surveillance before the outbreak

For some time before the outbreak, and during its peak in March 2003, a trained occupational health nurse was at the company, supported by MG - Rover occupational health nurses. A specialist occupational health physician was also available for one session a week. The occupational health nurse left in April 2003, and was replaced by agency nursing cover.

In July 2003, the sickness absence of some of those affected alerted the occupational health physician to a possible link to conditions at work. In late 2003 this physician recommended health surveillance using a questionnaire and spirometry[5]. The first diagnoses of occupational respiratory disease, EAA, were in December 2003. Consultant occupational health physicians from the Birmingham Chest Clinic were consulted by the company and became involved in an investigation. Further cases of EAA were then diagnosed. EAA linked to metalworking (or wash) fluids is not reportable under RIDDOR.

Key point RIDDOR needs to be amended to make cases of EAA arising from work with metalworking and wash fluids reportable.

Before July 2003 no symptoms of respiratory disease appear to have come to the attention of the occupational nurses or physicians provided by the company, which were subsequently linked by them to conditions at work.

HSE guidance is that in the light of the outbreak the level of awareness of the risk of serious respiratory disease from metalworking and wash fluids has to be raised among all involved – employees, employers, as well as occupational health and health and safety practitioners.

5 Spirometry is a means of checking the capacity of the lungs.

Some symptoms were reported to GPs before and during the outbreak. Sometimes these were recognised as possibly being linked to work, and referred onwards to a variety of consultants, for further investigation, but there was no means of linking these cases.

☞ **Key point** Means of helping GPs consider the possibility of work-related causes for adult - onset asthma, and subsequently linking these would help identify workplaces of concern and the early stages of outbreaks[6].

Company environmental monitoring and risk assessment

Environmental sampling was carried out by independent consultants between May 2002 and October 2003. This was a benchmarking exercise to determine levels of metalworking fluid mist concentrate in the air, initiated by the Powertrain Safety Manager. Monitoring carried out from 31 October 2003 to February 2004 was aimed at measuring levels of mineral oil mist in the air as a response by the company to an apparent increase in misting in the factory and the concerns of employees.

After December 2004, when cases of disease were emerging, the company relied on this sampling together with fluid monitoring data, to show that risks were low. Results from the monitoring indicated that environmental levels of metalworking fluid concentrate in air were generally below the guidance value of 1mg/m^3, current at the time, and that levels of mineral oil mist in air were also below the guidance value of 3mg/m^3 current at the time. The company believed this meant health surveillance was not required.

✍ **HSE guidance** in the light of the outbreak is that the application of COSHH criteria for respiratory health surveillance for those exposed to metalworking and wash fluid mist should not be dependent upon exceeding guidance values, as there is no agreed health-based limit for exposure to mist.

The monitoring and control of bacterial contamination

Large sumps

The large common sumps in the northern half of the factory were monitored before and during the outbreak for pH, concentration, tramp oil, bacteria and fungi. Checks were made three times a week. Dipslides for all the large sumps recorded 'clear' for bacteria throughout 2002, 2003 and 2004, with the exception of the Op 90 Sump, which showed six readings of 'moderate' (10^4 – 10^6 cfu/ml) and one of 'light' contamination (less than 10^3 cfu/ml), but only before April 2002. Thereafter, over the period of the outbreak, dipslides from this sump recorded 'clear' for bacteria.

☞ **Key point** Three workers diagnosed with EAA and two with OA demonstrated a serological response to crude metalworking fluid extract, taken in April 2004, from the large Mayfram sump. Ten workers diagnosed with EAA demonstrated a serological response to predominant bacteria, Ochrobactum anthropi and Acinetobacter sp, present as DNA fragments in the sump.

6 It is understood that GPs now have code OA 173D, by which to record suspected cases of occupational asthma, which should make identifying OA notifications to the NHS easier.

Key point In November 2005 the breathing of one worker diagnosed with EAA and another with OA showed significant reactions when challenged with samples of used metalworking fluid taken from the Mayfram sump in September 2004, but no reaction when challenged with samples of unused metalworking fluid of the type used in the same sump.

HSE guidance is that the outbreak has confirmed that there are links between harmful bacteria in metalworking fluids and serious respiratory disease, such as OA and EAA. Bacterial contamination needs to be prevented or controlled by users of metalworking and wash fluids.

Contaminated machines in the northern half of the factory

In August 2004 a few washing and metalworking machines (with small individual sumps) in the northern half of the factory were found to be heavily contaminated with bacteria. Some of the predominant bacteria from some washing machines and some surface scrapings nearby were the same as those isolated from the large Mayfram sump by Polymerase Chain Reaction (PCR) DNA analysis. All washing machines were capable of dispersing mist, some more than others.

The metalworking machines identified as contaminated in August 2004 were located along the eastern edge of the factory. These machines may have caused some disease nearby, but mist from them was unlikely to disperse over the wider area where most of those affected recalled the onset of breathlessness. Washing machines, however, were found to be expelling mist into this general area[10], where many of those diagnosed were working when they first became ill. Some of these machines were found to be heavily contaminated with bacteria in August 2004.

HSE guidance is that mist from washing machines needs to be assessed and controlled in much the same way as mist from metalworking machines.

Contaminated machines in the southern half of the factory

Some metalworking machines with small individual sumps as well as washing machines in the southern half of the factory were also found to be heavily contaminated with bacteria in August 2004. These machines, too, may have caused some disease, but the proportion of workers diagnosed with disease recalling onset of breathless in this half of the factory was much smaller than that in the other half of the factory. No washing machines expelling mist were observed in this half of the factory.

Monitoring of machines with individual sumps

Metalworking machines with individual sumps and washing machines were generally not monitored for bacteria using dipslides before and during the outbreak. Weekly checks on pH, concentration and smell were carried out on machines with individual sumps, in line with HSE guidance then current. Readings indicated low levels of bacteria and contamination was perceived to be under control.

7 Sera were taken from those diagnosed with EAA.
8 Predominant bacteria in metalworking and wash fluids may change rapidly over time.
9 Although the Mayfram had shown ‘clear’ over the period of the outbreak according to dipslide readings, bacteria in numbers too small to register on dipslides were isolated and identified by DNA analysis by PCR.
10 This was demonstrated by video while washers were still in production. Attempts to recreate operational conditions after the washers had ceased to be used were not successful.

Dipslides were used to check the cleanliness of washing machines for a short period in 1999. These showed the bacterial contamination of washing machines to be under control, and the use of dipslides was discontinued.

The weekly checks at washing machines and small sumps serving individual metalworking machines, together with cleaning at intervals and by smell was not enough to prevent high levels of bacteria. Bacteriological testing by HSL in August 2004 from some machines indicated poor control of bacteria, with very high levels recorded at some machines. Levels greater than 10^6 (10 million colony forming units per millilitre) were found in several washing machines, and small sumps serving individual metal working machines.

HSE guidance is that direct means of monitoring bacterial contamination, such as dipslides, are essential to check the condition of fluids. These should accompany less direct means such as levels of pH or smell.

Cleaning of machines with individual sumps

Cleaning was carried out for both metalworking and washing machines every few weeks or so, using a cleaning matrix, or when the machine smelt. The intervals on the matrix at which washing machines were cleaned were governed by their propensity to produce waste solid material. The cleaning process generally was not as recommended in HSE guidance, current at the time, principally in respect of circulation of wash fluid and system cleaner during the cleaning cycle.

HSE guidance in the light of the outbreak is that close attention needs to be paid to cleaning metalworking and washing machines and checking that cleaning has been effective, by, for example, using dipslides, or other direct means of measurement.

The prevention and control of mist

HSE technical development survey 1996

A detailed study of exposure to mist where aluminium cylinder heads and blocks ('Prismatic' operations) were machined[11] (the northern half of the factory) was carried out by HSL in February 1996[12]. This work was part of an HSE Technical Development Survey to help develop a suitable method[13] of measuring water – mix coolant levels in air. The survey found conditions to be similar to those encountered in other factories surveyed. Levels of personal exposure to metalworking fluid concentrate were found to be between 0.89 and 3.48 mg/m^3. Levels from background samples were found to be between 0.8 and 17.49 mg/m^3. These were generally higher than levels recorded by independent consultants at the time of the outbreak in 2002 and 2003, and subsequently by HSL in 2004.

1 mg/m^3 was a guidance value, which represented good practice but which was not based on possible health effects. HSE guidance at the time, said it was based on levels 'where there have been few complaints about respiratory irritation'. Unlike Maximum Exposure Limits (MELs) and Occupational Exposure Standards (OESs) this guidance value had no force in law.

11 There were also additional machining operations in the vicinity, relating to 'K' and 'A' Series engines, which were not present in 2003 and 2004.
13 GOH 1565 Metalworking fluid TDS visit report FCG file number M/FCG/1008/95 FCG Job No 185/S/95 S20:320.95
13 *Metal working fluids (Mwf) Exposure assessment document EH74/4* HSL, 1997.

Company action on mist

Before the outbreak, Powertrain Limited took steps to reduce mist on some machining processes, particularly from Prismatic operations. These included reducing coolant flow and atomisation, ensuring new machines were better enclosed, restricting the use of compressed air and minimising tramp oil. The involvement of the workforce in identifying and dealing with sources of mist, and the use of a Tyndall Beam in 1994 meant that some mist sources were addressed. On the available data[14], the company appeared to have succeeded in reducing sampled background and personal exposures to metalworking fluid concentrate and mineral oil mist between 1996 and 2003.

Company sampling 2003-04

Around April 2003 there was further concern over mist in the northern half of the factory, possibly arising from a change of hydraulic oil, which was not being released from the metalworking fluid and skimmed off. From October 2003 onwards, the consultant engaged by the company carried out further sampling. This time levels of mineral oil mist in air, rather than metalworking fluid concentrate, were measured. Environmental concentrations of mineral oil mist of between 1 and 4 mg/m^3 and an average concentration of just above 1 mg/m^3 were recorded. Personal samples indicated exposures of between 1 – 1.7 mg/m^3, with an average exposure of 1.3 mg/m^3. These levels were recorded after the outbreak had peaked and action taken to reduce tramp oil. The guidance value for exposure to mineral oil, or neat oil, mist at the time was 3mg/m^3. This value was not based on any possible health effects at this level of exposure, but like the water – mix guidance value, represented good practice.

Key point The outbreak appeared to develop and peak while exposures to mist from metalworking and wash fluids and levels of mineral oil in air were apparently at or near levels, which represented good practice, as set out in HSE guidance, current at the time.

HSE guidance in the light of the outbreak is that mist needs to be better controlled, and the current guidance values have been withdrawn.

At the time of the outbreak, despite exposures generally being within the guidance value for exposure to metalworking fluid concentrate, concern remained that was still too much mist in the air. Sampling during the outbreak generally measured only the amount of metalworking fluid concentrate in the air, and not the total aerosol or total inhalable particulate[15] (TIP). Mist from washing machines is likely to contain a higher proportion of water than concentrate, compared with mist from metalworking machines. This may partly explain why mist in the factory remained clearly visible while sampled concentrations of metalworking fluid were relatively low. In 2003 and 2004 increases in tramp oil may also have contributed to visible mist

HSE guidance in the light of the outbreak is that users should have regard to the total mist in the air and not only the metalworking fluid concentrate portion of it, and mist should be reduced as low as is reasonably practicable.

14 This data includes HSE/HSL's own Technical Development Survey of 1996, later sampling by a consultant hired by the company in 2002–4, where the analysis of samples was carried out at HSL, and HSL's own sampling in 2004.

15 The relationship of total inhalable particulate (TIP) (which will include water) to metalworking fluid concentrate is discussed in Simpson et.al. 'Occupational Exposure to Metalworking Fluid Mist and Sump Fluid Contaminants' in *Ann occup. Hyg.*, Vol. 47, No 1, pp 17-30, 2003; TIP can generally be at least more than twice the measured level of concentrate.