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The causative factors of dermatitis among workers exposed to metalworking fluids

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The causative factors of dermatitis among workers exposed to metalworking fluids

Sean Semple
Department of Environmental and Occupational Medicine
Aberdeen University
Fosterhill Road
Aberdeen
AB25 2ZP

Mairi Graham, Hilary Cowie & John W Cherrie
Institute of Occupational Medicine
Research Park North
Riccarton
Edinburgh
EH14 4AP

Metalworking fluids (MWF) are widely used in metal processing. Exposure to MWF is known to cause irritant contact dermatitis, but it is unclear which aspects of the fluids play an important role in disease development. This research first examined which MWF parameters were linked with increased skin irritation in a laboratory investigation. These studies suggested that MWF are no more irritating, at least over short time periods, than water. We concluded that improvements in the management of MWF concentration, pH, metal fines and bacteriological contamination are unlikely to have as great an impact on dermatitis risk as reducing dermal exposure to MWF.

The second phase involved a workplace study in six engineering plants. We developed a multimedia computer package to deliver a questionnaire on skin condition, guidance on working with MWF, and advice on reducing dermatitis risk. The multimedia package helped bring about changes in worker behaviour to reduce dermal exposure and reductions in exposure were sustained across two follow-up visits. Workers receiving the guidance were also found to increase their use of skin care creams. There was also evidence that the management of MWF improved. Towards the end of the project we identified a need for a new method of sampling the duration and frequency of wet-work and we developed a prototype wet-work sampler.

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EXECUTIVE SUMMARY

Metalworking fluids (MWF) are used across the engineering and metal processing sectors. Workers in jobs where contact to MWF occurs have a particularly high prevalence of skin problems- with some reports suggesting that the lifetime prevalence can be as high as 1 in 3. The relationship between MWF and the development of dermatitis is poorly understood and it is unknown if there are specific MWF attributes that play a particularly important role in disease development. To examine the impact of MWF on dermatitis this study was divided into two parts. The first laboratory based element aimed to examine if certain MWF parameters were linked with increased skin irritation. The second workplace-based field trial set out to determine if a multimedia questionnaire and training package could be employed to reduce dermal exposure to MWF and improve skin condition.

Using reconstituted epidermis we examined the effect of contact between MWF and skin. Trans-epidermal water loss (TEWL) was used to provide a measure of the epidermal barrier function, a common marker for irritation. Our laboratory studies suggested that MWF are no more irritating to the skin, at least over the short time periods employed in this study, than contact with water. This has important implications for dermatitis prevention within the engineering sector. Improvements in the management of MWF concentration, pH, metal fines and bacteriological contamination are unlikely to have as great an impact on skin disease risk as programmes aimed at reducing dermal exposure to MWF.

As part of our field-work we developed a novel multimedia package to deliver a questionnaire on skin condition, some guidance on working with MWF, and some simple advice on how to reduce the risk of developing dermatitis. We recruited six engineering sites within Scotland. On completion of an initial baseline visit this package was provided to half of the workplaces involved in our study with the remaining sites acting as controls. We assessed workers' (n=92) skin condition by questionnaire and TEWL measurements. We also measured a variety of parameters indicative of MWF management, and employed interception and removal methods to quantify work-shift dermal exposure to MWF. Sites were followed-up on two further occasions at 1-month and 6-month stages.

The key findings of the field-work suggest that the multimedia package can help bring about changes in worker behaviour to reduce dermal exposure. Reductions in exposure were sustained across the two follow-up visits. Workers receiving the guidance were also found to increase their use of skin care creams. There was also evidence that the management of MWF improved in both the control and intervention groups with the largest increases in the intervention group.

Towards the end of the project we identified a need for a new method of sampling the duration and frequency of wet-work rather than simply assessing dermal exposure by the interception and removal methods that we had employed. The IOM Wet-Work Sampler is a simple concept based on the measurement of changes in skin temperature when the hands are wet. Our preliminary laboratory trials suggest that this device may enable data acquisition to create a wet-work index that is likely to be much more closely linked to the risk of dermatitis than current mass-based sampling methods.

We recommend that guidance be developed to reduce the duration and frequency of wet-work within the engineering sector and that workers are made aware of the fact that while management of MWF parameters is important to help prevent inhalation-based ill-health, it is unlikely to have significant impact on the risk of skin disease. Further work to develop and disseminate the multimedia training package should be considered to tackle occupational skin disease among metalworkers.

1 INTRODUCTION

1.1 METALWORKING FLUIDS

Metalworking fluids (MWF) are used in a wide range of manufacturing industries where metal machining, grinding or cutting operations are carried out. MWF are known by a variety of terms such as 'coolant', 'cutting fluids', 'white water', 'slurry' or 'soup' and are typically used at the tool-metal interface to cool and lubricate. These fluids can be grouped into four classes: straight oil; soluble oil; semi-synthetics; and synthetics. Straight oils are highly refined mineral oils that are used without any dilution. The synthetic, semi-synthetic and soluble oil classes are all mixed with water prior to use. These different types of MWF have different roles in manufacturing industry and comprise different mixes of oils, emulsifiers, and water. Additives designed to prevent bacterial growth and/or improve odour are also commonly added. In addition to the chemical components of the MWF, metal particles (also known as fines) and biological contaminants may also build up in the fluid as it is used.

The known health effects of MWF are summarised in the Health and Safety Executive (HSE) Guidance Note EH62 (HSE, 1991). MWF pose a risk to health via two routes of exposure: inhalation of MWF aerosol, with consequent airway toxicity and dermal contact with MWF producing local effects on the skin. EH62 also notes that unrefined mineral oils have been shown to cause skin cancers but as exposure to this type of MWF is now almost exclusively historical the number of skin cancers arising from MWF exposure is likely to be very low.

1.1.1 Inhalation exposure and health effects

Inhalation of MWF is associated with an increased risk of asthma. Work by Rosenman *et al.* (1997) examined 755 workers handling MWF in Michigan and showed that almost 20% of these workers had developed asthma or asthmatic symptoms since beginning work with MWF. The findings of this study seemed to indicate that asthma was most common among individuals working with synthetic oils compared to mineral based MWF. This may be due to higher levels of biological contaminants in these water-based MWF.

McDonald and colleagues (2000) studied the incidence of occupational asthma in the UK from 1989-97 using the Surveillance of Work Related and Occupational Respiratory Disease (SWORD) data. Their data showed that 'metal treatment' workers had an average annual incidence of occupational asthma of 211 per million workers per year. This represents a greater than ten fold increase in risk when compared to the average of 19 per million workers per year for all occupations. A recent outbreak of occupational asthma and alveolitis at a car engine factory in the UK shows that the risks from inhaling MWF are often still poorly controlled (BBC News, 2004).

There is also some evidence of a risk of upper aerodigestive tract cancers from the inhalation of MWF. Zeka and colleagues (2004) examined a cohort of automotive workers exposed to MWF. Their findings are suggestive of a link between exposure to straight MWF and larynx cancer, with less convincing evidence of a relationship with oesophageal cancer and no evidence of an association with stomach cancer.

1.1.2 Dermal exposure and health effects

Contact between the skin and MWF will arise from direct handling of fluids either during top-up of sumps, maintenance and use of cutting machinery or during tool-changing activity. There will also be indirect dermal exposure from the deposition of MWF aerosol onto the skin and

from contact with contaminated work-surfaces, tools or products. Another significant route for dermal contact arises from MWF contaminated overalls or clothing.

While occupational contact dermatitis is the most common type of ill-health arising from dermal exposure to MWF, other skin diseases may also be caused. Reports of scrotal cancer among metalworkers arising perhaps from the practice of storing MWF-soaked rags in pockets, are suggestive of a causal link with earlier types of unrefined mineral oils (Calvert *et al*., 1998). This risk has been largely eliminated by changes in the oils used.

Occupational contact dermatitis is more common among metalworkers than most other industrial workers. Meyer and colleagues (2000) used the surveillance data from the UK EPI-DERM and the Occupational Physicians Reporting Activity (OPRA) schemes to calculate an all industry annual incidence of 12.9 new cases of occupational contact dermatitis per 100,000 workers. Between 1993 and 1999 there were 280 cases among workers classified as machine tool operatives giving an annual incidence rate among this population of 54 per 100,000 workers. Cutting oils and coolants were identified as the primary agents causing the dermatitis in over 50% of these cases. It should be noted that these incidence figures are likely to underestimate the true scale of dermatitis as they are generated from reports from consultant dermatologists (EPI-DERM) and occupational physicians (OPRA) and are likely to represent only those with particularly severe disease or those with access to workplace health surveillance. Many individuals who either consider their skin disease to be normal or part of their job, or who are treated by their GP may not be picked up by the EPI-DERM/OPRA surveillance schemes.

Pryce and colleagues (1989) provide a review of soluble oil dermatitis describing the clinical features of the disease and the substances that can induce or exacerbate the symptoms. This review highlights MWF as one of the primary causes of occupational contact dermatitis.

1.2 DERMATITIS

Dermatitis, also known as eczema, is caused by damage to the skin characterised by redness, swelling and flaking skin. Symptoms may also include cracking and blistering of the skin surface. Dermatitis can affect anyone at any age and although it can occur anywhere on the body it is most common on the hands. Dermatitis can either be due to an inherited predisposition to the condition or can be brought on by contact with certain substances. People born with a tendency to get dermatitis often have a family history of allergic diseases such as hay fever and asthma (atopy). Contact dermatitis however is caused by the interaction of the skin with some chemical or physical process. It can take one of two forms: irritant dermatitis or allergic dermatitis.

Irritant contact dermatitis is due to direct damage of the outer skin layer by a chemical or other substance. It is often caused as a result of repeated mild irritation from substances such as soaps, detergents and water. Allergic contact dermatitis occurs when the body's immune system reacts to a particular substance that has previously been applied to the skin. It is a much rarer condition than irritant dermatitis and it is not known what triggers allergic reactions or why some individuals react to certain substances.

Studies have shown that groups of workers who handle MWF can have a prevalence of dermatitis between 20 and 30%, much higher than the 4% recorded among the general population (Sprince *et al*., 1996). The causes of dermatitis in these workers are likely to be multifactorial. Metal-working and machining occupations will have exposure to a wide variety of metal types, different types of MWF, solvents and biocidal additives. It is likely that the skin

will also be subject to mechanical damage from sharp metal fines or abrasive washing techniques.

Although dermatitis can be treated to reduce the severity of symptoms it can rarely be completely cured and so it is important to prevent it from developing in the first instance. Management of MWF to ensure that fluid parameters are kept within certain limits is important. Reducing both airborne and dermal exposure may be key to preventing dermatitis, asthma and other ill-health effects.

1.2.1 Assessment of skin condition

The diagnosis of dermatitis is particularly problematic due to variability in skin condition between individuals and over time in the same individual. Identifying the cause of the skin condition requires knowledge of activities at home and in the workplace, including a listing of workplace exposures. Differentiating between allergic and irritant contact dermatitis is also difficult.

There are a number of objective measures of biophysical parameters of skin condition that can be used to assist in determining skin damage. Skin irritation can be gauged by either quantitative measurement or qualitative assessment of skin condition. Bioengineering techniques aim to measure changes in parameters such as blood flow (Laser Doppler blood flow meters), redness (erythema meters), and alterations in the barrier function of the skin as detected by trans-epidermal water loss (TEWL) and skin hydration (corneometers).

TEWL, measured in units of $g.cm^{-2}.h^{-1}$, is a well recognised method of detecting irritation and has been used in a variety of studies to look at the response of the skin barrier function to exposure to a range of chemicals (Pedersen *et al*., 2005; Smith *et al*., 2004). The measurement principle is based on the evaporation of water from the skin surface. The flux of water across the skin barrier is measured by sensors housed in a small hollow cylinder placed on the surface of the skin. Guidelines for TEWL measurement are provided in a paper by Pinagoda and colleagues (1990).

Skin hydration is similarly used as an indicator of skin condition. Dry skin can be a sign of repeated irritant effects or damage to the *stratum corneum*.

TEWL and skin hydration are also good indicators of skin disease. Dermatitis will produce either lower than average figures where skin thickening has taken place while higher than average TEWL is found when red, irritated skin is present. TEWL is also an accurate indicator of acute irritation as changes from pre- to post- exposure are indicative of irritation of the skin barrier.

The identification of dermatitis can also be made by a number of methods. Clinical evaluation of the skin condition can be carried out by medically trained personnel. Alternatively, self-reported symptoms or questionnaire methods can be utilised to determine if the subject has symptoms consistent with dermatitis (Sen *et al*., 2001).

1.2.2 Determinants of dermatitis in metalworkers

Irritant contact dermatitis can be caused by a variety of factors from physical and thermal trauma through to irritation from substances as diverse as acids, soaps, detergents and water.

In terms of those working with MWF, the factors that could potentially cause skin irritation may be listed as follows:

- Water
- Oil
- Microbiological contaminants (causing infection of irritated skin or wounds)
- Chemical contaminants/ additives
- Acidic or alkaline pH levels
- Temperature
- Presence of metal fines
- Handling metals
- Wearing gloves
- Frequency and nature of hand washing and drying

Allergic contact dermatitis from MWF may arise as a result of contact with many of the additives in MWF solutions. Materials added to MWF solutions such as monoethanolamine (MEA), colophony, formaldehyde, and other biocides have been shown to provoke allergic contact dermatitis among workers exposed to MWF (Geier *et al*., 2004).

1.2.3 Prevention of dermatitis

Dermatitis tends to be very difficult to cure once an individual has the established disease. Prevention is thought to be the key to tackling the incidence of contact dermatitis and to achieve this the most effective interventions are likely to be based on the principles of the occupational hygiene control hierarchy. Removal or elimination of the causative agent may be an option particularly where an ingredient of the fluid has been shown to have allergenic properties. Moves towards 'dry cutting' techniques that do not require MWF are also being explored. Substitution of one coolant for another less allergenic or irritant in nature is another option. Engineering controls to prevent or reduce contact or exposure may reduce the risk of dermatitis, and administrative measures in terms of better fluid management in order to reduce or eliminate contaminants or control pH levels are further good practice measures that may impact on the risk of dermatitis.

Other risk management techniques can be employed. These can include training workers to reduce their exposure, follow skin care programmes and training workers to recognise the symptoms of skin damage. Personal protective equipment in the form of gloves can have a role to play but must be balanced against both the risk of entrapment in moving machinery and resulting injury, and the increasing evidence that wearing gloves can in itself lead to skin irritation and dermatitis.

1.2.4 Training and health surveillance

Health surveillance of skin conditions among workers handling MWF is used to identify those with dermatitis or in the early stages of skin disease. Health surveillance is generally carried out by an occupational health nurse or other suitably trained individual who will administer a questionnaire and carry out a visual examination of the hands for signs of dermatitis. Health surveillance is generally only carried out annually, or at best every six months, so it is important to train the workers to recognise skin symptoms and provide guidance on how to protect the skin in the intervening time.

The provision of information to workers handling hazardous materials tends to be based on leaflets and other written information and yet many workers are either unable or fail to understand concepts when provided in this manner. Failure to understand written information can also affect on data collection via a questionnaire. For example, a subject may have difficulties recognising the terminology used to describe his or her skin symptoms thus leading

to an under-estimate of the true prevalence of the disease. This is likely to be especially true in industries where skin conditions are common and may be considered by many to be ‘normal’ for the job.

Multimedia training packages can offer a method to present information in a manner that allows the user to access health and safety material at their own pace and with additional material and demonstrations supplied where necessary. The inclusion of video and audio sources ensures that interest can be captured and concepts explained in a clear and concise way. The advantages of presenting a questionnaire in a multimedia format are also numerous. Instead of describing symptoms such as dryness and cracking of skin in words, a photograph or video footage can be used to demonstrate exactly how this might look. Different degrees of symptoms on a range of anatomical sites can also be presented.

Multimedia training can also enable the worker to be given information on exposure reduction, skin care and the symptoms of dermatitis in a more accessible format that may increase understanding of the disease process and elicit behavioural changes that may not occur if the information is presented via traditional paper or oral based methods. A well designed multimedia questionnaire provides an excellent opportunity to improve the methods of health data collection and can also play a role in providing the user with learning or training material related to the specific disease being studied.

1.3 MEASURING DERMAL EXPOSURE

Dermal exposure assessment can be achieved by either direct physical measurement of deposited material, indirect methods such as visualisation of contaminant, or modelling using statistical or deterministic procedures. Direct measurement can be further divided into interception methods, and removal techniques, for example wiping and washing, and tracer methods where a quantity of a marker substance is added to the material of interest in order to facilitate measurement. All have advantages and disadvantages in terms of accuracy, practical considerations, expense and what they usefully tell us about dermal exposure. None of the methods are suitable for all chemical types and exposure scenarios and many suffer from a lack of standardised methodologies.

Interception methods include whole body suits and absorbent patch sampling. Using suits or patches attached to the outside of the clothing tells us about the total amount of the substance that would be deposited on the skin or clothing. This has been described as the potential dermal exposure. Whole body suits cover all of the body surface and may be augmented with a hat or hood for the head and gloves for the hands. They can be analysed in terms of body part to identify those anatomical regions receiving greatest exposure. Patches are worn at various representative locations on the body with the mass collected on each patch being extrapolated depending on the patch size relative to the size of the body area being sampled. Sampling protocols, such as the World Health Organisation (WHO) method (WHO, 1982) and the Organisation for Economic Co-operation and Development (OECD) guidelines (OECD, 1997) for patch sampling vary in terms of the number of patches, their location, size and sampling material. Even the size of each anatomical region represented by similarly placed patches differs between protocols.

One of the primary weaknesses of patch sampling is the potential introduction of large errors when the exposure is non-uniform. If a patch for a given body area is subject to a splash or spill the method will over-estimate the potential dermal exposure for that body area. The converse is also true when proportionally less is deposited on the patch compared to the surrounding area. Work by Tannahill and colleagues (1996) compared exposure measurements made by whole-body sampling with those from patch sampling. In general there was a linear relationship

between the two methods though the authors noted that the accuracy of the patch method increased with increasing numbers of patches. In summary, when exposure is likely to be non-uniform the use and interpretation of patch sampling should be undertaken with caution.

Other difficulties with patch sampling include patch overloading and problems with detachment in highly active work situations or confined environments. Careful consideration of the quantity of chemical likely to be deposited and the absorption capabilities of the patch material should take place prior to sampling. Close observation of workers may be required to replace patches that appear overloaded or become detached during sampling.

The use of whole body suits, typically light weight cotton overalls, is often used to sample potential dermal exposure among spray painters and pesticide applicators, and was a widely used method for the multi-centre EU study RISKOFDERM to collect dermal exposure data across a variety of exposure scenarios (van Hemmen *et al*., 2003). Other investigators have also used similar suits worn by children and infants to investigate exposure to pesticide residues in nurseries (Cohen Hubal *et al*., 2000).

The absorbent properties of textile patches may introduce error to interception measurements. Chemicals may soak into overalls or clothing and then slowly transfer to the patch or whole body suit over time. Direct dermal exposure may occur for only a short period of the working day but contaminated or wet clothing is often worn by workers for the remainder of the shift. In such situations interior patches or suits removed after the dermal exposure event would be likely to underestimate the true exposure.

Two other aspects of interception sampling are likely to introduce error into the exposure assessment process. Firstly, absorbent materials such as cotton will not behave in the same manner as skin. Fluid applied to the skin will take one of three routes: it may run-off the skin, as is the case with the majority of a liquid deposited after a splash, spill or immersion event; alternatively, the liquid may evaporate from the warm skin surface into the surrounding air; or lastly, it may be absorbed into the *stratum corneum* by diffusive processes. Cotton and other similar sampling materials are more likely to absorb fluids than real skin and also the fluid is less likely to evaporate due to lower surface temperatures. Hence interception methods are likely to over estimate the amount of a chemical available for uptake through the skin. Lastly, and in common with most dermal measurement techniques, interception sampling measures the mass of the contaminant instead of the concentration. While mass is a useful measure and is often used as a surrogate of concentration, the mass of material deposited on the skin in occupational settings is likely to far exceed the mass uptake.

Removal techniques can be divided into wiping, washing or tape stripping of the exposed skin. All of these methods aim to collect the quantity of the material present on the surface of the skin or, in the case of tape-stripping, bound to the outer layer of the *stratum corneum*. Wiping may be carried out dry, or with absorbent material soaked in water, alcohol or any other appropriate solvent. Wipes are usually used on the hands but can be employed to measure any area of the skin. Templates have been used to ensure that only a pre-determined skin area is wiped. No standardised protocol exists describing the number of wipes or the amount of force that should be applied when collecting wipe samples and it is thus difficult to compare results obtained across studies.

Hand washing methods follow similar principles with the hand being placed in a sealed bag containing a volume of water or other solvent and vigorous shaking is used to remove the chemical from the surface of the skin. The sampling efficiency of removal techniques was reviewed by Brouwer *et al*. (2000). Six different wipe sampling strategies, each with a variety of skin loadings were shown to have sampling efficiencies ranging from 41 to 104% with

standard deviations between 6 and 28%, indicating high degrees of variability. Similar variation in sampling efficiencies were evident for hand-wash sampling studies with four methods across ten pesticides at a range of skin loadings giving mean wash efficiencies from 23 to 96%.

Tape stripping removes the outermost layer or layers of the *stratum corneum* of the skin with the aim of quantifying compounds present in the skin. This has been used extensively for the assessment of exposure to a range of chemicals (e.g. Nylander-French, 2000), including acrylates, jet fuel and epoxy components. These methods are clearly more invasive than surrogate skin and other removal techniques and suffer from error introduced by the lack of a method to standardise measurements to the quantity of *stratum corneum* cells removed. Recent work by Chao and Nylander-French (2004) aims to overcome this problem. Stripping does however give an indication of the amount of a substance that has already been absorbed into the skin, something that both wipe and washing methods will fail to record.

Deposition of material onto the clothing and skin can also be assessed using direct *in situ* visualisation techniques. Fluorescent tracers can be added to the bulk solution of the liquid under study and the deposition of this fluid may then be visualised using ultra-violet light. This method was initially developed by Fenske and co-workers (1986) and then further developed by Roff (1994) to produce a dodecahedral illumination system (Fluorescent Interactive Video Exposure System – FIVES). Later, a similar video imaging technique to assess dermal exposure (VITAE) was employed by Bierman and colleagues (1998) to measure the exposure of agricultural workers to pesticides. By calibrating image analysis software to fluorescent intensity based on the mass per unit area, these systems are able to quantify total body exposure at the point of image acquisition, and to also measure the skin surface area exposed, although this is often not reported. However, the system requires careful calibration and the quantity of tracer added to the bulk solution must also be closely regulated to ensure that interpretable images are produced. Issues such as timing of 'sampling' to prevent saturation of the image are similar to those relevant to surrogate skin sampling. Practical difficulties also exist in terms of expense, time to carry out the measurement, the acceptability of adding fluorescent tracers to the material being applied, and binding of the tracer to the skin preventing the same worker being measured on consecutive days.

The skin surface area exposed can be assessed by direct visualisation techniques. The area of skin exposed has been shown to be subject to high degrees of day-to-day, between-worker and anatomical variation. Wassenius and colleagues (1998) carried out a study to examine the variability of skin exposure of machine operators exposed to cutting fluids. Using video recording of work tasks and data on fluid evaporation times this paper describes how workers' hands were wet for anything from 0 to 100% of the job time. Tasks with short cycle times were more likely to have a higher degree of relative wet time but overall the degree of skin exposure was shown to be highly variable and independent of machine type or task process. A study of dermal exposure during spray painting (Lansink *et al*., 1997) demonstrated that paint overspray is not uniformly deposited over the body. More than 50% of the total mass of dermal exposure was to the lower legs and less than 3% to the hands. The study also found that only approximately 10% of the worker's coverall surface was covered with paint. The high degree of variation in terms of anatomical location and the amount of surface area covered will play an important role in determining the effect of the chemical on the skin.

While the assessment of exposure intensity and surface area exposed are key to dermal exposure assessment there are two other factors that are important in assessing the degree of risk from dermal exposure. These are the duration and frequency of exposure. The duration of contact may be of little importance if the material remains on the skin or clothing for a much longer period thereafter. In these situations the time until removal (e.g. by washing or evaporation) may be the controlling factor. However, the duration and frequency of contact may play a larger

role particularly when the rate of evaporation or run-off is high. It is important that the type and frequency of sampling are chosen to reflect these factors.

Measuring techniques are becoming increasingly sophisticated and standardised, and advances in this field will allow greater collection of dermal exposure data across a range of industries, processes and environmental conditions. While this is good news for future epidemiological studies that wish to incorporate the influence of dermal exposure on the risk of health effects, the situation for retrospective studies is not so positive. Few good quality measurements of dermal exposure currently exist and those that do have often been gathered by measurement protocols using exposure metrics of questionable value.

As a result, modelling dermal exposure has been the focus of much work over the past decade. The Estimation and Assessment of Substance Exposure (EASE) system developed by the UK Health and Safety Executive (HSE) and a similar technique by the US Environmental Protection Agency (EPA) (Mulhausen and Damiano, 1998) are generic models primarily used for regulatory purposes. These procedures model likely exposure levels based on information on frequency of contact and substance properties, but categorise exposure into broad ranges and so are of limited practical use. Initial validation work by Hughson and Cherrie (2005) has demonstrated that EASE tends to overestimate dermal exposures by up to two orders of magnitude.

The UK HSE used a database of dermal exposure measurements to produce an empirical model and indicative distributions for a range of tasks from the pesticide and biocide application sector (Phillips and Garrod, 2001). This work created a basic job exposure matrix with four levels of potential dermal exposure and three types of profiles to reflect the degree of variability across different tasks. Deterministic modelling has also been developed although these tend to be process specific. Work by Brouwer *et al*. (2001) examined the parameters controlling the deposition of paint spray aerosol onto painters' skin and clothing. The model produced a good correlation between estimated and measured exposures.

The development of the conceptual model by Schneider and co-workers (1999) has provided researchers with a structured framework to characterise and analyse exposure scenarios by dividing them into a range of sources, compartments and transport processes.

2 AIMS

This study aimed to identify factors that increase the risk of irritant contact dermatitis among workers exposed to MWF and to provide health-based guidance values for MWF management. The study also involved the development of a computer-based multimedia questionnaire to assess dermatitis in the workplace. Further project aims included evaluation of TEWL and skin hydration measurements as means of identifying dermatitis and an assessment of the impact of a multimedia training package in engineering firms using MWF.

To achieve these aims the project objectives were as follows:

- Investigate in a series of controlled laboratory experiments the chemical and biological properties of MWF that increase skin irritancy in terms of TEWL;
- Identify and recruit a range of work places where there was exposure to MWF;
- Design a simple multimedia questionnaire to determine the prevalence of hand dermatitis amongst industrial workers and to educate management and workers in the dangers of MWF exposure;
- Examine the validity of the questionnaire assessment of dermatitis against TEWL/ skin hydration measurement;
- Identify and recruit worksites to take part in the study.
- After baseline measurements, administer the multimedia package to a group of workers (intervention) while providing no further information to others (controls).
- Re-examine dermal exposure, skin condition and MWF composition in the engineering firms at 6 and 12 months following administration of the multimedia training package;
- Assess the effectiveness of the training package in terms of reducing dermal exposure and improving skin condition.

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3 METHODS

3.1 STUDY DESIGN

The study was divided into two discrete phases. The first, 'laboratory' phase aimed to examine the chemical and biological factors of MWF that may cause skin irritation. The second phase was an intervention study where, in addition to collecting baseline data on MWF parameters and dermal exposure to MWF across a number of engineering firms, a multimedia training-package was used in one half of the participating workplaces. The aim of the intervention study was to determine if the multimedia package is an effective method of reducing dermal exposure, improving MWF management and improving workers' skin condition.

3.2 PHASE I: WHAT CAUSES SKIN IRRITATION?

3.2.1 The laboratory study

A DERMALAB unit with TEWL and skin capacitance monitoring modules from Cortex technology in Denmark was used to measure TEWL. Trials using the equipment and familiarisation with the associated DASYLab software were undertaken. A transportable system including monitoring equipment and laptop computer was established and tested in a variety of situations and environments. A protocol for downloading and handling recorded data was established.

3.2.2 Reconstituted epidermis

Reconstituted epidermis (REp), made by SkinEthic Laboratories (Nice, France) was identified as the most suitable surrogate skin for testing the irritant effects of MWF. REp is expensive to purchase and, as it is a living tissue it has a limited experimental life. The costs of this material limited the number of tests and replicates we were able to carry out within our laboratory based investigation.

REp consists of human adult keratinocytes cultured on an inert polycarbonate filter. REp was delivered as samples of 0.63 cm^2 area (0.90 cm diameter circles) at 18 days growth. These were then transferred under sterile conditions to 6 well culture plates (each cell with diameter of 3.5 cm) and placed in 1 ml of maintenance media (MCDB 153 containing 5 $\mu g.ml^{-1}$ insulin; 1.5 mM Calcium Chloride; 25 $\mu g.ml^{-1}$ Gentamycin). The REp samples were then kept in an incubator at 37 ^oC at 5% CO_2 overnight. Laboratory trials and pilot studies to determine the most appropriate method of handling the tissue in tissue culture conditions were undertaken.

Testing was undertaken according to the following protocol:

1. Maintenance media was replaced on the morning after delivery.
2. TEWL was then measured by placing the probe on the surface of the REp (using a 'chimney' attachment). TEWL was measured for 20 seconds and the mean and standard deviation (SD) for these measurements recorded. This was repeated 15 times for each sample.
3. On completion of stage 2 the irritant was added to the surface of the REp and the sample container was covered with parafilm to prevent evaporation.
4. After the designated period of 'exposure' the parafilm was removed and the liquid material was removed from the REp surface using a pipette and by blotting with tissue paper.
5. TEWL was then again measured in a manner identical to that used in step 2.
6. Steps 3-5 were repeated if additional exposure times were examined.

3.2.3 Testing with 100% Ethanol

A single sample of REp was treated for 30 minutes using a known irritant (100% Ethanol). Comparison of pre- and post- ethanol treatment provided the following results. Fifteen TEWL measurements were made both pre and post ethanol application.

Table 1: Levels of TEWL ($g.cm^{-2}.h^{-1}$) for REp before and after treatment with ethanol

Experiment	***TEWL ($g.cm^{-2}.h^{-1}$)***		
	Mean	***SD***	***95% CI***
Pre-ethanol	14.7	0.7	
Post-ethanol	16.3	0.5	
difference	1.6	0.6	1.3-2.0*

* paired sample t-test: difference in the means is significant at $p<0.05$

The mean difference in TEWL level between the pre and post-ethanol treatment was statistically significant at 1.6 (95% CI 1.3-2.0) $g.cm^{-2}.h^{-1}$. This experiment demonstrated that the TEWL of REp responded as expected to a known irritant with increased water loss representing impaired barrier function of the tissue.

3.2.4 MWF Experiments

Three experiments were carried out which measured TEWL on REp, after treatment for different lengths of time with control or MWF treatments. These are summarised below -

- One experiment with two repeats of each of: air control, water-treated control, a 'worst-case' used MWF. The 'worst case' used MWF was a sample of water-mix MWF that had been removed from a factory sump and showed high levels of bacterial growth; an acidic pH (pH= 6.0), high concentration and a high level of metal fines.
- Two experiments with two repeats of each of: air control, water-treated control, an undiluted, unused water-mix MWF
- Two experiments with one each of: air control, water-treated control, an undiluted, unused water-mix MWF, a 1:2 dilution, unused water mix MWF, a 1:15 dilution, unused water mix MWF, a 1:50 dilution, unused water mix MWF.

For all experiments, a pre-test measurement of TEWL was recorded. This value was subtracted from each measurement of TEWL made during the experiment, prior to the statistical analysis. Statistical analysis was therefore carried out on change in TEWL from the pre-test level. Up to 15 repeats of each TEWL measurement were recorded. The variation between these was very small, and the mean of the measurements was used in the analysis.

The data were summarised in tables sub-classified by duration and treatment. Statistical analysis of variance methods were used, with 'change in TEWL' as the response variable. Explanatory variables were duration (expressed in time categories) and treatment. Detailed statistical results are shown in Appendix 1 and summarised below.

3.2.5 Results from REp TEWL experiments

Experiment with air control, water control and 'worst case' MWF.
One experiment was carried out, which included two repeats of each treatment. The experiment comprised five time points: 30, 60, 90, 120 and 180 minutes of cumulative exposure to the liquid challenge. The analysis of variance looked at a number of contrasts in the data –

- the air control versus the other two treatments
- the water control versus the 'worst case' MWF
- the two repeats of each treatment

The data for this experiment are summarised in Table 2.

Table 2: Air, water and 'worst case' MWF. Change in TEWL ($g.cm^{-2}.h^{-1}$) from pre-exposure value by duration and treatment

Total exposure duration (minutes)	***Air control***		***Water control***		***'Worst-case' MWF***	
30	*	0.7	*	*	*	*
60	3.0	*	5.8	6.1	5.2	6.7
90	*	6.3	*	*	*	*
120	*	3.7	*	9.9	*	7.8
180	9.2	*	4.8	*	4.2	*
Average change	**4.6**		**6.6**		**6.0**	

* TEWL not measured at this time point.

Analysis of variance methods showed no significant differences between the air control, the water control and exposure to the 'worst-case' MWF.

Experiments with air control, water control and undiluted water-mix MWF.
Two experiments were carried out. Each experiment included two repeats of each treatment. The first experiment comprised four time points: 30, 60, 90 minutes and 18 hours. The second experiment comprised seven time points: 15, 30, 45, 60, 75, 90, and 180 minutes. The analysis of variance looked at a number of contrasts in the data –

- the air control versus the other two treatments
- the water control versus the undiluted MWF
- the different durations
- the two repeats of each treatment

The data for the first experiment are summarised in Table 3.

Table 3: Air, water and undiluted MWF treatment (experiment 1). Change in TEWL ($g.cm^{-2}.h^{-1}$) from pre-exposure value by duration and treatment.

Total exposure duration (minutes)	***Air control***		***Water control***		***MWF***	
30	-0.7	1.1	2.7	4.1	2.2	0.4
60	-0.8	3.2	2.3	5.7	2.6	1.5
90	1.5	1.4	3.7	4.0	2.8	1.4
18 hrs	-2.6	0.4	0.5	1.2	-0.2	0.0
Average change	**0.4**		**3.0**		**1.3**	

Results from the analysis of variance showed that overall, the change in TEWL for the air control was lower than for the other two treatments (mean=0.44 $g.cm^{-2}.h^{-1}$ compared to 2.18 $g.cm^{-2}.h^{-1}$ for the two treatments combined), while change in TEWL for the water control was higher than MWF (mean=3.02 compared to 1.34 $g.cm^{-2}.h^{-1}$). There was a significant difference between durations, which was due almost entirely to the 18 hour time point. If this time point was omitted, the significant difference between durations was no longer apparent. Differences between the treatments did not vary significantly across durations.

Results for the two air controls were significantly different (2.2 $g.cm^{-2}.h^{-1}$ mean difference), while the difference between the results for the two water controls were of borderline significance (mean difference= 1.4 $g.cm^{-2}.h^{-1}$). The mean difference between the two MWF results was 1.03 $g.cm^{-2}.h^{-1}$ and was not significant statistically. Compared to the differences within treatments, the difference between treatments was not large.

The data for the second experiment are summarised in Table 4.

Table 4: Air, water and undiluted MWF (experiment 2). Change in TEWL ($g.cm^{-2}.h^{-1}$) from pre-exposure value by duration and treatment

Total exposure duration (minutes)	***Air control***		***Water control***		***MWF***	
15	-1.2	-0.1	2.8	1.9	2.1	0.4
30	-0.5	0.7	3.2	2.8	0.7	0.6
45	-0.3	0.4	3.6	3.0	1.0	1.6
60	0.6	0.7	4.7	2.5	1.6	1.2
75	2.1	2.2	3.6	2.7	1.3	0.9
90	2.4	1.9	5.5	3.7	1.8	2.5
180	1.7	3.0	3.2	3.2	3.7	3.2
Average change	**1.0**		**3.3**		**1.6**	

Results from the analysis of variance again showed that overall, the change in TEWL for the air control was lower than for the other two treatments (mean = 0.97 $g.cm^{-2}.h^{-1}$ compared to 2.46 $g.cm^{-2}.h^{-1}$ for the two treatments combined), while the change in TEWL for the water control was again higher than MWF (mean = 3.31 compared to 1.61 $g.cm^{-2}.h^{-1}$). There was a significant difference between durations, with average TEWL increasing monotonically across durations. There was some evidence that the differences between the untreated and treated change in TEWL, and between the water and MWF measurements differed across duration, but these differences were small compared to the overall effects.

Results for the two water controls were significantly different (mean difference 0.97 $g.cm^{-2}.h^{-1}$), while the difference between the results for the two air controls was of borderline significance (mean difference 0.57 $g.cm^{-2}.h^{-1}$). The different responses to the treatments illustrate that the REp samples are non-identical living tissue and there is likely to be some degree of variation between samples. The mean difference between the two MWF results was 0.26 $g.cm^{-2}.h^{-1}$ and was not significant statistically. Differences between the treatments were significantly higher than differences within treatments.

Experiments with air control, water control and different dilutions of MWF.
Two experiments were carried out. Each experiment included air control, water control, undiluted MWF, 33% MWF, 6% MWF and 2% MWF. The first experiment comprised four time points: 30, 60, 90 and 270 minutes. The second experiment comprised seven time points: 15, 30, 45, 60, 90, 180 and 1200 minutes. The analysis of variance looked at a number of contrasts in the data:

- the air control versus the other two treatments (water and MWF);
- the water control versus MWF treatment;
- the different durations of exposure;
- the different dilutions of MWF.

The data for the first experiment are summarised in Table 5.

Table 5: MWF concentrations (experiment 1). Change in TEWL ($g.cm^{-2}.h^{-1}$) from pre-exposure value by duration and treatment

Total exposure duration (minutes)	***Air control***	***Water control***	***100% MWF***	***33% MWF***	***6% MWF***	***2% MWF***
30	-0.2	2.4	1.6	2.3	1.7	1.2
60	-0.4	1.8	0.6	1.7	2.3	0.9
90	-0.5	2.0	3.5	5.7	3.2	2.7
270	-2.2	1.7	2.4	3.0	1.7	1.6
Average change	**0.8**	**2.0**	**2.0**	**3.2**	**2.2**	**1.6**

Results from the analysis of variance showed that overall, the change in TEWL for the air control was lower than for the water and MWF treated samples (mean = -0.83 compared to 2.20 $g.cm^{-2}.h^{-1}$ for the other treatments combined), but there was no overall difference between the change in TEWL for the water control and for MWF treated samples (mean = 1.98 compared to 2.26 $g.cm^{-2}.h^{-1}$). Differences between the dilutions of MWF were statistically significant but there was no clear pattern with increasing dilution.

There was a significant difference across durations, but there was no clear pattern with increasing time. Differences between the air control and the other treatments varied across durations, but this variation was small compared to the overall effect.

The data for the second experiment are summarised in Table 6.

Table 6: MWF concentrations (experiment 2). Change in TEWL ($g.cm^{-2}.h^{-1}$) from pre-exposure value by duration and treatment

Total exposure duration (minutes)	*Air control*	*Water control*	*Neat MWF*	*33% MWF*	*6% MWF*	*2% MWF*
15	-1.0	4.3	2.9	*	*	*
30	-1.1	6.2	2.3	2.0	2.7	3.8
45	-2.7	1.0	-0.8	*	*	*
60	-1.8	4.7	3.5	0.9	-0.1	4.5
90	0.9	7.1	3.7	4.1	4.2	6.3
180	0.3	6.3	4.1	3.4	4.7	4.2
1200	-3.2	1.4	1.7	0.6	1.0	3.7
Average change	**-1.2**	**4.4**	**1.5**	**2.2**	**2.5**	**4.5**

* data not available

Results from the analysis of variance again showed that overall, the change in TEWL for the air control was lower than for the water and MWF treated samples (mean= -1.23 compared to 2.88 $g.cm^{-2}.h^{-1}$ for the other treatments combined), and that results for the water control were higher than for all MWF treatments (mean = 4.43 compared to 2.49 $g.cm^{-2}.h^{-1}$). Differences between the dilutions of MWF were statistically significant with a trend of increasing average change in TEWL with increasing dilution.

Using a 'worst-case, poorly managed' MWF with extreme values for the parameters we were investigating (i.e. low pH, high MWF concentration, high metal fine content and high endotoxin/microbiological level), we examined the induced changes in trans-epidermal water loss (TEWL). Despite various exposure conditions we were unable to identify a difference between the 'worst-case' fluid and treatment with the water control.

Three explanations for this are possible. The first is that it is the quantity and frequency of 'wet work' that is the primary cause of irritation and not any specific parameter of the MWF. The second explanation is that the size of 'experimental error' introduced in the tests is larger than the differences we were trying to detect. It is possible that reducing the experimental error by refining the procedures or by increasing the duration of the test would, in theory, allow detection of smaller differences between clean and dirty MWF. Additionally, the short duration of exposure carried out in the laboratory studies may be insufficient to detect differences in the treatments. As the REp has a limited test life of approximately 24 hours it is not possible to increase the exposure duration beyond those already tested. Thirdly, it is possible that the experimental model failed to reproduce workplace exposure scenarios and events such as minor trauma.

The results from these experiments indicate that epidermis treated with either water or MWF was significantly more irritated (increased TEWL) than untreated air controls. However, neither water-mix concentration nor the use of 'worst-case' MWF showed any significant differences when compared with water-treated tissue and generally MWF produced smaller increases in TEWL than treatment with water.

3.3 MULTIMEDIA QUESTIONNAIRE

The development of a multimedia questionnaire and associated training elements was one of the core objectives of this project. The questionnaire was based on a previously developed questionnaire (Vermeulen *et al.*, 2000a) but further utilised audio-visual methods to assist the

worker in self-assessment and recognition of skin problems. Piloting among a variety of occupational health professionals and the target audience was used to ensure that the package was well understood and easy to operate. In tandem with the questionnaire development, an educational element was developed to act as the multimedia intervention with the aim of increasing knowledge amongst the workers and hopefully reducing workplace exposure to MWF, and improving skin care and fluid management.

The questionnaire was developed using Macromedia Director 8.5 software with additional programming using the Lingo programming language. An initial storyboard was developed and piloted among occupational hygiene professionals. Using input from other interested parties a total of eleven drafts were completed before a finalised questionnaire was produced.

The final version contained over 350 Macromedia Director 'cast' elements and incorporated text, images, and audio files. The questionnaire system begins with a short introduction about dermatitis. This is followed by the questionnaire about skin condition before moving on to collect some information relating to the workers contact with MWF, handling of metals and their current skin care regimen. There is a simple advice section at the end of the questionnaire on reducing exposure to MWF, wearing water-resistant gloves when handling fluids, using skin care creams and washing with soap and water. The questionnaire is fully interactive and captures details of the subject's responses via 42 separate screens. Not all of these screens are visited by each user as progress and navigation is dependent on questionnaire responses. Users are able to return to previous screens, return to the beginning or skip the introduction about dermatitis and proceed directly to the questionnaire. A log file is created on each use and this also provides information about the user's progress through the package, which screens were visited for longest and any changes in responses to questions.

Figure 1 provides a selection of screen shots taken from the package.

Figure 1: Screenshots from Multimedia package developed for worker training

One of the key aims of the multimedia package was to provide the user with images of each of the signs of dermatitis that would allow them to identify if they had or were experiencing a similar condition. However, symptoms may affect only small areas of the skin or be quite minor in appearance, so there are consequent difficulties in capturing these small areas in a photograph and being able to present these images clearly on a computer screen. The images that we employed were selected to achieve a balance between having easy to recognise pictures of dermatitis while at the same time trying to prevent the user from interpreting his or her, more minor skin complaints, as not warranting a positive response when compared to the image. The text and voiceover emphasised that some of the images illustrated particularly severe cases of dermatitis and that the user may have experienced less serious symptoms over only part of their skin.

3.4 PHASE II: FIELD STUDY

3.4.1 Intervention study design

The field study aimed to collect data on MWF exposure, MWF management and skin condition across a small sample of engineering companies in Scotland. In addition the project set out to test if the multimedia questionnaire and training package produced changes in worker knowledge and behaviour that resulted in identifiable reductions in dermal exposure to MWF, improvements in MWF management and changes in skin condition.

The study was designed as an intervention study where we gathered baseline data on all parameters at all six worksites at the first visit. We then randomly divided the worksites into two groups. The intervention group received the multimedia training package at the end of the first visit while the control group did not receive any further feedback. Two follow-up visits were carried out at all sites. The first occurred one month after the baseline visit with the second follow-up at between 6 and 12 months from the baseline visit. The same worker cohorts were followed throughout the study with some degree of loss to follow-up experienced at all sites.

3.4.2 Worksite recruitment

Engineering firms were recruited via links with the trade association, a search of the internet and from professional contacts of the research team. The firms were not intended to be representative of the entire engineering sector but covered a wide range of product and service delivery. This included reconditioning large items for military equipment through to the manufacture of all sizes of electric motors. In order to be able to compare the intervention and control groups we targeted firms of broadly similar employee numbers. All six sites employed in excess of 150 workers; though often the numbers involved in the machine tool departments were much lower than this with the number of workers directly exposed to MWF being generally between 10 and 40.

In advance of each visit the workers were provided with an information sheet (Appendix 2) outlining the aims of the project and details of the information we hoped to collect. Participation was voluntary and workers were informed that they had the right to withdraw at any time during the study.

3.4.3 Dermatitis questionnaire

During each of the visits a paper-based dermatitis questionnaire was administered to each worker who agreed to participate. This questionnaire was based on the standard skin symptom triggers detailed in appendix 1 of HSE INDG165 ‘Health surveillance programmes for employees exposed to metalworking fluids’ (HSE, 2001). This guidance recommends that if an

employee responds positively to two or more symptoms and reports that they endured for more than three weeks or occurred more than once since the last review their skin should receive further investigation. The symptoms investigated by the questionnaire were as follows:

- redness and swelling of fingers or hands;
- cracking of skin on fingers or hands;
- blisters on fingers or hands;
- flaking or scaling of skin on fingers or hands;
- itching of fingers or hands with skin cracks or splits;
- spots, redness, swelling of any other part of your body.

3.4.4 Dermal exposure measurement

Gloves are not routinely worn by most machine operators due to the risk of entrapment and entanglement. This presented difficulty in measuring dermal exposure to MWF as we had intended to measure dermal exposure using interception sampling techniques with cotton sampling gloves. Instead we initially used a modified version of a wrist-sampler that was used to measure exposure to rubber dust in a study by Vermeulen and co-workers (2000b). This sampler comprises a 3 cm x 3 cm patch containing nine layers of cotton attached to the wrist area of the workers lead hand. The patch sampler was backed with polythene to ensure that there was no seepage of MWF from contaminated work clothes on to the patch.

Initial use of this patch method quickly showed that generally very low or zero dermal exposure levels were recorded. Observation of workers showed that there was considerable dermal exposure but almost no collection of fluid on the wrist patch. It was concluded that this type of sample was unrepresentative of hand exposure for this work scenario.

Wipe sampling was then selected as a more appropriate methodology to measure dermal exposure of the hands. Trials for two wipe materials were conducted to determine the number of wipes and wipe timings required to achieve a suitable recovery efficiency. The first material tested was a dry wipe of 10cm x 10cm 60% Cotton 40% Polyester cloth. The second wipe material was a similar sized moist hand wipe (Boots Travel Wipe). Recovery was tested by administering a known volume of water-mix MWF directly on to the surface of the wipe material or on to the surface of a hand. After a specified period the hand was wiped once on the palm, once on the back of the hand and once on the length of each finger to collect any MWF residue.

All samples were analysed by Inductively Coupled Plasma/ Atomic Emission Spectrometry (ICP/AES) using Boron as a marker of MWF contamination and results were calculated using blank correction for the mass of boron on a blank wipe. For direct application to the wipe material recovery efficiency for the cotton/polyester cloth was 88% while that for the Boots Travel Wipe was 77%.

3.4.5 Measurement of MWF parameters

As part of the evaluation of MWF management and fluid condition in the workplace phase of the study a number of MWF parameters were measured. These were:

- MWF concentration (water-mix MWF only)
- MWF pH (water-mix MWF only)
- Temperature
- Metal fines content
- Level of bacterial contamination
- Level of endotoxin contamination

- Presence of mycobacterium species

Fluid strength, pH and metal fine concentration analysis was carried out by the laboratory at the Institute of Occupational Medicine, Edinburgh. The fluid strength of the sample was measured by adding concentrated acid to a known volume of sample. The acidified sample was then centrifuged at 2400rpm for 20 minutes. The volume of the top layer was then measured and this volume used to calculate the fluid strength.

The pH of the samples was measured using a calibrated gel filled pH electrode with a meter.

The metal fines concentration was measured by centrifuging a known volume of sample, decanting the top layer and filtering the residue remaining with an isopropyl alcohol/water mix.

Bacterial, endotoxin and mycobacteria analyses were carried out by the Health and Safety Laboratory (HSL). Samples of MWF emulsion were serially diluted and used to inoculate nutrient agar plates incubated at 25 and 37^0C**.** The use of this combination of treatments maximises the yield of culturable bacteria typically found contaminating MWF. Results were expressed as colony forming units (cfu) per ml of MWF.

Endotoxin (Gram negative bacterial cell wall component) concentration in MWF samples was quantified using the kinetic QCL Limulus assay (BioWhittaker). Dilutions of samples in pyrogen free water were assayed by reacting with colorimetric reagent in a multiwell plate format, the rate of reaction being used to calculate concentration against endotoxin standards. Results were expressed as endotoxin units (EU; measurement of biologically active endotoxin) per ml MWF.

The presence of Mycobacteria in MWF was tested using molecular based tests. DNA was extracted from the MWF sample and then used in a two stage assay in which initially a primer was used to detect the presence of Mycobacterium genus DNA sequences. If positive samples were found, a second stage assay characterised the Mycobacterium species.

3.4.6 Assessment of skin condition and skin damage

During workplace monitoring a selection of workers' skin was assessed by a range of means. These included:

- Paper based questionnaire
- Multimedia questionnaire
- Measurement of trans epidermal water-loss and skin capacitance

Paper-based skin-health surveillance questionnaire
Each subject was asked to complete the skin health questionnaire at each of the three visits. This questionnaire is provided in Appendix 3 and is based on the HSE Health Surveillance guidance notes. Pilot work had shown that this took an average of ten minutes to complete. This questionnaire determined if the individual had experienced dermatitis at any time in the previous 12 months.

Computer-based questionnaire
In the three worksites allocated to the intervention group each participating worker was also asked to complete the multi-media based questionnaire/training package at the end of the first visit. It was explained to workers that this second questionnaire aimed to gather information on skin condition and some of the questions were similar to those in the paper questionnaire. The administrator checked that the worker was confident in the use of the mouse and keyboard and

provided a brief lesson on using the system if required. Again the multi-media questionnaire aimed to determine if the worker had experienced dermatitis in the previous 12 months.

Measurement of biomarkers of skin condition
TEWL was measured on the centre back of each hand at the end of the work shift or sampling period. Where possible sampling was carried out in a room with no draughts or forced air-movement and with a temperature between 20 and 22 ^{o}C and with relative humidity between 30 and 50% to ensure accurate and stable TEWL readings. During these tests subjects should not be sweating and so administration of the questionnaires was carried out prior to the sampling to allow the worker to cool down after any physical work. Measurement was made using the DERMALAB TEWL probe placed firmly on the skin and set to sample at 1 second intervals for a period of 30 seconds. The final value recorded was the mean of the last eight measurements. A value for standard deviation of the final eight samples was also recorded. For each worker values for mean and standard deviation TEWL (left and right hands) were recorded together with the environmental conditions.

Skin hydration was also measured for each worker using the DERMALAB skin capacitance probe. Measurements were taken by placing the probe firmly on the back of each hand. Again the probe was set to sample every second for a period of 30 seconds with the final value being the mean and standard deviation for the last eight measurements. For each worker values for mean and standard deviation of skin hydration (left and right hands) were recorded.

Defining skin disease and skin damage
Dermatitis lies at one end of a spectrum of skin damage with impaired skin barrier function and no noticeable symptoms at the other. Determining where a given individual lies on this spectrum and whether there is evidence of acute change in skin condition after a single work-shift required a series of definitions to be established. We defined chronic skin disease by two methods. Workers were categorised as having dermatitis if the questionnaire criteria of reporting two or more symptoms and either more than one episode occurred in the last 12 months or one episode lasted longer than 3 weeks was satisfied. An alternative, objective measure of skin disease was based on the worker having seriously impaired skin barrier function at the beginning of the work-shift. This definition of chronic skin disease categorised a worker as suffering from dermatitis when their pre-work TEWL for one or both hands was in excess of 20 $g.cm^{-2}.h^{-1}$. This value was approximately three times the mean figure for this cohort of engineers and also similar to the 95th percentile level measured at pre-work among a cohort of nurses (Schmid *et al*., 2005). These two definitions of skin disease measure different things. The first is a self-report of symptoms while the second is a high level of TEWL that is likely to be associated with chronically irritated skin. The project also looked at how much agreement, in terms of worker categorisation, there was between these two definitions.

Acute skin damage across the working day was also assessed according to one of two definitions: an increase of TEWL in either hand by more than 20% of the pre-work-shift value indicating evidence of acute irritation; or a decrease of skin hydration with reductions in skin capacitance of greater than 20% from the pre-work-shift level. A reduction of skin hydration of this magnitude was judged to provide evidence of significant skin drying over a single work day. While both of these 20% change criteria are arbitrarily assigned it is felt that they represent serious changes in skin condition within an eight-hour period and are likely to be good indicators of short-term skin damage that may lead to more chronic skin damage if repeated on a daily basis.

Again, the project set out to determine how well these two methods were associated with one another.

4 FIELD STUDY RESULTS

4.1 WORKSITE CHARACTERISTICS

The six worksites recruited to this study were based in Scotland. Table 7 provides an overview of the characteristics of each site.

Table 7: Worksite descriptions.

Worksite	*Location*	*Workforce size*	*Participants*	*Intervention/Control*
Site 1	Midlothian	200-250	25	Intervention
Site 2	Grampian	200-250	18	Intervention
Site 3	Fife	>250	12	Intervention
Site 4	Dumfries & Galloway	<50	8	Control
Site 5	East Lothian	100-150	16	Control
Site 6	Border	150-200	13	Control

4.2 WORKER CHARACTERISTICS

A total of 92 workers participated from the six different work sites. Three of these work sites were subject to the training intervention and the other three received no intervention. Each work site was visited three times. The first of these visits was the baseline visit, the second was 1 month after the baseline visit and the third was 6 to 12 months after the baseline visit.

Of the 92 participants, five (5%) were females (2 at worksite 1; 3 at worksite 5) and the remaining 87 (95%) were males. Table 8 shows the distribution of study participants by age group and work site.

Table 8: Distribution of study participants by age group and work site.

		Age Group								
		20-29		*30-39*		*40-49*		*50 +*		
	Worksite	*N*	*%*	*N*	*%*	*N*	*%*	*N*	*%*	*All*
Intervention	Site 1	3	*12*	2	*8*	6	*24*	14	*56*	25
	Site 2	3	*17*	4	*22*	7	*39*	4	*22*	18
	Site 3	1	*8*	1	*8*	5	*42*	5	*42*	12
Control	Site 4	7	*54*	2	*15*	3	*23*	1	*8*	13
	Site 5	2	*25*	1	*12*	4	*50*	1	*12*	8
	Site 6	1	*8*	3	*25*	2	*17*	6	*50*	12
	All	17		13		27		31		88*

*There were four participants, all from Site 6, with no information on age.

The mean age of the workers in the control worksite was 38.5 years (standard error: 2.4 years) while the mean age of the workers in the intervention sites was 44.9 years (standard error 1.4 years). This difference in ages between the two groups (mean difference -6.42 years 95% CI: -11.98, -0.87) was statistically significant (p=0.024) with the workers in the control group an average of nearly 6.5 years younger than the workers in the intervention group.

In the following sections, the results are described for the total number of participants that make up the intervention group (n=37) and are compared with the total number of participants that make up the control group (n=55).

4.3 EXPOSURE RESULTS

There are pairs of measurements of exposures on right and left hands for 196 of the 276 possible values (92 individuals x 3 visits). Data were analysed on the log scale because of a very skewed distribution. A paired t-test on these pairs of values showed:

Mean difference (on log scale) = -0.053 (95% CI: -0.16, 0.05) p = 0.33

The mean difference is not statistically significantly different to zero i.e. there is no statistically significant difference, on average, between measurements on the right and left hands.

Further statistical analyses examined whether any significant differences were found between hands at each visit, for each workplace and for both the control and intervention groups. No differences were found. In addition, a scatterplot of the pairs of values showed that for most samples, the measurements from the right and left hands were similar.

It was decided therefore to use the average exposure for the two hands in the statistical analysis, and where measurements were available for only one hand, to use that single value (concerns 18 subjects from worksite 1 at visit 1).

Table 9: Distribution of exposure to metal working fluids (MWF) for each visit by intervention or control group. Each cell contains N (number of individuals sampled), geometric mean (GM) and geometric standard deviation (GSD).

	Mean exposure to metal working fluids (ml per hand)					
	Intervention Group			***Controls***		
Visit	***N***	***GM***	***GSD***	***N***	***GM***	***GSD***
Baseline	43	0.28	*9.06*	37	4.03	*5.58*
1-month	40	0.51	*2.44*	33	0.77	*5.77*
6-12 months	31	0.24	*5.51*	30	3.92	*3.26*

Statistical analysis shows that there are differences between intervention and controls with the intervention group exposure lower than controls on average. Within each of intervention and control groups there are differences between visits – for intervention the levels at the 1-month follow-up visit is generally higher than at baseline and 6-month follow-up; for controls levels at 1-month follow-up are generally lower than baseline and 6-month follow-up visits.

Overall measurements at site 3 are low (within intervention group) and at site 4 the measurements are high (within control group) (results not shown here).

It is likely that the large differences between the intervention and control companies are, in part, due to the different measuring techniques used at companies 1 and 3. During the baseline visits a patch method was employed at sites 1 and 3. At the other sites and at all sites for the 1 and 6 month follow-up visits the wipe methodology was employed. Table 10 therefore presents the data excluding the values from companies 1 and 3 at the baseline visit. The same patterns are apparent in this table as in Table 9, although the downward trend in the intervention group is stronger.

Table 10: Distribution of exposure to metal working fluids (MWF) for each visit by intervention or control group excluding worksites 1 and 3 (baseline visit) where patches were used to measure exposure. Each cell contains N (number of individuals sampled), geometric mean (GM) and geometric standard deviation (GSD).

	Mean exposure to metal working fluids (ml per hand)					
	Intervention Group			*Controls*		
Visit	***N***	***GM***	***GSD***	***N***	***GM***	***GSD***
Baseline	14	1.20	*2.42*	37	4.03	*5.58*
1-month	40	0.51	*2.44*	33	0.77	*5.77*
6-12 months	31	0.24	*5.51*	30	3.92	*3.26*

Analysis of variance shows that there are differences between the intervention and control groups that vary by visit (specifically the intervention group is lower than the controls at baseline and 6-month follow-up visits, and there are no differences between them at the 1-month follow-up stage.) The difference between the groups at 6-month follow-up is significantly greater than the difference at the baseline visit. The significant overall effect of 'visit' reflects the low measurements in the control group at 1-month follow-up.

There is some evidence of a decrease in exposure with subsequent visits in the intervention group.

Figure 2 shows the distribution of mean exposure by intervention/control group for each visit in the form of a boxplot. In this plot, the box extends from the first to third quartile of the data, with the line across the box indicating the median value. The lines extending from the box show the 10^{th} and 90^{th} percentiles Any values lying outside these limits are shown as single points.

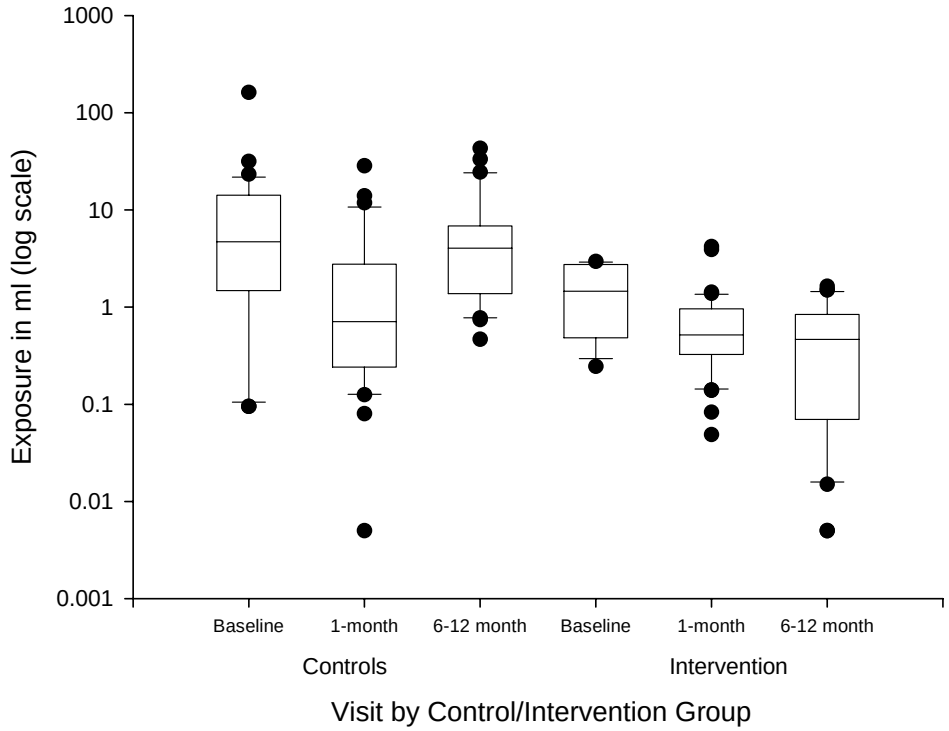

Figure 2: Boxplot of the log of exposure (ml per hand) to Metal Working Fluids for each visit by intervention and control group workers.

The process of individual dermal exposure to MWFs is highly variable and dependent on the task but can be summarized as occurring at four main stages of the metalworkers job.

- Machine set-up often involves handling drill bits and other tools within the theatre of the cutting machine. This is frequently carried out with items that are coated in MWF from previous use.
- Machine operation. Where this is completely automated there is little contact with the MWF. However in many manual and semi-automated machines the worker will have the capability of moving the MWF nozzle to direct it accurately to the cutting edge. This will frequently result in a short but significant whole hand exposure event.
- Workpiece removal. On completion of the task the cut item will be removed from the tool. This item will be coated with MWF and handling is usually done without gloves or without any attempt to remove excess fluid.
- Machine/sump maintenance. Inspection of the sump fluid, removal of excess swarf and general machine maintenance can give rise to dermal exposure to MWFs.

Clearly the frequency of the machine set-up/operation/removal cycle can have a large influence on the degree of dermal exposure.

After implementation of the intervention the workers often identified aspects of their own behaviour that they were aware of that they could change. They often mentioned how they could switch off the MWF flow before adjusting the nozzle direction instead of getting fluid on their hands and wrist. Many also described how they could remove excess fluid from workpieces prior to handling. While there is some evidence that the intervention may have brought about some of these behavioural changes we did not carry out detailed work behaviour observations to determine if these specific practices were the ones that resulted in reduced dermal exposure levels.

4.4 SKIN DISEASE

Skin disease was classified according to two different methods. The first based on self-report and response to a questionnaire on symptoms. The second based on an objective measure of the barrier function of the skin (TEWL) taken at the beginning of the shift.

Definition 1: Participants were defined as having dermatitis if they reported two or more symptoms and either these symptoms lasted for more than three weeks or they occurred more than once in the previous twelve months.

The annual prevalence of dermatitis, using definition 1, is shown in table 11 for both the intervention and controls group at each visit. At the first visit the prevalence of dermatitis in the three intervention worksites was 36% (n=19) compared to 19% (n=6) at the control sites. For the workers at the intervention sites the prevalence of dermatitis decreased markedly by the first follow-up visit (24%; n=11) and further still by 6-month follow-up (19%; n=6). A much smaller decrease is evident among workers from the control sites, reducing from 19% (n=6) to 18% (n=5) to 13% (n=4) by 6-month follow-up.

Table 11: Annual prevalence of dermatitis as assessed by definition 1 (symptoms). Each cell shows the number of subjects with dermatitis (N) and the percentage of the total number of subjects in the cell.

	Intervention		***Controls***	
Visit	***N***	***%***	***N***	***%***
Baseline	19	*36*	6	*19*
1 month	11	*24*	5	*18*
6-12 months	6	*19*	4	*13*

Definition 2: Participants were defined as having impaired skin barrier function if the TEWL measurement at baseline was greater than 20 $g.m^{-2}.h^{-1}$ (in either the left or right hand).

As seen from table 12, the prevalence of impaired skin barrier function at visit one was lower in the intervention (15%; n=8) compared with the control group (40%; n=15). The prevalence of impaired skin barrier function remained around 15% for the intervention group at both follow-up visits. The control group however, experienced a fall in impaired skin barrier function to 15% at one-month follow-up and this reduction is sustained at 6 months follow-up.

Table 12: Prevalence of impaired skin barrier function as assessed by definition 2 (TEWL>20). Each cell shows the number of subjects with dermatitis (N) and the percentage of the total number of subjects in the cell.

	Intervention		***Controls***	
Visit	***N***	***%***	***N***	***%***
Baseline	8	*15*	15	*40*
1 month	7	*16*	5	*15*
6-12 months	6	*19*	5	*17*

The figure we have selected (20 $g.m^{-2}.h^{-1}$) as an indicator of skin disease is arbitrary. It equates to approximately the 95^{th} percentile value of TEWL measured on the dorsum of the hands of a cohort of trainee nurses (Schmid *et al*., 2005); is a level indicative of irritation induced by exposure to sodium lauryl sulphate (SLS) and represents approximately the 80^{th} percentile of the levels measured at the baseline cohort. A level of 30 $g.m^{-2}.h^{-1}$ would have represented close to the 95^{th} percentile while 15 $g.m^{-2}.h^{-1}$ would have been about the 70^{th} percentile.

Table 13 shows the relationship between the two methods of defining skin disease. The level of agreement between the two definitions ranges from 62% to 68%. The agreement between the two definitions is due, almost entirely, to the number of subjects who did not have dermatitis under either definition. There was little agreement in the positive classification of dermatitis using the two definitions.

Table 13: Agreement between definition one (dermatitis symptoms) and definition two (TEWL>20).

Dermatitis (symptoms)		*Dermatitis (TEWL>20)*		*All*
		No	*Yes*	
Baseline	No	45	14	59
	Yes	18	7	25
	All	63	21	84
1 month	No	47	9	56
	Yes	14	1	15
	All	61	10	71
6-12 months	No	37	10	47
	Yes	9	1	10
	All	46	11	57

4.5 SKIN DAMAGE

We also set out to examine evidence of changes in skin condition over a work-shift. We assessed skin damage by two methods. The first method was based on the concept that irritation leads to reduced barrier capabilities of the skin and hence increased TEWL levels when compared to baseline values. The second method uses the premise that damaged skin produces reductions in skin hydration.

Definition one: Participants were defined as having skin damage if their TEWL levels had increased by over 20% from the start of the shift to the end of the shift on either hand.

Displayed in table 14 is the prevalence of skin damage at each visit in the intervention group compared to the control group using definition one. Skin damage as measured by this definition is very common among both control (87%; n=28) and intervention group (77%; n=40) workers at the baseline visit. By the 6 month follow-up visit however there is a marked reduction in intervention workers showing signs of skin damage (39%; n=12) while controls continue to have evidence of irritated skin in almost 80% of workers.

Table 14: Prevalence of skin damage as assessed by definition one (TEWL increase >20%).

	Intervention		*Controls*	
Visit	*N*	*%*	*N*	*%*
Baseline	40	*77*	28	*87*
1 month	32	*71*	32	*97*
6-12 months	12	*39*	23	*77*

Definition two: Participants were defined as having skin damage if their skin hydration measurement (as measured by capacitance) had decreased by over 20% from the start of the shift to the end of the shift on either hand.

Table 15 shows the prevalence of skin damage at each visit in the intervention group compared to the controls using definition two. Evidence of skin damage as measured by skin hydration is much less common than that identified by TEWL with 27% of both groups having greater than 20% reductions in skin hydration levels during the baseline visit. However, the percentage of workers showing decreased skin hydration at 6 month follow-up was greater in the intervention group (48%; n=15) than the control workers (23%; n=7).

Table 15: Prevalence of skin damage as assessed by definition two (skin hydration decrease >20%).

	Intervention		***Controls***	
Visit	***N***	***%***	***N***	***%***
Baseline	14	*27*	10	*27*
1 month	12	*27*	7	*21*
6-12 months	15	*48*	7	*23*

Table 16 displays the relationship between definition one and definition two for skin damage. The level of agreement between the two definitions is poor; ranging from 24% to 30% across the three visits.

Table 16: Agreement between definition one and definition two for skin damage.

Skin damage (TEWL)		***Skin damage (hydration)***		***All***
		No	***Yes***	
Baseline	No	12	9	21
	Yes	53	15	68
1 month	No	7	7	14
	Yes	52	12	64
6-12 months	No	10	16	26
	Yes	29	6	35

4.6 SKIN CARE PRACTICES

The distribution of participants wearing gloves at each visit is shown in table 17. Approximately twenty percent of the workers in the intervention sites wore some form of protective gloves for some of their work time. The equivalent figure among control group workforces was ten percent. There was almost no change in glove wearing in either group across the three visits.

Table 17: Distribution of participants wearing gloves for some of their work time.

	Intervention		*Controls*	
Visit	***N***	***%***	***N***	***%***
Baseline	11	*21*	3	*9*
1 month	9	*20*	3	*11*
6-12 months	6	*19*	3	*11*

Table 18 shows the distribution of participants who reported using skin care creams in the intervention group compared to the controls for each visit. At the baseline visit the proportion of participants using skin care creams was fairly similar in the intervention group (54%; n=28) compared to the controls (44%; n=14). The proportion of participants using skin care creams increased in the intervention group across 1 month follow-up (60%) and 6 month follow-up (68%); while remaining static (43%) in control group workers.

Table 18: Distribution of participants using skin care creams.

	Intervention		*Controls*	
Visit	***N***	***%***	***N***	***%***
Baseline	28	*54*	14	*44*
1 month	27	*60*	12	*43*
6-12 months	21	*68*	11	*42*

4.7 DERMATITIS AND EXPOSURE

At the baseline visit we assessed the exposure and pre-shift TEWL of those who were assessed as having dermatitis according to definition one (symptoms) with those who were not. Exposure and TEWL value was calculated as the average of right and left hands (or right hand where no measurement available for left hand), calculated on the log scale and transformed to geometric mean and GSD.

Table 19: TEWL and MWF exposure values for those assessed with/without dermatitis (definition one) at the baseline visit.

	TEWL ($g.m^{-2}.h^{-1}$)			*MWF exposure (ml)*		
Dermatitis	***N***	***GM***	***GSD***	***N***	***GM***	***GSD***
Yes	25	12.88	*1.80*	23	0.68	*8.33*
No	59	12.11	*1.82*	52	1.14	*12.43*

Table 19 and figure 3 shows that pre-shift TEWL does not appear to be a good predictor of the presence of dermatitis in this group of workers. It must be noted however that the definition of dermatitis is based on self-report of symptoms at some point in the previous 12 months while TEWL values are simply measures of skin condition that morning. It is possible that a number of subjects had experienced dermatitis at some stage in the past year but that these symptoms had resolved and the skin barrier function had returned to normal levels.

The relationship between MWF exposure and reports of dermatitis symptoms shown in table 19 and figure 4 is of particular interest. There is a high degree of variability in the data as reflected by the large GSD values, but it would appear that those reporting dermatitis symptoms tend to have lower dermal exposure levels compared to those not classified as having dermatitis. This

may represent some active behaviour on the part of those with skin problems to limit their contact with fluids while at work.

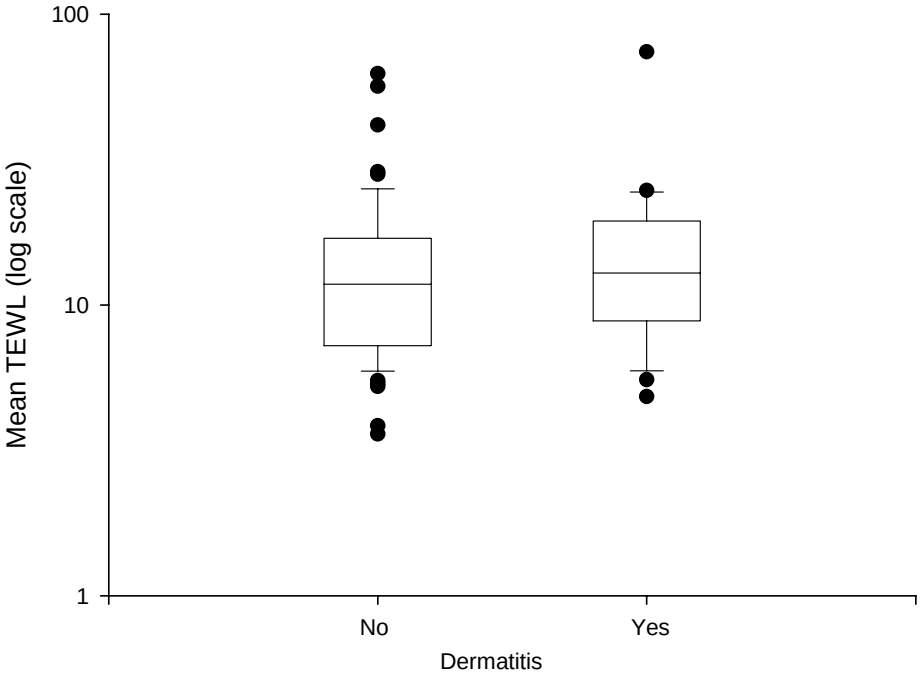

Figure 3: Distribution of mean TEWL (measured at the beginning of the baseline visit) among those with dermatitis and those without.

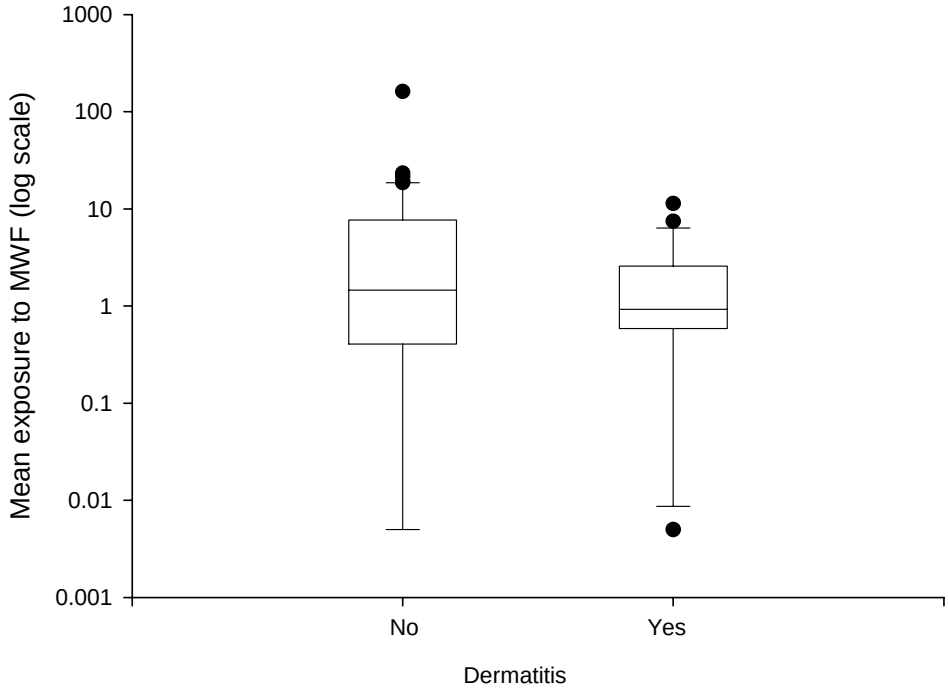

Figure 4: Distribution of exposure to the MWF (measured at the baseline visit) among those with dermatitis and those without.

4.8 MANAGEMENT OF MWF

This section describes the management of MWF as reflected by measurements such as MWF concentration and presence of bacteria in the sump. Detailed results of the statistical analysis of variance (ANOVA) are given in Appendix 1 with the results summarised here.

Table 20 shows the average levels of MWF concentration by visit for water-mix fluids in the intervention and control companies. MWF concentrations were statistically significantly higher in the control companies than in the intervention companies at the baseline visit. Concentrations at the control companies were lower than in the intervention companies at the 6-month follow-up visit. Results from the ANOVA also showed that there was a significant decrease in concentration between the baseline visit and both follow-up visits among the controls but not among the intervention group.

Table 20: Distribution of concentration of water-mix metal working fluids (%) for each visit by intervention or control group. Each cell shows the number of samples (N), arithmetic mean (AM) and arithmetic standard deviation (ASD).

	Concentration of metal working fluids (%)					
	Intervention Group			***Controls***		
Visit	***N***	***AM***	***ASD***	***N***	***AM***	***ASD***
Baseline	42	7.49	*6.62*	30	9.70	*4.09*
1-month	34	6.62	*2.25*	28	6.41	*2.90*
6-12 months	24	8.06	*2.07*	24	5.69	*2.83*

Table 21 shows the distribution of the pH of the MWF for intervention and control companies at each visit.

Table 21: Distribution of pH of metal working fluids for each visit by intervention or control group. Each cell shows the number of samples (N), arithmetic mean (AM) and arithmetic standard deviation (ASD).

	pH of metal working fluids					
	Intervention Group			***Controls***		
Visit	***N***	***AM***	***ASD***	***N***	***AM***	***ASD***
Baseline	42	8.60	*0.49*	36	7.91	*1.52*
1-month	36	7.91	*0.47*	31	8.55	*0.48*
6-12 months	27	8.20	*1.19*	29	8.13	*1.06*

Analysis of variance showed that (a) the intervention group started at a significantly higher level than the control group and (b) that there was a significant decrease in pH between baseline visit and 1-month follow-up among the intervention group, while levels at the 6-month follow-up were lower than at the baseline visit although this difference was of borderline statistical significance ($p<0.10$). Among the controls levels at 1-month follow-up were significantly higher than at either baseline or 6-month follow-up.

Numbers of fines in the MWF were higher in the intervention companies at the 1 and 6 month follow-up visits, and higher in the control companies at the baseline visit (Table 22). None of these differences were significant statistically, nor was there any evidence of significant changes across visits.

Table 22: Distribution of fines (mg/litre) in metal working fluids for each visit by intervention or control group. Each cell contains the number of sumps sampled (N), geometric mean (GM) and geometric standard deviation (GSD).

	Distribution of fines in metal working fluids (mg/litre)					
	Intervention Group			*Controls*		
Visit	***N***	***GM***	***GSD***	***N***	***GM***	***GSD***
Baseline	43	145	*2.55*	30	175	*2.70*
1-month	34	185	*2.68*	28	104	*2.77*
6-12 months	24	183	*2.64*	24	144	*4.16*

Table 23 shows the distribution of levels of sump bacteria in control and intervention companies at each visit.

Table 23: Distribution of levels of sump bacteria (cfu/ml) of metal working fluids for each visit by intervention or control group. Each cell contains the number of sumps sampled, geometric mean (GM) and geometric standard deviation (GSD).

	Distribution of sump bacteria levels (cfu/ml)					
	Intervention Group			*Controls*		
Visit	***N***	***GM***	***GSD***	***N***	***GM***	***GSD***
Baseline	45	15.7	*109*	36	881.8	*2006*
1-month	20	344.5	*990*	25	955.3	*2404*
6-12 months	26	37.9	*236*	29	602.5	*681*

There is a very large range in the data, with many zero values and then values extending as high as $1.6 \times e^{10}$ reflected in the large standard deviations. Results from the analysis of variance show that the levels in the intervention group are lower than the control group, but that there are no statistically significant differences between visits for either group.

Table 24 shows similar information for endotoxin levels.

Table 24: Distribution of endotoxin levels (EU/ml) of metal working fluids for each visit by intervention or control group. Each cell contains the number of sumps sampled, geometric mean (GM) and geometric standard deviation (GSD).

	Distribution of sump endotoxin levels (EU/ml)					
	Intervention Group			*Controls*		
Visit	***N***	***GM***	***GSD***	***N***	***GM***	***GSD***
Baseline	45	1743	*9.1*	36	807	*14.7*
1-month	20	132	*19.3*	25	296	*10.7*
6-12 months	27	2558	*19.2*	29	1914	*9.4*

There is a large range in the data reflected in the relatively large standard deviations. Results from the analysis of variance show no statistically significant differences between the starting levels in the two groups, but a significantly lower level at 1-month follow-up compared to either of the baseline or 6-month follow-up visits in both groups.

None of the fluids tested at all six work sites showed the presence of Mycobacteria.

4.9 HOLISTIC MEASURES OF FLUID MANAGEMENT

In order to assess if there was any improvement in overall fluid management in the intervention group compared to the controls the number of sumps that failed to meet the recommendations for good practice as described in HSG231 (HSE, 2002) was calculated.

Criterion 1: Concentration of metal working fluids is between 2% and 6%
While the dilutions for water-based MWF varies depending on the fluid, the machine type and the metal being processed, the majority of the fluids used in the plants visited were recommended to be used at concentrations between 2 and 6%. Below 2% the fluid is likely to be so dilute that bacterial growth may be significant and as the fluid is less likely to be carrying out adequate cooling and lubrication the build up of fines may also occur.

Over three-quarters of sump samples in control companies failed criterion 1 at the baseline visit compared to around half of those in the intervention companies. The proportion of control sumps failing this criterion decreased across visits, while the proportion of intervention companies failing the criterion increased at 6-month follow-up.

Table 25: Distribution of sumps that failed to meet criterion 1 (MWF concentration) at each visit by intervention and control group. Each cell contains number of sumps failing and the percentage of total sumps this represented.

	Sumps failing MWF concentration criterion			
	Intervention		***Controls***	
Visit	***N***	***%***	***N***	***%***
Baseline	22	*52*	23	*77*
1 month	18	*53*	18	*64*
6-12 months	19	*79*	6	*25*

Criterion 2: pH of metal working fluids is between 8.5 and 9.5
Like concentration, fluid pH depends on the specific fluid type and use scenario. HSG231 (HSE, 2002) however recommends a pH range of between 8.5 and 9.5. Values out-with this range are likely to be representative of other failures in the fluid composition such as bacterial growth and excessive additive levels, and may in themselves be irritating to the skin at the more acidic or alkaline ranges.

Again, more sump samples in control companies than intervention companies failed criterion 2 at the first visit, with the proportion increasing in intervention companies at 1 and 6-month follow-up, and being lower among control companies at 1-month follow-up, then subsequently rising again at 6-month follow-up.

Table 26: Distribution of sumps that failed to meet criterion 2 (pH) at each visit by intervention and control group. Each cell contains number of sumps failing and the percentage of total sumps this represented.

	Sumps failing pH criterion			
	Intervention		***Controls***	
Visit	***N***	***%***	***N***	***%***
Baseline	9	*21*	22	*61*
1 month	30	*83*	12	*39*
6-12 months	19	*70*	16	*55*

Criterion 3: Fines of metal working fluids are less than 100ppm
Fines are small metal particles in the fluid. These are likely to be abrasive especially during drying of deposited fluid on the skin with towels and rags. The HSE metalworking fluid good practice guidance, HSG 231 (HSE, 2002) recommends that fine levels are kept below 100 ppm (or 100 mg/litre).

Similar proportions of control and intervention sump samples failed criterion 3 at each of the three visits.

Table 27: Distribution of sumps that failed to meet criterion 3 (fines) at each visit by intervention and control group. Each cell contains number of sumps failing and the percentage of total sumps this represented.

	Sumps failing fines criterion			
	Intervention		***Controls***	
Visit	***N***	***%***	***N***	***%***
Baseline	31	*72*	20	*67*
1 month	23	*68*	17	*61*
6-12 months	17	*71*	16	*67*

Criterion 4: Presence of mycobacterium in sump is negative
Mycobacteria have been associated with occupational skin infections (Cole, 1987) and this study aimed to determine if there was any association between dermatitis and mycobacteria levels in MWF.

Mycobacteria were not detected in any sump samples.

Criterion 5: Bacteria levels in sump are less than 1000 cfu/ml
Awosika-Olumo and colleagues (2003) argued that skin disease in workers handling MWF may be induced by bacterial contamination. Criterion 5 was established at the level of 1000 colony forming units per ml (cfu/ml) in accordance with levels indicative of good control as established by HSG231 (HSE, 2002).

More control sumps failed criterion 5 at each visit than intervention sumps. The proportion of control sumps failing criterion 5 remained fairly constant across visits, while the proportion of intervention sumps failing was higher at the 1-month follow-up visit than at either baseline or 6-month follow-up visits.

Table 28: Distribution of sumps that failed to meet criterion 5 (bacteria) at each visit by intervention and control group. Each cell contains number of sumps failing and the percentage of total sumps this represented.

	Sumps failing bacteria criterion			
	Intervention		***Controls***	
Visit	***N***	***%***	***N***	***%***
Baseline	8	*18*	17	*47*
1 month	6	*30*	11	*44*
6-12 months	5	*19*	14	*48*

Criterion 6: Endotoxin levels in sump are less than 1000 units/ml
Endotoxins are parts of bacterial cell walls and have been shown to cause irritation of the airways (Rylander, 1999). Endotoxin levels can indicate that there has been a high level of

bacterial growth in a sump and high levels can be found in the absence of elevated bacterial levels when biocide has recently been added to a sump. The HSG231 good practice guide recommends that levels of less than 1000 Endotoxin Units/ml (EU/ml) demonstrate good control.

The proportion of sumps in control and intervention companies failing criterion 6 was similar at each visit. In both groups the proportions were highest at baseline and 6-month follow-up visits, and lower at the 1-month follow-up visit.

Table 29: Distribution of sumps that failed to meet criterion 6 (endotoxin) at each visit by intervention and control group. Each cell contains number of sumps failing and the percentage of total sumps this represented.

	Sumps failing endotoxin criterion			
	Intervention		***Controls***	
Visit	***N***	***%***	***N***	***%***
Baseline	23	*51*	18	*50*
1 month	5	*25*	7	*28*
6-12 months	17	*63*	19	*65*

Figure 5 summarises the percentage of sumps failing criteria at each of the visits.

The main point that is noteworthy in figure 5 is the increase in the percentage of sumps that passed all criteria (i.e. 0 failures) among the intervention group across the three visits. There is an increase from 15% at baseline to 39% at 1-month follow-up and then to 55% by 6-month follow-up. While there is also a noted improvement in the control group it is less pronounced (0, 16, and 22% at baseline, 1-month and 6-month visits respectively). It is likely that the presence of an external occupational hygienist visiting the plant to measure MWF would have produced some degree of MWF management improvements in both groups but figure 5 suggests that the improvements were more marked and sustained in the intervention plants receiving the multimedia training package. Management of MWF was often carried out at an individual level with operators having a great deal of control of their main machine and most were able to regulate concentration levels, cleaning regimens and contaminant levels so it is not surprising that those receiving additional information on the hazards of MWF exposure and skin disease were more likely to have better managed sumps.

Other than administrative controls to encourage workers to dry their hands after contact and provision of tools and hooks to assist in retrieving items from the sumps (primarily to avoid cuts and other injuries from swarf and not to reduce dermal exposure to fluids), control measures in all workplaces were limited. A number of workers at some of the sites used compressed air to remove excess MWF from tools and work pieces. While this ‘control’ measure may have had some positive influence on dermal exposure to MWF it is likely to have generated high levels of airborne MWF mist and increased the risks to health from the inhalation route.

Some sites were better than others in providing cloths and absorbent materials to clean up spills and excess fluids. Where supply was plentiful the workers tended to have better housekeeping arrangements and were more likely to dry their hands after a wet-work task. Supply was also likely to have an influence on whether they would store the contaminated cloth for future use.

In addition to the gloves and barrier cream control measures identified in the report there appears to be little potential for improving control through engineering means. Dry-cutting techniques clearly offer possibilities in the future but none of the plants we visited had

introduced such technology and it would appear that widespread introduction may be some time away yet. The main potential for improvement of dermal exposure controls is in terms of behavioural change and it is this avenue that our intervention study explored.

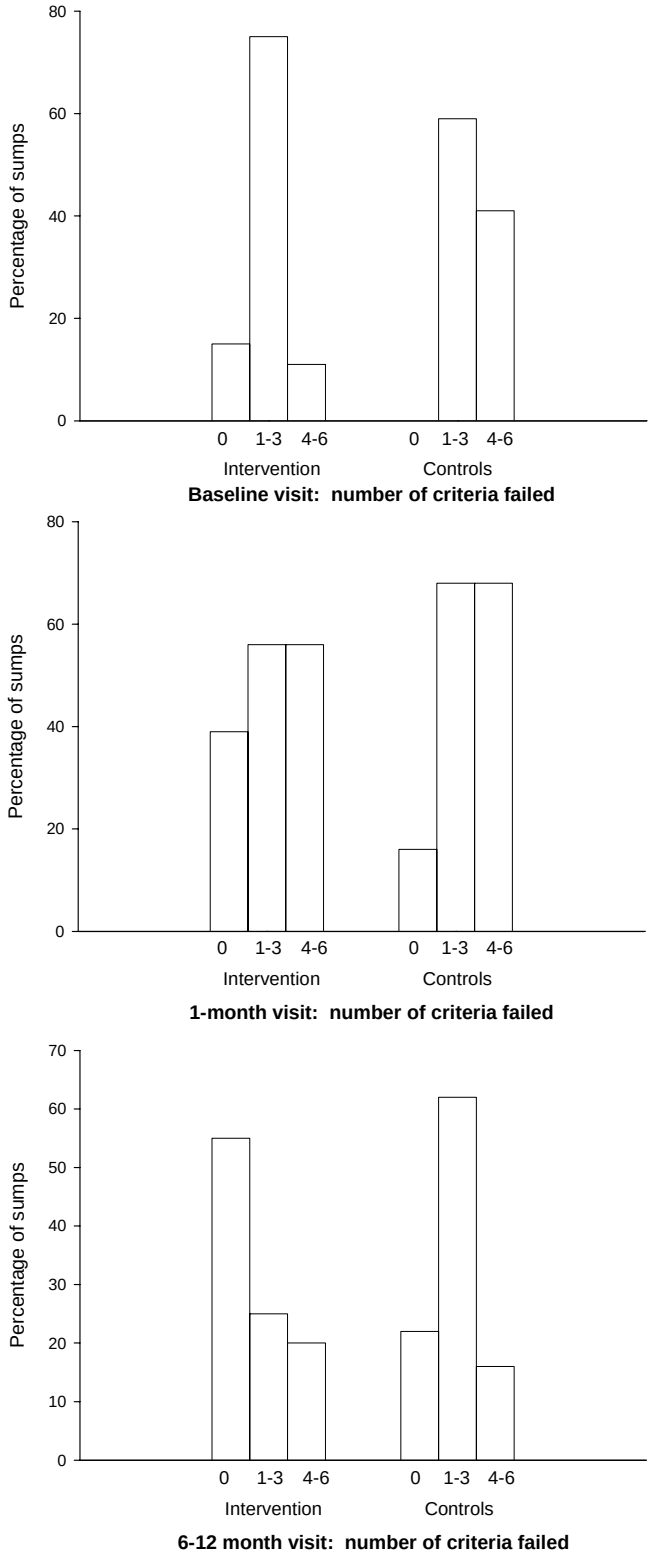

Figure 5: Percentage of sumps that failed criteria at each visit by intervention and control group.

5 THE IOM WET-WORK SAMPLER

5.1 BACKGROUND

The German Federal Ministry for Economics and Labour has introduced technical guidance (TRGS 531) designed to protect the skin of people who have to work with water or wear water resistant protective gloves (English translation available at http://www.cdc.gov/niosh/topics/skin/pdfs/WetWorkTRGS531.pdf). The standard essentially recommends that workers should not have their hands wet for more than 2-hours or more than 20 times each day and that impervious gloves should not be worn for more than 4-hours per day.

This technical guidance and other preventative measures introduced in Germany have had an impressive impact on the incidence of dermatitis in many different types of workplace, including metal surface processors where MWF is used. Dickel *et al* (2001) found that overall incidence of occupational skin disease in Bavaria decreased from 10.7 per 10,000 between 1990 to 1992 to 4.9 per 10,000 in the period from 1993 to 1999. Dickel *et al* (2002) showed a ten-fold reductions in the incidence of dermatitis amongst hairdressers from 1990 to 1999. Much of the disease observed in these studies was attributed to wet-work and the reductions in the incidence of skin disease to the restrictions on wet-work introduced in Germany.

There is scientific interest in developing a clearer understanding of the causal exposures involved with irritant dermatitis from wet-work and occlusion of the skin from wearing impervious gloves. Prof Coenraads and colleagues from the Netherlands have investigated the exposure of nurses to wet-work by using a questionnaire and direct observation (Jungbauer *et al*, 2004). They found that the direct observation, which they considered a "gold standard" produced estimates of the average duration of wet-work that were about half that based on the questionnaire data and the frequency was twice that reported in the questionnaires. They argue that the risk of dermatitis may be related to the frequency of wetting-and-drying cycles within a defined period of time and that reliable data was needed for epidemiological investigations.

In the present research project we have shown that the main causal factor for disruption of the barrier function of the *stratum corneum* from metal working fluid exposure is the water content. We therefore believe that it is most appropriate to focus on measures of exposure on the amount of time the hands are wet and the frequency of wetting, since these measures have been shown to have an important role in determining the risk of dermatitis from wet-work.

In the main workplace part of our study we have used an interception (patch) sampler, which was unsuccessful, and removal sampler (i.e. wiping the skin). We believe the latter approach has given us a reasonably reliable measure of exposure to MWF, but we are not certain that it is the best measure based on the research carried out in Germany and the Netherlands.

Towards the end of the current research project we invented a new sampler for measuring exposure during wet-work. It is unfortunate that the inspiration for this sampler came at the end of our work and so we were unable to use it in the field investigations. However, we have taken the opportunity to include preliminary details of the sampler and some limited laboratory investigations to demonstrate its potential.

5.2 DESCRIPTION OF THE NEW SAMPLER

The IOM wet-work sampler is a simple device that comprises two thermocouples mounted in a holder and linked to a data-logger. The first thermocouple is located approximately 2mm above the skin while the second thermocouple is located under the holder in contact with the skin surface. Figure 6 shows the prototype holder with the two thermocouples. A plan is in Appendix 4.

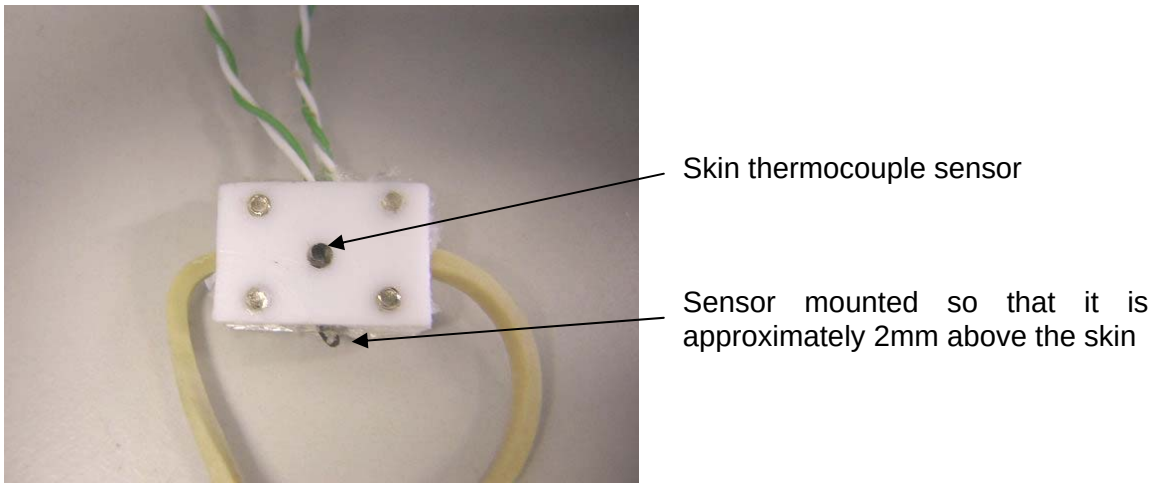

Figure 6: The prototype IOM wet-work sampler

The holder is held on the subject's finger using an elastic band (Figure 7). The wires from the thermocouple are kept in place with a Velcro wristband or tape and the data-logger may be worn in a pocket, on a belt or as shown on the arm. The total cost of the system is approximately £300 plus the time to fabricate the holder for the sensors.

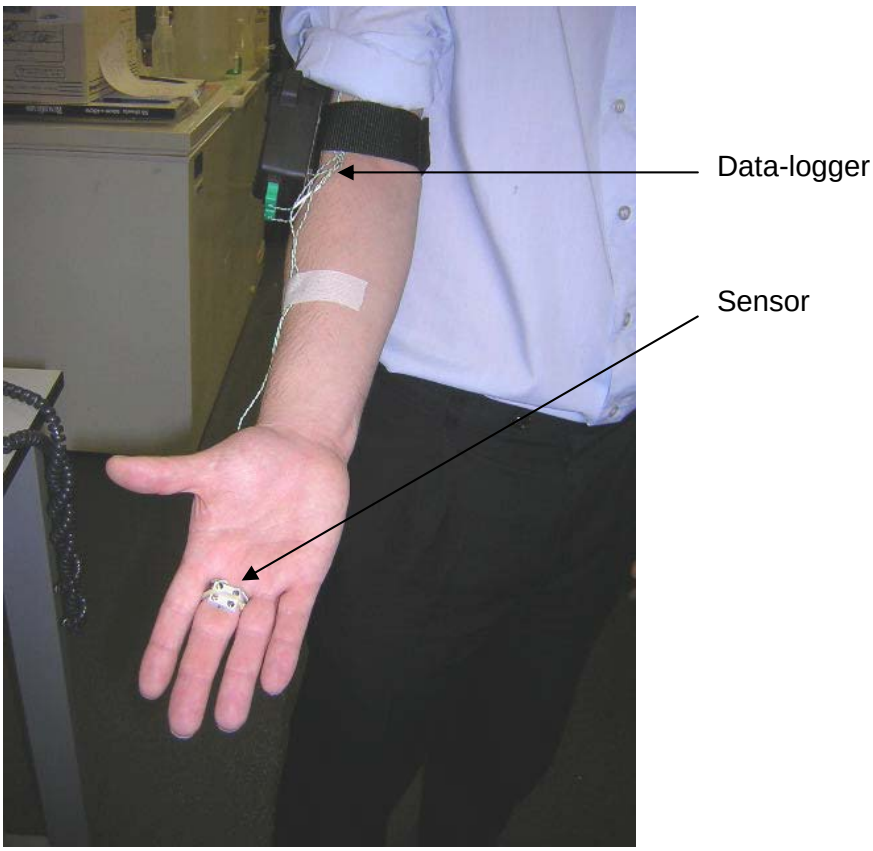

Figure 7: The prototype IOM wet-work sampler worn on finger

In normal operation with the sensors dry the thermocouples indicate skin temperature and a value slightly below skin temperature. However, if the person immerses their hand in water the sensors are influenced by the liquid temperature, with the one above the finger responding most quickly to the change in temperature. Once the hand is removed from the liquid it begins to warm this warming process is slowed by the exchange of heat energy from the skin to the water enabling the water to evaporate. Figure 8 shows a typical trace of the thermocouple readings for the following exposure sequence (15 minutes rest, 5 minutes wet wiping, 15 minutes dry wiping and 15 minutes rest), repeated twice and the difference in temperature between the two sensors.

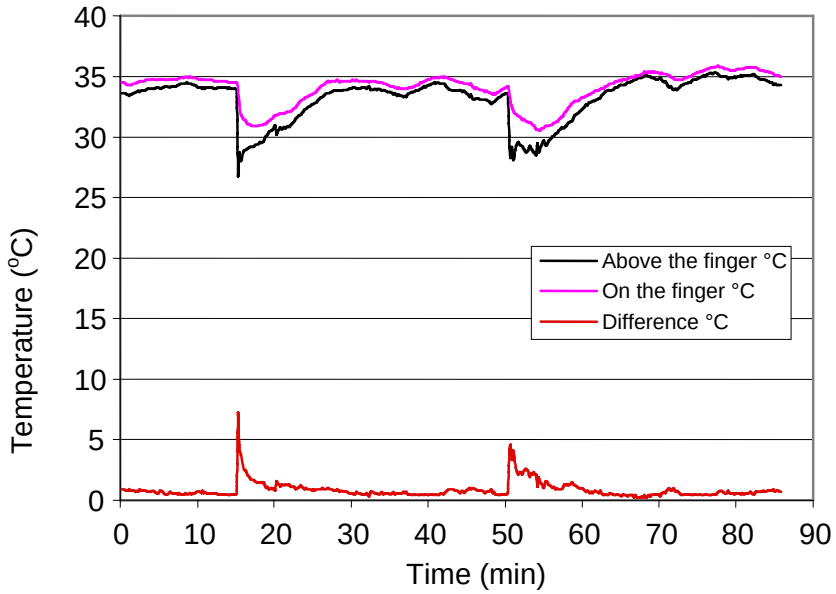

Figure 8: Typical thermocouple measurements from an immersion test with the prototype IOM wet-work sampler

The difference curve (red) shows a distinct pattern with a spike at the start followed by a fairly consistent decline in the temperature difference. The apparent drying time for the sensor is about 10 minutes with the 5 minute wet-work task, i.e. about 15 minutes in each cycle when the hand was wet.

We are currently exploring possible options for the analysis of the data, but a simple approach is to count the number of time periods where the recorded temperature difference is more than the mean temperature difference plus two standard deviations in the periods when there was no wet-work, i.e. the initial 15-minute period of the task and two ten minute periods at the end of the dry wiping. This corresponds to a difference between about 0.4 to 0.9 °C, depending on the subject and the trial. Figure 9 shows the difference trace for the trial in blue and the red bars indicate when the measured difference exceeds the threshold. Using these data the proportion of time designated as “wet-work” is 21%, which is what would be expected if the sensor drying time was about 4 minutes.

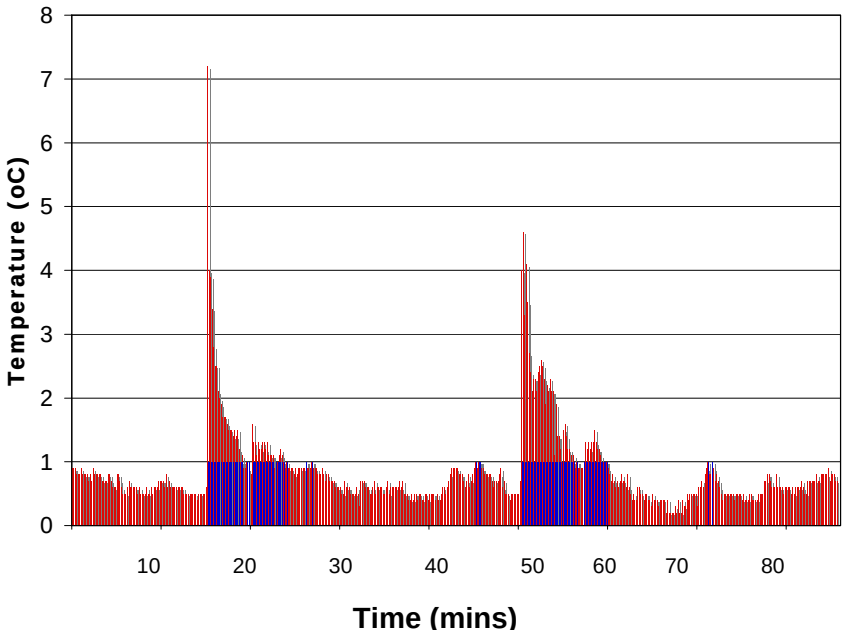

Figure 9: Illustration of using a threshold temperature difference to identify periods of wet-work

There are clearly some periods when the criteria produced a false positive indication of wet-work and others where the hands are wet when the criteria would indicate dry hands. However, on balance we feel that this approach is suitable for the present purposes.

We have repeated the task above on two separate occasions with four volunteers (two male and two female). Table 30 shows the average skin temperature of the subject, the average difference between the readings from the two thermocouples and the proportion of time spent in wet-work based on the criteria described above.

Table 30: Results from the preliminary evaluation of the IOM wet-work sampler

Subject	***Gender***	***Test 1***			***Test 2***		
		Average skin temp (^oC)	***Average difference between sensors (^oC)***	***% task wet-work***	***Average skin temp (^oC)***	***Average difference between sensors (^oC)***	***% task wet-work***
AA	M	33	0.8	21	34	1.0	46
SS	M	32	0.8	28	29	0.5	10
KC	F	25	0.4	12	24	0.6	20
AM	F	25	0.4	25	27	0.5	39

These data showed marked differences between the skin temperature of the male and female volunteers, although only based on four people, and there is no strong evidence to support a gender difference in skin temperature (Niu *et al*, 2001). The two males had skin temperature during the tests between 32 and 34 ^oC, whereas the females average skin temperature was between 24 and 27 ^oC. These data are similar to that reported by others for skin temperature on the finger (Niu *et al*, 2001). The lower skin temperature resulted in a corresponding smaller difference in temperature between the two sensors and this made the identification of periods of wet-work more difficult.

All of the temperature difference traces produced the characteristic sign of two immersions in a cool liquid, i.e. a spike in the temperature difference between the sensors and then to varying degrees a period of increased temperature difference above background. The proportion of time that the task was judged to involve wet-work ranged from 12 to 46%, which corresponds to sensor drying times between zero to 15 minutes. The average sensor drying time was 7 minutes.

We have also explored how the IOM wet-work sampler responds when the water is hotter than skin temperature. In this case the initial spike is in the opposite direction to that shown in Figure 8, i,e, the sensor above the finger increases first and then the skin surface sensor follows suit. Once the hand is removed from the water the sensor above the finger starts to cool first and the temperature difference reverts to that seen in the earlier experiment.

5.3 DRYING TIME FOR WET HANDS

We have carried out a number of short experiments to assess the drying time for wet hands using a method developed by one of our MSc students (Verma, 2004). The subject's right hand was immersed in water and then removed. Excess water was allowed to drip off and then after a period of time (between zero and 10 minutes) the residual water on the hands was wiped off using a pre-weighed paper towel. The mass of the wet towel was determined and the mass of water was calculated as the difference in weight.

This experiment was undertaken by two people on two separate occasions, whilst the hand was either kept still or was moved back and forth. The data, averaged for both subjects and normalised to the weight of water remaining on the hands after zero minutes, are shown in Figure 10.

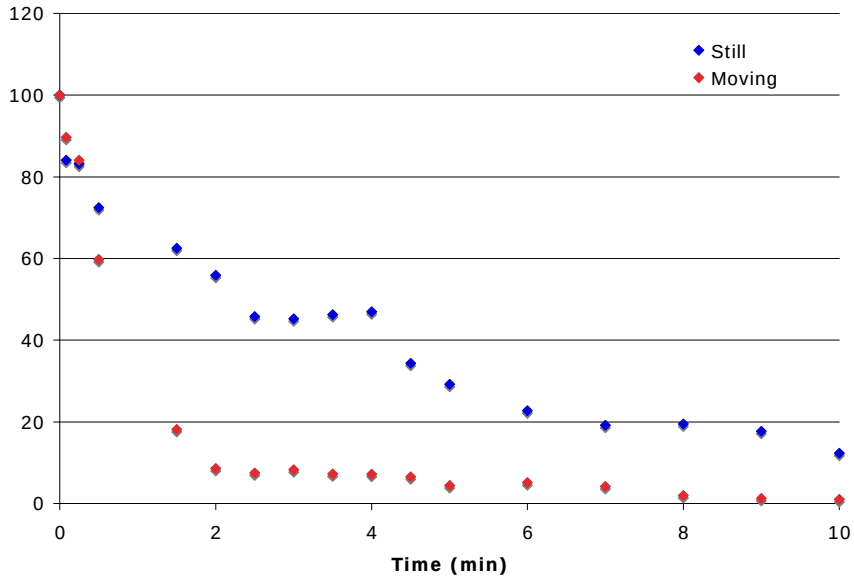

Figure 10: Average percentage water remaining on the skin at different times while the hand is either still or moving

When the hand was moved the water was relatively quickly removed and less than 10% remained after about 2 minutes. With the hand kept still the decrease in the amount of water on the skin was less quick with about 50% remaining after 2 minutes and a little more than 10% still there after 10 minutes. The decline in water on the hand seems to occur in two phases with

an initial fairly rapid reduction followed by a slower decrease, which may be due to water in between the fingers or in skin folds being less easily lost.

These drying times are compatible with the range of data obtained from the controlled experiments with the wet-work sensor and so we believe that it responds similarly to skin in indication the total time the skin is wet.

Potential for erroneous readings with the prototype IOM wet-work sampler
There are a number of circumstances that we have identified where there is the potential for the sensor to give erroneous readings. These may occur when there are changes in environmental temperature, changes in air movement over the sensor or the wearing of protective gloves. We have undertaken a small number experiments to assess the potential importance of each of these circumstances.

Figure 11 shows the thermocouple trace for someone who has spent 10 minutes in a relatively low temperature room (18 ^{o}C), then in a moderate temperature room (22 ^{o}C), a warm room (27 ^{o}C) and then back to the low temperature room.

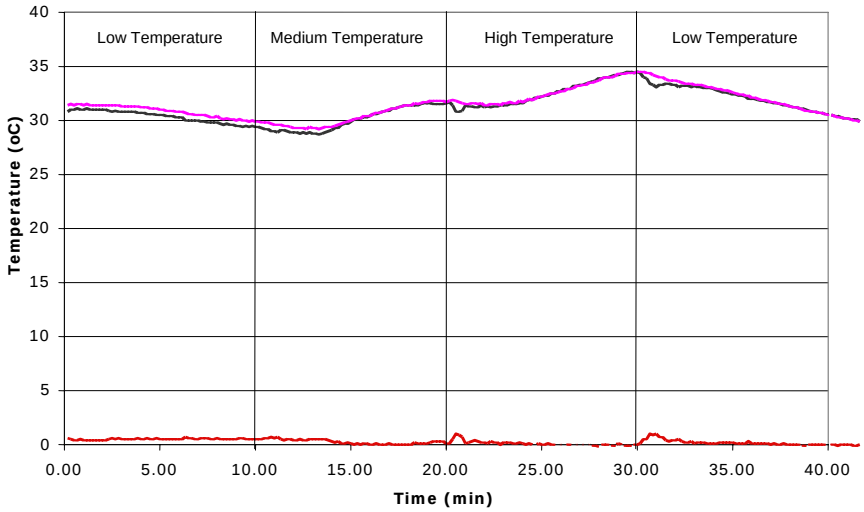

Figure 11: Sensor response to differences in environmental temperature

There are a couple of instances where the difference in temperature between the two sensors increases, on both occasions around the time of transition between different temperature regimes. However, these do not show the characteristic spike associated with the immersion of hands and the difference generally only lasts for about a minute. We do not believe that ambient temperature or changes in air temperature are an important source of bias for the IOM wet-work monitor.

Figure 12 shows a similar temperature trace for the sensor worn first with the hand held still and then while it was moved vigorously from side to side (at approximately 1m/s).

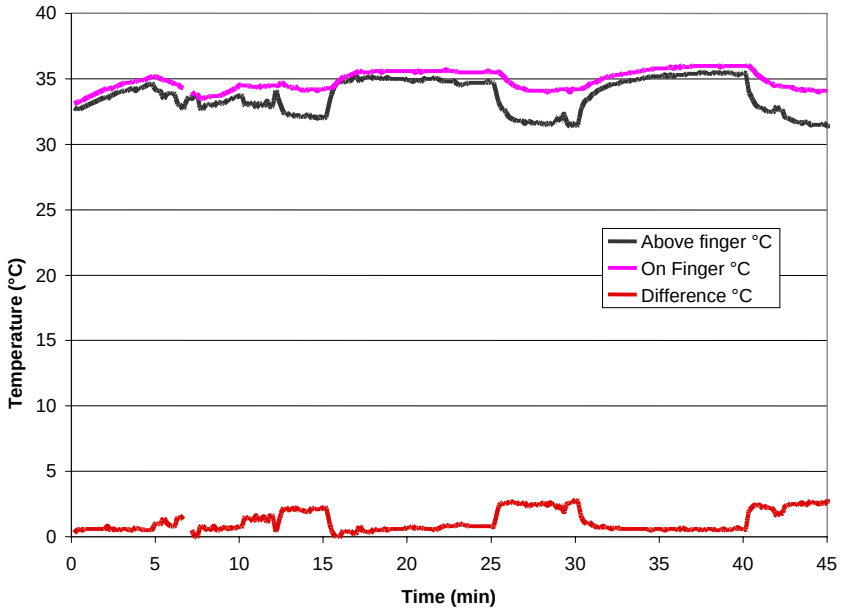

Figure 12: Sensor response to differences in air movement

During the periods of hand movement the thermocouple reading for the sensor above the finger showed a marked dip and the one on the skin showed a smaller decrease, which gives rise to an increased difference in temperature between the sensors. Using the simple data analysis approach to that described earlier then these periods would be classified as wet-work. However, the pattern of the temperature difference was quite different from that seen with actual wet-work and so we do not believe it would be difficult to discern these with a more sophisticated analysis approach. Also, the movement of the hand was much more vigorous than is likely in most situations and certainly during the wiping tasks described above there was no indication that the sampler was being seriously affected by air movement.

We also tested the prototype IOM wet-work sampler while wearing a glove (Figure 13). In this test we ran for 15 minutes with the hand dry and then wet the hand for 1 minute, then put the glove on for 15 minutes and finally took the glove off.

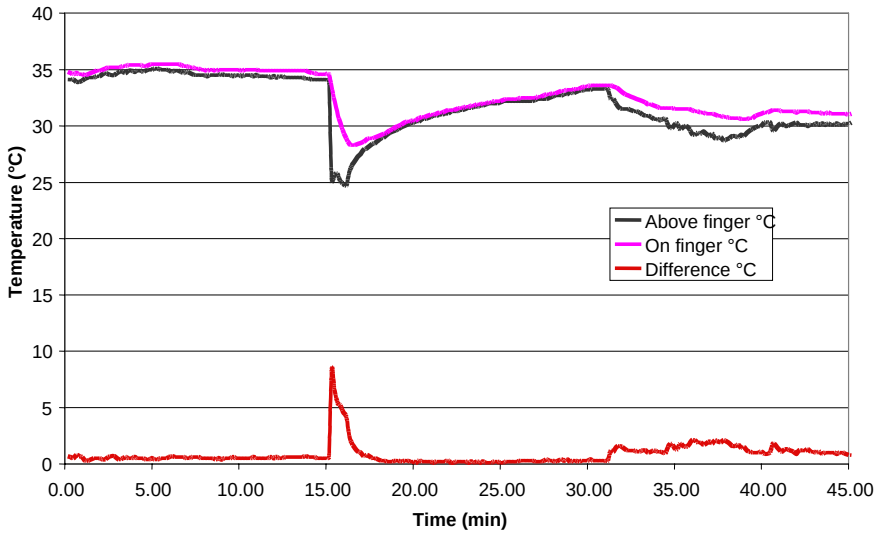

Figure 13: Sensor response while wearing a glove

The characteristic dip in temperature is associated with the wetting event, but once the gloves are donned the two temperature sensors quickly converge to show almost identical readings. This is not unexpected since the environment inside the glove is insulated and the water can easily flow inside the glove providing a more homogeneous environment. The temperature inside the glove increases as the blood flow through the hand heats the water on the skin. Once the glove is removed the temperatures on the sensors diverge as the water evaporates from the skin.

We have also carried out experiments when gloves are worn over dry skin. In this case the sensor readings converge when the glove is worn and diverge when the glove is removed. This response provides a possible way for us to identify periods of glove wearing, e.g. when the two temperatures are less than about 0.5 ^{o}C.

5.4 POTENTIAL BENEFITS AND LIMITATIONS

The IOM wet-work sampler provides a cost effective way of collecting exposure data that is likely to be relevant to the risk of dermatitis. Up to now it has only been possible to obtain such data by asking the worker about the frequency and duration of wet-work, but this is unreliable (Jungbauer *et al.*, 2004). The alternative strategy of observing workers and recording the wet events is costly and time consuming, and may also be prone to error.

The German guidance (TRGS 531), which has been a clear success in reducing the incidence of dermatitis, is based on restricting the amount of time and the number of occasions the hands are wet; both measures can be obtained from the IOM wet-work sampler. The sampler therefore provides a convenient basis to set practical objective guidance for industry to help reduce the incidence of dermatitis from wet-work. Specific dermatitis risk management initiatives could also be assessed for their effectiveness in a timely way using the IOM wet-work sampler.

We believe that it may be possible to design the data analysis routines for the sampler to enable periods of glove wearing to be identified. This type of information could provide additional useful data to help evaluate risk management strategies.

One limitation of our approach is that the sampler does not give any indication of the area of skin exposed, which may be an important risk determinant for irritant dermatitis. However, we believe that frequency and duration of wet-work are more important and probably provide the key variables for managing risk. We do not therefore see this as a serious limitation.

While we believe it is possible to patent the device we have invented, we have decided that it is more important to make the design widely known so that it can be rapidly used in studies investigating the causes of dermatitis from wet-work and in designing appropriate control strategies. IOM retain copyright on the design.

5.5 NEXT STEPS

The IOM wet-work sampler is still at a prototype stage and there is some further development and testing necessary. The following are suggested improvements that could be made to the measurement system:

- development of a smaller flexible holder for the thermocouples;
- investigate more thoroughly the effect of environmental conditions, e.g. air temperature, humidity and air flow;
- investigate more the effect of liquid temperature on sensor response;
- development of a more reliable and user friendly data analysis routine;

- evaluation of the suitability of the device to assess periods of glove wearing;
- checks on the reproducibility of sensor manufacture.

In addition, we believe that the sampler should be tested in a number of workplaces where wet-work occurs to assess the reliability and suitability of the system. This could be done by comparing it with self-assessed wet-work parameters and direct observation data on frequency and duration of wet-work.

6 DISCUSSION

While exposure to MWF is accepted as being a risk factor for the development of irritant contact dermatitis there is little in the way of scientific evidence to explain what aspect of the work is responsible for the development of the disease. It is possible that skin damage may result from some chemical present in the fluid, materials that become resident in the fluid after use (e.g. bacteria, fines etc.), handling of metals as part of the machining process, simply the presence of fluid on the skin for prolonged periods of time, the wearing of gloves or, perhaps, some combination of two or more of these parameters.

Our laboratory trials set out to examine if we could identify which parameters of MWF cause most irritation. The hypothesis for the work was that acute changes in TEWL represent skin damage and that repeated exposure to agents causing such changes would be likely to increase the chance of dermatitis development or exacerbation of existing skin damage. This theory of cumulative barrier function impairment is based on that proposed by Malten in 1985 (cited in Jungbauer, 2004) and is shown in figure 14.

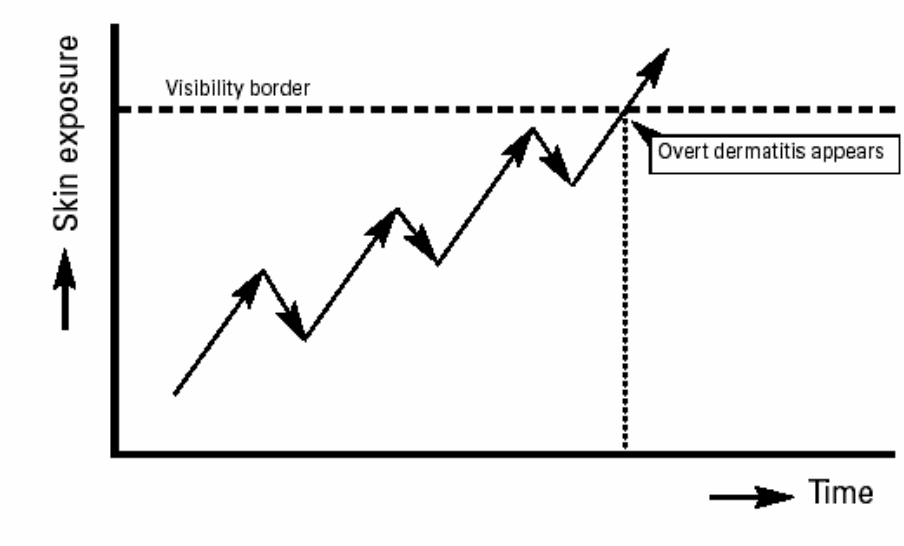

Figure 14: Development of Irritant Contact Dermatitis from cumulative barrier function damage (extracted from Jungbauer, 1985).

Our laboratory experiments used reconstituted epidermis and allowed measurement of TEWL after application of MWF, or water and compared the results to the level measured in an air-control experiment. Reconstituted epidermis is a good model for skin and is perhaps the best surrogate for skin other than *in vivo* experiments. It has been employed to assess the effect of organic solvents on the barrier function of the skin (Garcia *et al*., 2000) and to determine changes in release of cytokines from skin subjected to irritant materials (Coquette *et al*., 2003).

The laboratory experiments were able to show that the reconstituted epidermis showed increased TEWL values after treatment with a known irritant (100% ethanol). Water-treated epidermis also provided evidence of increased TEWL values in all experiments although this was not linked to duration of exposure. In some experiments where we applied water or MWF to the reconstituted epidermis we found that TEWL was increased after short durations but the level began to return to pre-exposure baseline with increasing exposure durations. This recovery may be an experimental artefact or may be indicative of what occurs in real life with long

immersion exposures compared to repeated short exposures. The laboratory experiments could not however identify significant differences between exposure to water and exposure to MWF. This was true of different dilutions of MWF ranging from a 2% solution of a water-mix fluid through to an undiluted solution. Similarly, what we deemed to be a worst-case fluid (i.e. one that was taken from a poorly managed sump), did not appear to elicit any greater response, as measured by TEWL, than exposure to water.

An explanation for the finding that even poorly managed MWF appear to be no more irritating than water may follow one of three routes. Firstly, it may be that skin barrier function, as assessed by TEWL after one-off or relatively short-term exposures is not a very good indicator of what will happen to the skin after chronic exposure. The skin's ability to recover from the irritation may be just as important as the magnitude of the irritation generated by the acute event itself. It may be that different materials cause more lasting effects. Materials that produce a long-lasting change in barrier function may prevent the skin from fully recovering before the next day's exposure. The time-course of the recovery may differ between water and MWF. The laboratory experiments used in this study could not examine these hypotheses due to the limited life of the reconstituted epdiermis.

Secondly, it may be that the variability in the TEWL levels across the reconstituted epidermis masked any real differences between the water control and the MWF-exposed samples. Reconstituted epidermis samples, although grown from culture, are not identical and will have some degree of biological variability. While there was generally a statistically significant difference between TEWL levels for air control and treated samples, the variability between replicates tended to be as large as that found between different time-points or different treatments. Difficulties with the limited lifespan of the cell culture, the cost of the epidermis material and the timing of the measurements limited the number of replicates and experiments that it was possible to undertake. However, from our data there is no suggestion of any important difference.

A third explanation is that the findings are real and that the degree of risk of developing dermatitis is similar for working with water as working with MWF. Such a conclusion would be supported by the evidence that workers in other wet-work centred employments are also at high risk of dermatitis. Dickel and colleagues (2001) report occupational skin disease incidence rates per 10,000 worker per year of 97.4 for hairdressers, 23.9 for florists, 7.3 for healthcare workers and 6.4 for metal processors. The common factor in all these occupations is wet-work and indeed, as discussed in chapter 5, the German technical guidance document TRGS531 aims to limit the amount of time per day that a worker is required to have wet hands.

The results of our laboratory experiments are supportive of the hypothesis that wet-work is the driving force of skin disease development among workers exposed to MWF and, in order to reduce the prevalence of dermatitis among this sector there is a need to control wet-work exposure rather than focus on MWF fluid management. While it may be important to ensure that MWF are properly managed both for risk of disease from inhalation exposure and to maximise tool-operation efficiency, the focus for skin disease prevention must instead emphasise the need to reduce dermal exposure and engage in skin care activities.

The multimedia questionnaire developed as part of this study can be used to gather data on each user's skin health and also provides the user with some element of education on how best to reduce exposure and what steps to take to improve skin care. In general we found this system to be well received in the workplaces where it was used. The workers reported that it was easier to understand than paper-based information and that they found the images particularly helpful in being able to see examples of dermatological symptoms. There were many other advantages of the multimedia system. Some workers indicated that the images showed them how bad

dermatitis could be and so served as a warning to reduce exposure and take better care of their skin, others were able to relate their own, perhaps milder, symptoms with those shown on the screen. The voiceover system was noted by some as annoying in that it often repeated information that was already present on the screen, others found it helpful in explaining some points further and in greater detail. Although some workers had little experience of using a laptop computer or using a mouse to navigate through the package, there was little opposition and after a very brief introduction all were able to operate the system easily. Some further minor refinements are required to ensure that users who wish to return to previous pages can do so via the path they have taken and are not subject to additional questions that the program logic has removed due to previous responses. There is also scope to analyse how the package is used by workers using the log-file generated on completion. This log-file provides the administrator with data on how long was spent viewing information on each page, the data entered in any interactive elements and the page navigation in terms of going back to view certain pages.

The field study set out to examine MWF exposure across a number of workplaces, to determine if there were changes in dermal exposure, skin symptoms and/or skin protection activity in those sites that received the multimedia based intervention compared with those workers who did not. The baseline data before the intervention was administered also provides details of MWF management across a small sample of engineering workplaces in Scotland.

Measurement of dermal exposure to MWF proved to be more problematic than envisaged. Our initial methodology employed patch samplers positioned on the wrist. It soon became apparent that due to the risk of entrapment and entanglement the patches had to be worn some distance up the forearm. Observation of the workers showed that very little fluid was reaching this patch and it was unlikely to provide representative data on workers' exposure. As gloves were not an option for the same reasons of entanglement and as visualisation techniques were unsuitable due to the need to add fluorescent markers to the fluid, we settled on a wipe sampling protocol employed in other studies (Brouwer *et al*., 2000). Wipe sampling allows collection of material remaining on the hand at the time of collection. For material such as MWF that will run-off from the skin after contact or immersion activity, the use of wipe sampling is not ideal. Wiping provides data on any residue of MWF-origin but does not capture what has been removed throughout the shift or period since last sampling. Wipe sampling for MWF provides only a very crude index of dermal exposure over an 8-hour work-shift. There is a real need for a methodology capable of assessing dermal exposure that is representative of the risk of dermatitis. A wet-work index as previously introduced by Verma (2004) and described in the development of the IOM Wet-Work Sampler (Chapter 5 of this report) offers future possibilities.

Despite the limitations of the sampling method, it would appear that there were larger and more sustained reductions in dermal exposure to MWF among the worksites that experienced the multimedia package compared to those that did not receive it. Control sites did show reductions at 1-month follow-up but had returned to baseline levels by the third visit. This effect may be produced by the visit of an outside occupational hygienist measuring MWF exposures. The focus on dermal exposure is likely to have increased hazard awareness among both intervention and control workers. It would appear however that this effect was not sustained over the 6-month follow-up period.

The management of the MWF can be assessed by looking at individual fluid indicators or by grouping all parameters together to identify the number of sumps failing one or more criterion. The concentration of water-mix MWF is often a good indicator of good fluid management. Water-mix MWF should generally be in the region of 3-5%, depending on the fluid type, the tool and the metal being engaged. Values below 2% could be taken as showing that too much water has been added to a sump and is likely to represent poor management, similarly, values

above 6% may demonstrate that water has been allowed to evaporate from the mix and proper maintenance of concentration has not been achieved. While there was little change in the mean values over the three visits, the control group levels at the baseline visit were statistically significantly higher than at either of the follow-up visits. The most noticeable finding, however, was that the spread between the minimum and maximum narrowed considerably after the baseline visit particularly in the intervention group. The range at the first visit was 0.6 to 32%. In the intervention group this was narrowed to between 4.0 and 12% by the 6-month follow-up visit suggesting that the educational intervention may have helped to improve fluid management. However, it is difficult to conclude due to the fact that the baseline spread in the control group was a much tighter 2 -18% with less room for improvement than that seen in the intervention group.

However, little evidence of change in MWF can be taken from the data on the other parameters. The spread of pH values increases between the baseline visit and 6-month follow-up in the intervention group. The concentration of fines also increases between baseline and follow-up in sumps sampled at the intervention site while showing modest reduction in the control group. Levels of both sump bacteria and endotoxin showed no consistent decrease or increase across visits for either group of companies.

If we examine MWF more holistically however we can detect that there may have been a significant change in the management of the fluids between visits particularly in relation to the intervention sites. At baseline some 15% of the sumps measured in the intervention sites could be classified as having no identifiable fluid parameter problems. By 1-month follow-up this increased to 39%, while by 6-month follow-up this was further raised to 55%. There was also an improvement noted for the control group with the percentage of sumps showing no failure on any criterion rising from 0 at baseline to 16% at 1 month and 22% at 6 month follow-up.

Biocides and other additives in MWF have been linked to sensitization and the development of allergic contact dermatitis. Metalworkers with occupational skin disease (OSD) are generally diagnosed more frequently with irritant contact dermatitis (ICD) as opposed to allergic contact dermatitis (ACD). OSD commonly develops from being initially irritant based to a mixture of ICD and ACD and there is even some argument that there may be an immunologic component to ICD (Levin and Maibach, 2002).

The range of MWF additives that may cause sensitization is large and it was felt that it was beyond the scope of the present study to undertake chemical analysis of sumps for the presence of such materials, or to carry out patch testing of individuals.

While we accept that the management of biocide and other fluid additive levels will have some influence on occupational skin disease symptoms, we believe that ICD as produced by wet-work will be the primary driver for OSD development in the majority of workers.

One of the important findings of this work is the difference found in terms of classifying skin disease by questionnaire and using TEWL as a spot-check measure of skin condition. If dermatitis was defined as having two or more relevant skin symptoms and having these symptoms lasting for more than three weeks or occurring more than once in the previous twelve months, then skin disease was found to exist in approximately one-third of workers at the intervention sites and about one-fifth of workers at the control sites. The administration of the intervention package appears to have had a marked impact with the percentage classified as having dermatitis decreasing to 24% by 1-month and 19% by 6-month follow-up. This represents a fall from 19 workers at baseline to only 6 workers 6 months after intervention. The figures for the control group show some reduction but due to the smaller numbers in the control group the actual number of people classified as having dermatitis was only reduced from 6

(baseline) to 5 (1-month) to 4 (6-month). The reasons for the large fall in the intervention group are unclear. It may be that the workers, on viewing the images of dermatitis symptoms at the end of the baseline visit, decided that their own symptoms were not as severe as those illustrated and so changed their responses when re-questioned at the follow-up visits. Alternatively it may be that workers receiving the educational intervention altered their behaviour to reduce their exposure and take better care of their skin and hence reduced the prevalence of skin symptoms. It is also possible that there was a selection bias effect introduced at follow-up visits. While we aimed to monitor the same cohort of workers throughout the study some workers were on holiday or unavailable when we returned at the 1-month and 6-month visits. It is difficult to know if some individuals chose to avoid our visits and if so perhaps these subjects were those suffering from dermatitis.

The second definition of skin condition used an objective assessment of skin barrier function. Individuals with much higher pre-shift TEWL levels than the normal population were deemed to be suffering from dermatitis. Interestingly, this measure of skin disease was more resistant to change, particularly in the intervention group, than the subjective questionnaire system. In all visits the intervention group had between 15 and 19% of the population classified as having dermatitis. The control group however showed a marked decline in the percentage of workers with abnormally high TEWL levels, falling from 40% at visit 1 to about 15% in both follow-up visits. The reasons for this are unclear though it may be that the elevated levels in the control group during the baseline visit was to do with the population being unsure of what was involved in the monitoring procedure. Stress or anxiety about the procedure can lead to sweating and artificially elevated results (Pinnagoda *et al*., 1990), although this should have been similar for both the intervention and control groups. Across the three visits approximately one-third of the TEWL/symptom-based categorisations of skin condition were non-concordant. This suggests that in a substantial proportion of this population these measures were not assessing the same condition. The symptom questionnaire asks if the subject has experienced symptoms in the previous 12 months, while the TEWL measurement provides a snapshot of skin condition on that morning. This is also reflected in the data presented in table 19 showing little difference in TEWL levels at pre-shift on the baseline visit among those reporting dermatitis symptoms and those without symptoms.

The study also looked at acute skin damage as assessed by either a 20% increase in TEWL when compared to pre-shift levels, or a 20% decrease in skin hydration levels. It was considered that both of these were good indicators that the skin had suffered some significant degree of irritation that day. Both intervention and control groups had a high proportion (approximately 80%) of workers showing signs of skin damage when assessed by TEWL increase at the baseline visit. While this figure remained similar in the control group at subsequent visits, the intervention group showed a significant decrease with less than 40% showing large TEWL increases by the 6-month follow-up visit. This may again be indicative of workers reducing their exposure to wet-work or taking more care of their skin after receiving the educational intervention.

The evidence from the skin hydration measurement is less clear however. Approximately one-quarter of both intervention and control workers demonstrated drying skin over a shift at the baseline visit. This remained fairly constant over visits for the control workers but increased to nearly half of intervention workers by the 6-month visit. The level of agreement between these two markers of skin damage was also noted to be poor. This is perhaps not surprising in that these markers of skin condition may follow different time-courses depending on the individual or even on the type of irritation experienced. Immersion in fluid for long periods could lead to barrier function changes while short-repeated contact with fluids might be more likely to cause skin drying.

In terms of behavioural changes we found that both groups were fairly resistant to wearing protective gloves during their work. This is likely to be due to an established culture in the industry due to the risk of entrapment. There was, however, more evidence of change when it came to the use of skin care creams. While approximately half of both groups reporting using such creams at baseline, this rose to nearly 70% among the intervention group workers by the 6-month follow-up visit. The control group showed no similar increase. Again this may be evidence that the multimedia package catalysed some change in worker behaviour.

In conclusion it would appear that the multimedia intervention produced some changes in worker behaviour. The intervention group showed decreases in dermal exposure to MWF and also an increased proportion wearing barrier creams. These actions may explain why the intervention group demonstrated a large fall in the percentage of workers who showed evidence of acute skin damage over the working shift. If across-shift changes in TEWL can be taken as providing a marker of damage that may eventually lead to clinical dermatitis then this improvement is particularly encouraging and suggests that the multimedia intervention package could play an important role in helping workers understand dermatitis and how to protect themselves from developing the disease.

6.1 RECOMMENDATIONS FOR FUTURE WORK

Three main points are of note from this project. Firstly, current HSE guidance on MWF management (HSG 231) is almost entirely focussed on controlling MWF parameters that are linked to toxicity in terms of the inhalation route. While HSG 231 does acknowledge that the risk of dermatitis can be reduced by "avoiding prolonged skin contact with fluids" and that "the greater the contact with the fluid the greater the risk of skin problems" this information is surrounded by the general emphasis that fluid management is the primary tool in OSD prevention. This report adds to increasing evidence that while some of these fluid parameters may exacerbate pre-existing dermatitis, they are unlikely to be the primary causes of new cases of skin disease. Irritant contact dermatitis among workers handling MWF is more likely to arise as a result of wet-work rather than any specific MWF parameter. Reducing dermal exposure to MWF is the key to controlling skin disease in this group of workers and future guidance should continue to emphasise this point.

Secondly, the multimedia questionnaire and training package appears to be an effective mechanism for changing worker behaviour. Reductions in dermal exposure and improvements in skin care activities can be brought about by this multimedia system. Further work should be carried out to refine the existing package and to introduce it throughout the engineering sector as a combined health surveillance and training tool.

Thirdly, the assessment of the risk of developing dermatitis in occupations such as metal processing where repeated wet-dry cycles occur over a shift is not adequately served by existing dermal sampling techniques. The IOM Wet-Work Sampler, developed towards the end of this project, offers a means of determining the duration and frequency of hand wetness and examining the true relationship that exists between wet-work and skin disease. It will also enable comparison between wet-work exposure and the exposure limit used in Germany to determine if the two-hour limit is a suitable threshold for risk of skin disease. Further work to refine the IOM Wet-Work Sampler and to carry out field-trials should be a priority for those involved in the investigation and prevention of occupational skin disease.

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APPENDIX 1 – DETAILED STATISTICAL RESULTS

This appendix contains further details of the statistical analyses of phases 1 and 2. Specifically, tables are presented which show the results of the analysis of variance (ANOVA) carried out in both the laboratory and field work data analyses. Each ANOVA table shows the terms included in the statistical model, degrees of freedom (df), sum of squares (ss), mean square (ms) and variance ratio (vr) for that term. The variance ratio is calculated as the mean square for each variable divided by the residual mean square. The variance ratio is distributed as an F-statistic with higher values indicating variables which are statistically associated with the response variable being analysed (indicated by a p-value of <0.05).

The first set of tables refers to the analysis of the REp TEWL experiments reported in section 3.2.5.

Table A1: Air, water and 'worst case' MWF. Response = change in TEWL ($g.cm^{-2}.h^{-1}$) from pre-exposure value. (Duration of exposure was not included in the model due to sparseness of data).

Source of variation	*df*	*ss*	*ms*	*vr*	*p-value*
Air control vs treated	1	9.24	9.24	1.48	0.264
Water control vs MWF	1	0.91	0.91	0.15	0.714
Within air control	1	7.70	7.70	1.23	0.304
Within water control	1	7.29	7.29	1.17	0.316
Within MWF	1	6.50	6.50	1.04	0.342
Residual	7	43.75	6.25		
Total	12	75.39			

Table A2: Air, water and undiluted MWF (experiment 1). Response = change in TEWL ($g.cm^{-2}.h^{-1}$) from pre-exposure value.

Source of variation	*df*	*ss*	*ms*	*vr*	*p-value*
Air control vs treated	1	16.22	16.22	16.91	0.003
Duration	3	26.20	8.73	9.10	0.004
Air –v- treated. Duration	3	0.39	0.13	0.14	0.937
Water control vs MWF	1	11.39	11.39	11.88	0.007
Water –v- MWF.Duration	3	0.79	0.26	0.27	0.843
Within air control	1	9.46	9.46	9.86	0.012
Within water control	1	4.20	4.20	4.38	0.066
Within MWF	1	2.10	2.10	2.19	0.173
Residual	9	8.63	0.96		
Total	23	79.38			

Table A3: Air, water and undiluted MWF (experiment 2). Response = change in TEWL ($g.cm^{-2}.h^{-1}$) from pre-exposure value.

Source of variation	*df*	*ss*	*ms*	*vr*	*p-value*
Air control vs treated	1	20.80	20.80	72.80	<0.001
Duration	6	22.54	3.76	13.15	<0.001
Air –v- treated. Duration	6	5.75	0.96	3.36	0.021
Water control vs MWF	1	20.23	20.23	70.80	<0.001
Water –v- MWF.Duration	6	5.61	0.94	3.27	0.023
Within air control	1	1.14	1.14	4.00	0.061
Within water control	1	3.30	3.30	11.56	0.003
Within MWF	1	0.23	0.23	0.81	0.380
Residual	18	5.14	0.29		
Total	41	84.75			

Table A4: Air, water and different concentrations of MWF (experiment 1). Response = change in TEWL ($g.cm^{-2}.h^{-1}$) from pre-exposure value.

Source of variation	*df*	*ss*	*ms*	*vr*	*p-value*
Air control vs treated	1	30.50	30.50	75.30	<0.001
Duration	3	9.55	3.18	7.86	0.007
Air –v- treated. Duration	3	3.92	1.31	3.23	0.075
Water control vs MWF	1	0.25	0.25	0.62	0.450
Water –v- MWF.Duration	3	2.98	0.99	2.46	0.130
MWF Dilutions	3	5.32	1.77	4.38	0.037
Residual	9	3.65	0.41		
Total	23	56.17			

Table A5: Air, water and different concentrations of MWF (experiment 2). Response = change in TEWL ($g.cm^{-2}.h^{-1}$) from pre-exposure value.

Source of variation	*df*	*ss*	*ms*	*vr*	*p-value*
Air control vs treated	1	98.44	98.44	108.93	<0.001
Duration	6	111.73	18.62	20.61	<0.001
Air –v- treated. Duration	6	3.60	0.60	0.66	0.681
Water control vs MWF	1	21.00	21.00	23.24	<0.001
Water –v- MWF.Duration	6	6.98	1.16	1.29	0.333
MWF Dilutions	3	21.89	7.30	8.07	0.003
Residual	12	10.84	0.90		
Total	35	238.73			

The second set of tables refers to the analysis of the exposure to MWF reported in section 4.3.

Table A6: Exposure to MWF (ml) in relation to intervention/control status and visit (baseline, 1 month, 6-12 month).

Source of variation	*df*	*ss*	*ms*	*vr*	*p-value*
Intervention vs control	1	201.23	201.23	73.74	<0.001
Visit	2	7.72	3.86	1.41	0.246
Intervention –v- control.Visit	2	63.82	31.91	11.69	<0.001
Residual	208	567.65	2.73		
Total	213	840.42	3.95		

Table A7: Exposure to MWF (ml) in relation to intervention/control status and visit (baseline, 1 month, 6-12 month). Excluding worksites 1 and 3 baseline visit.

Source of variation	*df*	*ss*	*ms*	*vr*	*p-value*
Intervention vs control	1	125.50	125.50	60.10	<0.001
Visit	2	38.22	19.11	9.15	<0.001
Intervention –v- control.Visit	2	48.28	24.14	11.56	<0.001
Residual	179	373.76	2.09		
Total	184	585.77	3.18		

The final set of tables refers to the analysis of the management of MWFs reported in section 4.8.

Table A8: MWF concentration(%) in relation to intervention/control status and visit (baseline, 1 month, 6-12 month).

Source of variation	*df*	*ss*	*ms*	*vr*	*p-value*
Intervention vs control	1	0.24	0.24	0.01	0.906
Visit	2	134.80	67.40	4.01	0.020
Intervention –v- control.Visit	2	152.86	76.43	4.54	0.012
Residual	176	2959.74	16.82		
Total	181	3247.65	17.94		

Table A9: MWF pH in relation to intervention/control status and visit (baseline, 1 month, 6-12 month).

Source of variation	*df*	*ss*	*ms*	*vr*	*p-value*
Intervention vs control	1	0.30	0.30	0.34	0.560
Visit	2	0.43	0.21	0.24	0.788
Intervention –v- control.Visit	2	15.97	7.98	8.94	<0.001
Residual	195	174.16	0.89		
Total	200	190.85	0.95		

Table A10: Fines (mg/litre) in MWF in relation to intervention/control status and visit (baseline, 1 month, 6-12 month).

Source of variation	*df*	*ss*	*ms*	*vr*	*p-value*
Intervention vs control	1	1.57	1.57	1.44	0.232
Visit	2	0.56	0.28	0.26	0.772
Intervention –v- control.Visit	2	4.85	2.43	2.23	0.111
Residual	177	192.82	1.09		
Total	182	199.80	1.10		

Table A11: Levels of sump bacteria (cfu/ml) in relation to intervention/control status and visit (baseline, 1 month, 6-12 month).

Source of variation	*df*	*ss*	*ms*	*vr*	*p-value*
Intervention vs control	1	406.89	406.89	9.77	0.002
Visit	2	70.71	35.36	0.85	0.430
Intervention –v- control.Visit	2	65.02	32.51	0.78	0.460
Residual	175	7288.23	41.65		
Total	180	7830.86	43.50		

Table A12: Endotoxin levels (EU/ml) in relation to intervention/control status and visit (baseline, 1 month, 6-12 month).

Source of variation	*df*	*ss*	*ms*	*vr*	*p-value*
Intervention vs control	1	4.50	4.50	0.67	0.415
Visit	2	148.77	74.39	11.03	<0.001
Intervention –v- control.Visit	2	17.92	8.96	1.33	0.268
Residual	176	1187.06	6.74		
Total	181	1358.26	7.50		

APPENDIX 2 – SUBJECT INFORMATION SHEET

Research into the causes of Dermatitis

A study by the University of Aberdeen

Why is this necessary?

Occupational dermatitis is a large problem affecting many thousands of workers in heavy engineering environments using metal working fluids (sometimes called ‘coolant’ or ‘white water’). Little is known about what causes dermatitis and we are investigating what factors may be responsible and looking at ways of preventing dermatitis from occurring.

What will the research involve?

We plan to measure the skin condition of workers using metal working fluids. This will involve placing a small monitor on the back of the hand to measure the moisture content of the skin and how much water passes through the skin. This procedure takes less than a minute and is completely painless. In a representative sample of workers we will also measure how much contact with metal working fluid takes place. Together with measurements of the metal working fluids being used this will help us identify what causes dermatitis.

You will also be asked to complete a short questionnaire about any skin symptoms you may have experienced.

We would also like to take a photograph of each of your hands in order to compare skin condition with the measurements we make.

Further information

All the research data obtained will be treated in the strictest confidence. You do not have to take part in this research if you do not wish. If you have any questions about what is involved please feel free to contact your Health and Safety manager xxxxxxx, or the University of Aberdeen researcher, Dr Sean Semple.

APPENDIX 3 – PAPER QUESTIONNAIRE

Dermatitis Questionnaire

Q1 Name

Q2 Date of birth

Q3 Sex of subject

- ❑ Male
- ❑ Female

Q4 Job title

Q5 Production area(s) and machine number

Q6 In the past twelve months have you had any of the following symptoms?

	No	Yes
Redness & swelling of hands or fingers	❑	❑
Cracking of skin on hands or finger	❑	❑
Blisters on hands or fingers	❑	❑
Flaking or scaling of skin on hands/fingers	❑	❑
Itching of fingers/hands, with cracks or splits	❑	❑
Spots, redness or swelling of any other part of your body	❑	❑

Q7 Did any of these problems last for more than three weeks?

- ❑ No
- ❑ Yes

Q8 Did any of these problems occur more than once?

No ❑

Yes ❑

Q9 Does your skin get better with periods off work?

No ❑

Yes ❑

Q10 What are the main types of oils or coolants that you work with?

Q11 Do you use water resistant gloves while handling cutting oils or components covered with oil?

No ❑ Go to Q13

Yes ❑

Not applicable ❑ Go to Q13

Q12 If yes, do you also wear cotton liner gloves?

No ❑

Yes ❑

Q13 Do you wear barrier creams or other hand care products?

No ❑ Name

Yes ❑ | |

Q14 How do you clean your hands at work and how often?

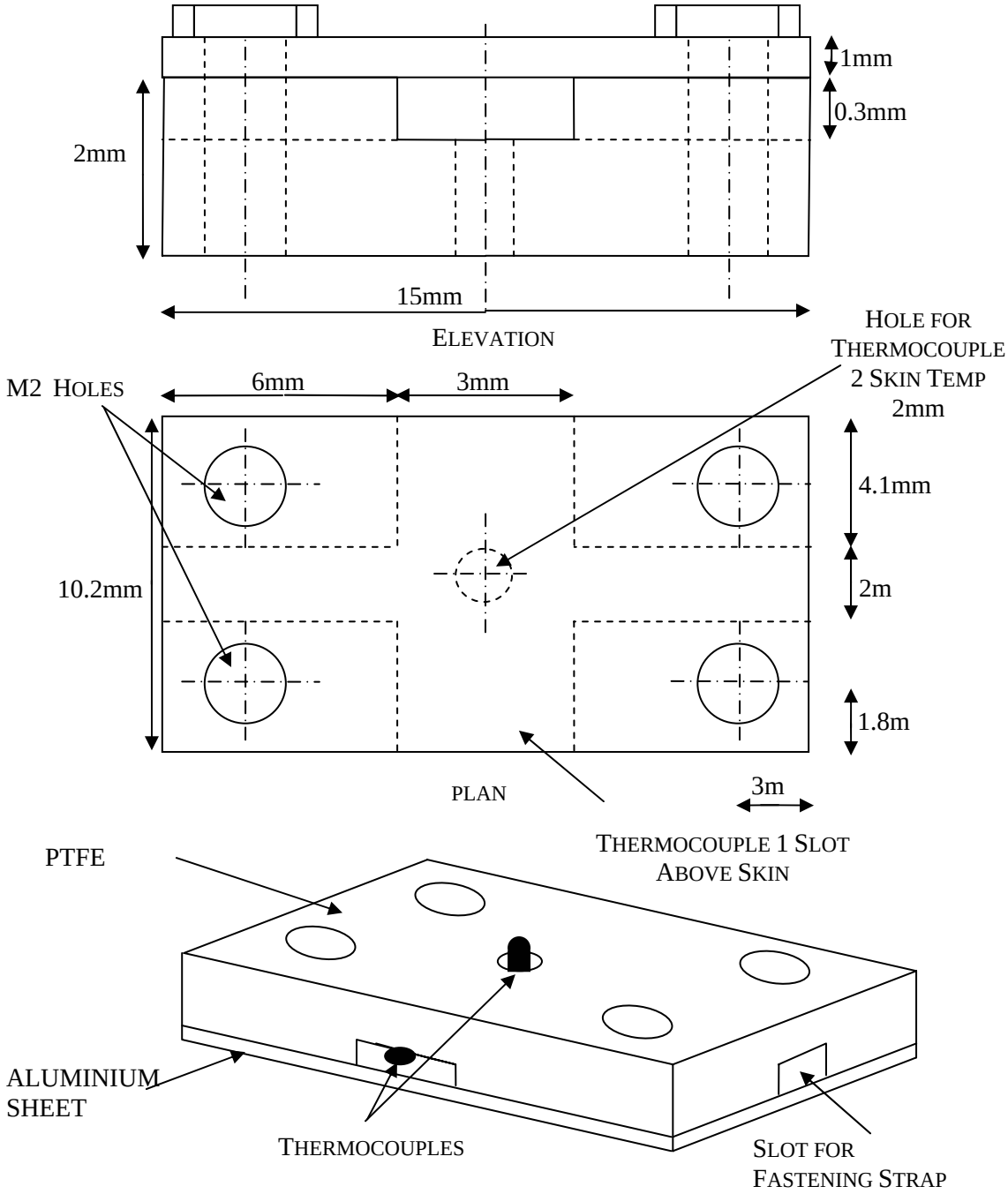
Q15 Do you/ have you ever suffered from eczema or psoriasis?

No ❑

Yes ❑

THANKS FOR TAKING TIME TO COMPLETE THIS QUESTIONNAIRE

APPENDIX 4 - DRAWING OF THE IOM WET-WORK SAMPLER



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The causative factors of dermatitis among workers exposed to metalworking fluids

Metalworking fluids (MWF) are widely used in metal processing. Exposure to MWF is known to cause irritant contact dermatitis, but it is unclear which aspects of the fluids play an important role in disease development. This research first examined which MWF parameters were linked with increased skin irritation in a laboratory investigation. These studies suggested that MWF are no more irritating, at least over short time periods, than water. We concluded that improvements in the management of MWF concentration, pH, metal fines and bacteriological contamination are unlikely to have as great an impact on dermatitis risk as reducing dermal exposure to MWF.

The second phase involved a workplace study in six engineering plants. We developed a multimedia computer package to deliver a questionnaire on skin condition, guidance on working with MWF, and advice on reducing dermatitis risk. The multimedia package helped bring about changes in worker behaviour to reduce dermal exposure and reductions in exposure were sustained across two follow-up visits. Workers receiving the guidance were also found to increase their use of skin care creams. There was also evidence that the management of MWF improved. Towards the end of the project we identified a need for a new method of sampling the duration and frequency of wet-work and we developed a prototype wet-work sampler.

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