Use of Patches and Whole Body Sampling for the Assessment of Dermal Exposure

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There has been a growing awareness of the importance of dermal exposure in recent years. A wide range of techniques are employed to measure exposure, of which surrogate skin techniques such as patch sampling and whole body sampling are frequently used. One of the problems associated with dermal sampling is that different methods often produce different results due to differences in the principles involved in sample collection. As a consequence little progress towards establishing dermal exposure limits has been made. Both patches and clothing act as passive samplers and are intended to collect all of a substance deposited on them. This paper details the principles underlying patch and whole body sampling and outlines some of the advantages and disadvantages of each. A conceptual model has recently been proposed for dermal exposure and the role that surrogate techniques may play in the application of this model is discussed. Finally, suggestions are made as to how these techniques may be made more relevant and areas of future research highlighted. © 2000 British Occupational Hygiene Society. Published by Elsevier Science Ltd. All rights reserved.

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INTRODUCTION

Exposure to hazardous substances occurs primarily through inhalation, ingestion or dermal exposure. In occupational settings the inhalation and dermal processes are generally assumed to be more important, with inhalation the more important of the two. However, in recent years dermal exposure has grown in importance, particularly where exposure by inhalation is limited e.g. use of pesticides in sheep dipping.

Substantial progress has been made in unifying the measurement of inhalation exposure. For example, the development of simple aspirated sampling instruments with collection characteristics corresponding to one or more of the biologically relevant sub-fractions has produced harmonised procedures for sampling in Europe and North America. Based on these methods, inhalation standards are now available for a wide range of potentially hazardous materials. This is not so for sampling of dermal exposure, where a plethora of sampling methods, often employing different physical principles, continue to be used. Little information on comparability between these methods is available. Schneider et al. (1999) noted that these methods often give widely differing results because of the different mechanisms involved in the sample collection. Due to these difficulties, progress towards the establishment of dermal exposure limits (DOELs) as proposed by Bos et al. (1998) has been limited.

Fenske (1993) classified the methods of assessing dermal exposure into three groups. These are:

1. Surrogate skin techniques where patches and whole body suits are used as collection media.
2. Removal techniques where substances deposited on the skin are removed by washing or wiping.
3. Fluorescent tracer techniques where the ultraviolet fluorescence of materials deposited or retained on the skin surface is measured directly by appropriate detection of imaging systems.

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Patch sampling and whole body sampling are commonly used to estimate dermal exposure. These methods are conceptually simple. In patch sampling, absorbent patches are attached to an operator’s cloth-
ing or skin at various locations on the body prior to exposure. Following exposure, the patches are removed and the amount of a substance on each patch is determined by an appropriate analytical method. Exposure to the corresponding body part or suit area is then obtained from the product of the mass collected by the patch and the ratio of the patch area to the body part area.

Despite widespread use of such patch sampling techniques, there has been little emphasis on the development of a basic model of dermal exposure or even on the use of consistent terminology. Schneider et al. (1999) identify the absence of these two features as one of the main reasons for a lack of standardisation of methods for measuring dermal sampling. In their paper they develop a conceptual model of dermal exposure based around six compartments and eight transport processes which govern the transport of material between the compartments.

In this paper we briefly review the patch and whole body suit methods for assessing dermal exposure and consider how they relate to the conceptual model. Finally we discuss the unresolved complexities of this approach to dermal sampling and identify areas requiring future research.

**PATCH SAMPLING**

The object of patch sampling is to estimate the amount of a particular substance deposited on clothing or the skin or penetrating outer clothing layers. The patches act as passive samplers and are intended to collect all of the substance of interest during an exposure period. At the end of the sampling period, the patches are removed from the clothing and placed in sealed plastic bags or jars. It is generally recommended that samples should be stored on ice before and during transport to the laboratory, where they should be transferred to the deep freeze. Should the contaminant being measured be unstable, stabilisation in the field with solvent should be carried out (Popendorf and Ness, 1994; Niven et al., 1994).

In the laboratory, the contaminant is extracted and analysed. Once analysis is completed and the amount of contamination determined, it is then related to the surface area of the corresponding body part. The calculation of body surface area is based on different figures in different protocols. For example, the surface areas vary for the WHO (1982) and EPA (1986) methods, but the OECD protocol (OECD, 1997) uses the same surface areas as the EPA method. In a modification of this, Tannahill et al. (1996) related the amount on the patch to the surface area of the corresponding suit area. This has the disadvantage that it requires that the area of each section be measured for all sizes of suit used.

Patch sampling has been used to estimate a wide range of substances including pesticides, copper oxide, polycyclic aromatic hydrocarbons (PAHs) and dusts. Batchelor and Walker (1954) describe one of the earliest studies where the patch method was used. In this study cellulose patches were used to determine parathion exposure in orchard spraymen. The first review paper detailing methods for measuring dermal exposure to pesticides was published by Durham and Wolfe (1962). Since then a number of organisations have also published guidelines on dermal sampling for pesticides, including ‘standard’ methods for patch sampling and/or whole suit sampling. (World Health Organisation (WHO), 1982; Environmental Protection Agency (EPA), 1986; Organisation for Economic Co-operation and Development (OECD), 1997; Health and Safety Executive (HSE), 1999). OECD (1997) has set down comprehensive guidelines that include detailed quality control procedures. Although such methods detail sampling methods and strategies, their use is limited in that the accuracy of the methods used is yet to be demonstrated. The principles have also been reviewed in a number of comprehensive articles (Fenske, 1993; Popendorf and Ness, 1994; Ness, 1994; Chester, 1995).

**Materials used in patch construction**

A wide range of materials are used in the construction of patches and the Worksafe Australia report (1995) presents a comprehensive list of these materials. These include cotton, rayon/polyester, dacron/cotton, flannel, filter paper, filter paper impregnated with lanolin, aluminium foil and 6 mm polyurethane foam pads. The WHO method (WHO, 1982), EPA method (EPA, 1986) and OECD guidelines (OECD, 1997) all recommend the use of α-cellulose paper. The OECD guidelines also suggest that 100% cotton or polyester cotton material can be used as alternatives. Cohen and Popendorf (1989) have suggested the use of charcoal cloth for monitoring dermal exposure to volatile compounds. The HSE method (HSE, 1999) recommends that patches be made of fabric, polymer, paper, charcoal cloth or composite materials. Polypropylene pads have been used for monitoring PAHs (Jongeneelen et al., 1988; Van Rooij et al. 1993, 1994), layers of gauze for monitoring cyclohexane soluble matter (Kromhout et al., 1994) and 3,3′-dichlorobenzidine (London et al., 1989). For dusts or other dried particles, patches constructed with layers of surgical gauze are recommended. In general, when assessing exposure to liquids, the sampling medium must be absorbent enough to retain all liquid which contacts it. Sampling for particles presents its own problems, but current recommendations (e.g. OECD, 1997) are that the medium used should be porous enough to retain the particles landing on it. Patches are generally backed with a waterproof material such as aluminium foil or polyethylene in order to ensure that contamination from the skin or overalls beneath it does not occur. In addition, the backing generally adds a degree of
robustness to the patch. Alternatively the patch may be placed in a protective envelope (Fenske et al., 1990; Popendorf et al., 1995).

Different materials will obviously have different absorption, retention and repellency characteristics which will affect estimated exposure. Different weights of the same type of cloth have also been shown to have different absorption, retention and repellency characteristics (Niven et al., 1993). Tan-nahill et al. (1996) also showed that there were substantial differences in characteristics between unwashed and washed overalls of the same fabric. In addition, the material which the outer patches, used to measure potential exposure, are made of may be very different from that of the normal or protective clothing worn. As a result it is likely that the repellency, retention and absorption characteristics of the sampling media will differ from the worker’s typical clothing which in turn will influence measured exposure levels. Hence estimated exposure as measured by the patches may be very different to that actually experienced.

Size and location of patches

Patches used for measuring exposure to pesticides typically have dimensions of approximately 10 x 10 cm, though smaller patches have been used (Fenske et al., 1990; Popendorf et al., 1995; de Cock et al., 1998). Patches used for other substances have tended to be smaller. For example, the patches used by Van Rooij et al. (1993, 1994) had a monitoring area measuring 18 mm in diameter, from which a circular piece 15 mm in diameter was punched for analysis. Kromhout et al. (1994) used patches with a surface area of 9 cm². Popendorf and Selim (1995) used different sizes of patches, with collection areas of 25.65 and 42.03 cm². Those with the larger surface area were placed on the parts of the body with a larger surface area such as the chest, back and upper legs. A variable number of absorbent patches can be attached to areas of the body both outside clothing, to measure potential exposure, and inside clothing to measure actual exposure.

Different protocols recommend the use of different numbers of outer patches, ranging from 6 (WHO, 1982), through 10 (EPA, 1986), to 13 (OECD, 1997). The HSE method (HSE, 1999) suggests the use of what it refers to as a full set of patches (11) or a reduced set of patches (6) which is based on the WHO protocol. In contrast, generally only one or two inner patches are used and it is recommended that these be placed on areas of the body where it is perceived that contamination will be significant (EPA, 1986; HSE, 1999). Inner patches should not be occluded by outer patches. In other industries fewer patches have often been used and these have typically been placed on the skin surface. Kromhout et al. (1994) used only one patch which was worn on the lower side of the wrist of the hand of preference. Van Rooij et al. (1993, 1994) placed patches at six skin sites. An exception to this is the work by Popendorf and Selim (1995), who used both an outer set of 16 patches and an inner set of up to 14 patches.

Only a very small proportion of the body surface area is represented by the patches, typically between 3 and 8%, depending on the number of patches. In addition, depending on the area of the body part, a patch of a set size will represent a variable proportion of the area. This is illustrated by Fenske (1993) who presents figures showing that a 25 cm² patch represents 4.3% of the surface area of the forearm compared with 0.73% of the chest and stomach surface area. Since exposure is calculated by extrapolating the amount of contaminant on the patch to the surface area of the body region it represents, increasing the size of the patch will minimise potential error. Therefore, the larger a patch is the more likely it is that it represents true exposure of the corresponding body part. The selection of sites for patch placement should ultimately depend on the likely pattern of exposure during a particular activity. For example, if exposure is limited to the arms and upper body, there is no benefit in sampling the legs. In such a case it may also be of benefit to increase the number of patches placed on the back and chest.

Quality control procedures

Prior to carrying out field work, the recovery rate of the contaminant from the patch to be used should be determined. Stability over time should also be investigated by preparing patches with known quantities of contamination and analysing them immediately and at suitable time intervals thereafter, until the maximum anticipated storage period has been reached. It is important that laboratory samples are stored under the same conditions as field samples throughout this time.

During the field survey, field spikes, in which the amount of contaminant added should reflect the levels expected during the survey, should be prepared. These are then exposed to the same conditions under which samples are collected and are subsequently handled, transported and stored. Field samples should also be analysed alongside the main samples. This will allow any losses occurring to be determined and hence allow for correction of field results should this be necessary. The OECD guidance document (OECD, 1997) states that recovery efficiencies of 95% or above are acceptable. For lower recovery efficiencies it recommends that the values obtained are adjusted accordingly.

Information regarding recovery efficiency is often absent or insufficient. Often it would appear that only laboratory recoveries are determined. It is frequently not clear what the recovery efficiencies are. In most cases, authors claim that recovery efficiencies are satisfactory. However, there are exceptions to this. For example, Popendorf (1988) reported that the results...
of both laboratory and field spike recovery tests were highly variable and often low when spiked below 100 μg. They did not correct results for recovery losses due to, among other reasons, the high variability in gauze recovery rates. They also reviewed the work of a number of other researchers, who also reported highly variable recovery efficiencies. Popendorf et al. (1995) showed that different substances can have different recovery efficiencies from the same material. Popendorf and Selim (1995) illustrated for one particular substance that although lab spike recoveries were essentially 100%, field spike recoveries were sufficiently low to justify the application of a correction factor. It is therefore important that recovery efficiencies both in the laboratory and the field are investigated thoroughly for both the substance being monitored and the material being used as the monitor. Recovery, stability and collection efficiencies over the range of likely loadings in the field must be determined. Previous work should not be relied on.

Replacement of patches

There are no standards governing the replacement of patches. However, it is generally recommended that they should be replaced immediately should saturation occur. This obviously requires close observation during the sampling period. Ideally, the sampling period should be long enough to collect sufficient contamination for analysis, but not so long that significant losses occur, for example, due to evaporation. Additionally, replacement of patches at appropriate intervals, for example during the lunch break, is recommended. However, it is difficult to know what the optimum exposure period for patches should be. This will partly depend on the contaminant of interest, the type of material used in the patch and also the analysis being carried out.

Although it is suggested that patches be replaced at suitable intervals, it is still likely that losses will occur, partly as a result of evaporation and changes in the contaminant over time. The use of field spikes will, to a certain extent, address these problems, particularly where material is lost by evaporation. However, dirt and other substances encountered during exposure may interfere with the contaminant being measured and so lead to erroneous estimates being made.

Advantages and disadvantages

The major disadvantage of patch sampling is that it only estimates the amount of a substance deposited on a particular area. It assumes that contamination is uniformly distributed over the area represented by the patch. However, the patch represents only a relatively small proportion of a particular region and extrapolation could lead to underestimation, should droplets miss the patch when spraying, or overestimation, should a splash land on the patch. Kromhout et al. (1999) showed that these limitations could be overcome by combining the patch method with fluorescent tracer techniques, with the latter providing information on the exposure distribution and the former allowing quantification of exposure. Patch sampling requires considerable preparation prior to its use, although it does have the advantage of ease of use and relatively low cost. In comparison with outer patches, only a limited number of inner patches (one or two) are generally used and as such their use for the estimation of actual exposure is restricted.

WHOLE BODY SUIT SAMPLING

The object of whole body sampling is to measure the amount of a particular substance landing on clothing or on the skin or penetrating clothing layers. Typically, lightweight overalls or similar are used to estimate exposure to the areas of the body covered. Exposure to the head is measured either by a hood attached to the overalls or a separate hat. Exposure to the hands and feet can be measured by using gloves and socks respectively. Exposure to various body regions can be determined by sectioning of the suit, with analysis of the relevant region.

A variation of the above method used normal clothing to measure exposure (Chester, 1995). This method has the advantage that it can be used in conjunction with biological monitoring, unlike the standard whole body suit methods which add another layer between the contaminant and the skin and so interfere with the normal process of contamination and absorption. It is also possible to combine both of these methods. Cotton overalls to measure potential exposure and long-sleeved T-shirts, long-trousered underpants and socks worn under the overalls to measure actual exposure were used by de Vreede et al. (1998).

Unlike patch sampling techniques, the use of whole body sampling techniques is mainly confined to the measurement of pesticide exposure. An exception to this is the study by Van Rooij et al. (1994). This research used whole body sampling to estimate exposure to polycyclic aromatic hydrocarbon in woodpreserving and aluminium workers.

Materials

Unlike patch sampling, a relatively limited range of materials has been used for suit sampling. Most typically 100% cotton or a cotton and polyester mix are used (Fenske, 1993; OECD, 1997), though the use of Strentex ‘Corovin’ disposable overalls (Abbott et al., 1987) and Tyvek coveralls (Van Rooij et al., 1994) have also been reported. Worn under protective clothing the method has been used to provide some indication of its effectiveness. Following sampling, the suits are removed and usually sectioned, each section being stored separately and the substance being monitored extracted and analysed.
Advantages and disadvantages

As for patch sampling, recovery rates and stability of the sampling material should be investigated prior to field work. Similarly, field spikes should be prepared during the field survey.

Since the whole area is represented in this method, no scaling of the amount recovered from a particular section is required. It therefore has the advantage that it does not rely on uniform distribution of the contaminant over large sections of the body. However, large volumes of solvent are required to extract the contaminant and since the concentration of the contaminant may be low, concentration of the solvent may be required, making the technique both time-consuming and costly. Using an extra layer of clothing to measure exposure can lead to problems, with the movement of the wearer being restricted. In addition, it may be uncomfortable for the operator, particularly with respect to temperature. Perhaps for these reasons it has been less popular than the patch method.

COMPARISON OF THE TWO METHODS OF SAMPLING

In a study comparing the patch method with the whole suit method in spraying applications, Tannahill et al. (1996) concluded that the patch method was an acceptable method for estimating potential dermal exposure. However, where a more accurate measurement was required they recommended that a change of approach may be necessary. For example, the authors suggested that in the case of the front torso, better agreement between the two methods may have been achieved if the patch had been placed at the centre of the torso, rather than to the side and supplemented by a second patch or the size of the patch increased, e.g. by having a long thin patch running vertically down the middle of the torso.

The material used for both patches and suits may contain substances which interfere with subsequent analysis and in such cases the contaminants need to be removed prior to sampling either by extraction with solvents or washing with detergent. It should be noted that different solvents have different extraction efficiencies, thus making it difficult to compare results from different studies.

One disadvantage of both the patch method and the whole body method is that neither will mimic skin uptake. In addition, there are no standardised guidelines for the type of material that patches or sampling suits should be made of, the only criterion being that they should be absorbent. It should also be noted that, where they are used to investigate the effectiveness of protective clothing, both the patch method and whole suit method assume that all contamination beneath the protective clothing occurs as a result of penetration or permeation through the clothing and takes no account of contamination as a result of direct deposition to the skin contamination layer.

COMPARISON OF SURROGATE SKIN TECHNIQUES WITH OTHER METHODS OF ASSESSING DERMAL EXPOSURE

All methods used for assessing dermal exposure have advantages and disadvantages. The use of fluorescent tracer techniques are outlined in this issue by Cherrie et al. (2000). Although this method has the advantage of allowing estimation of actual skin exposure, in comparison with other techniques it is expensive, particularly with respect to the initial outlay of equipment. In addition, the technique requires the addition of a tracer to the substance of interest, which may not only behave differently from that substance, but may be harder to remove from the skin.

Where patches are used to estimate exposure the individual requires careful observation throughout the sampling period since the method assumes uniform contamination over the area represented by the patch. Patches also need to be robust enough to withstand the rigours of the tasks being undertaken and care has to be taken to ensure that patches or clothing are replaced before they become saturated and this again requires careful observation.

Removal techniques, discussed by Brouwer et al. (2000) in this issue, although easy to use and inexpensive, have the major drawback of only measuring what is on the surface of the skin and so take no account of what has already been absorbed. They also rely on the substance of interest being easily removed from the skin by washing or wiping. In addition, the solvent used for removal may affect the integrity of the skin. However, the main disadvantage of skin washing techniques are that they are not practical for measuring whole body exposure.

POTENTIAL USE OF PATCHES AND WHOLE BODY SUITS IN THE COMPARTMENT MODEL

In their paper, Schneider et al. (1999) develop a conceptual model of dermal exposure based around six compartments and eight transport processes which govern the transport of material between the compartments. A detailed description is also found in the paper by Schneider et al. (2000) in this issue. The six compartments are: source, air, surface contaminant layer, outer and inner clothing contaminant layer and skin contamination layer.

Movement of material between compartments is described by a set of transport processes:

1. Emission of the substance into the air and onto surfaces, the outer clothing and the skin contaminant layer.
2. Deposition of the substance from the air to surfaces, outer clothing and the skin contaminant layer.
3. Resuspension or evaporation of the substance from surfaces, outer clothing and the skin contaminant layer.
4. Transfer of substances by direct contact between surface, skin and outer and inner clothing contaminant layers towards the worker.
5. Removal of substances by direct contact between skin, inner and outer clothing and surface contaminant layers away from the worker.
6. Redistribution of substances within a compartment, e.g. from one part of the skin contaminant layer to another.
7. Decontamination whereby the substance is deliberately transported out of the system, e.g. by ventilation of the surrounding air or washing the skin surface.
8. Penetration or permeation which involve the transport of the substance through rate-limiting barriers such as clothing and the stratum corneum.

Schneider et al. (1999) list where the various methods for measuring dermal exposure may be used in their model. Patch sampling and whole body methods may have a number of roles to play in the measurement of parameters involved in the compartment model both in measuring compartment mass and transport processes. The paper by Vermeulen et al. (2000) in this issue illustrates the use of patch sampling within the framework of the model.

Specifically, they have identified that patch sampling and whole suit methods are appropriate for measurement of the mass of the hazardous substance in the skin contaminant layer. They can also be used to estimate the mass of substance transferred from: the surface contaminant layer to the skin contaminant layer; the inner clothing contaminant layer to the skin contaminant layer; the outer clothing contaminant layer to the skin contaminant layer. They can also be used to estimate the mass of substance deposited from the air compartment to the skin contaminant layer.

**DISCUSSION**

Despite the existence of a number of standards governing surrogate skin monitoring, there is still a great deal of variation both between studies carried out by different groups of researchers and among studies carried out within particular groups of researchers. This is particularly evident with respect to the number of different materials used in the construction of patches. It has not yet been shown that different patch and whole body samplers monitor dermal exposure with the same accuracy and it has been suggested by van Hemmen and Brouwer (1995) that such methods are likely to result in overestimation of exposure. This underlines the need for the development of accurate measurement techniques partly in order to facilitate comparison of different studies.

Surrogate sampling techniques assume that the materials used as collection media, capture and retain chemicals in a manner similar to that of the skin. However, this is clearly not the case, since neither patches nor suits have the same texture or properties as skin. The amount on the patch or suit material will therefore not be representative of the amount actually present for uptake on the skin. This obviously has implications when issues such as sampling efficiency are being considered.

One of the main limitations of surrogate skin techniques is that they measure the mass of a substance deposited on the skin. However, since the uptake of substances through the skin is driven by diffusion, it is the concentration of the substance rather than the mass that is the most important factor in determining dermal uptake. This has been illustrated in a study carried out by Niven et al. (1993). They found significantly higher concentrations of diazinon metabolites in next-morning urine samples from operators who handled concentrated sheep dip than in those who did not. Although some workers were observed to be soaked with working strength sheep dip, urinary metabolite concentrations were not particularly high. There is a need, therefore, for methods of monitoring to be developed that measure concentration rather than mass. The model by Schneider et al. (1999) gets round this by defining the concentration on skin as the mass of hazardous substance on the skin surface divided by the sum of the mass of hazardous substance plus the mass of all other liquid substances. Other liquid substances will include sweat, skin oil and barrier cream if it is used. However, a potential problem arises as to how these substances should be measured since a thorough knowledge of the substances to be measured is required. There is also the problem of how to distinguish these substances from the actual substance of interest.

Although patch or whole body suit sampling methods do not provide information on the quantity of substance passing through the epidermal barrier, they do allow for an assessment of the total dermal reservoir or sink which is available for absorption into the blood. This concept of the limit of mass which may be taken up into the body is discussed further in the paper by Cherrie et al. (2000) in this issue, and is also developed by Semple et al. (2000) in relation to the uptake of solvents in painters. In many situations where the mass of material deposited on the skin is insignificant compared with that absorbed by inhalation, this method can be used without reference to complicated uptake kinetics to demonstrate that the risks to health from dermal exposure are negligible.

Most protocols suggest that patches should be replaced if they become saturated. Results from the original and replacement patches are usually combined. This, however, may overestimate exposure as wet clothing in contact with the skin may or may not act as a continuous reservoir of contamination. As discussed above, contamination may not necessarily be absorbed across the skin. In such a situation,
replacement of patches is likely to lead to overestimation of exposure.

The model proposed by Schneider et al. (1999) provides a framework for a uniform terminology which if used universally should lead to greater consistency across the field of dermal exposure and hence allow comparability of studies. Its use will increase awareness of all exposure routes and will allow visualisation of the main factors influencing exposure. Its usefulness, however, is limited in certain aspects due to a lack of a biologically relevant sampler. Priority should therefore be given to developing monitors which more closely mimic the skin and which measure concentration rather than mass. Cherrie and Robertson (1995) suggested the construction of a sampler which incorporates an artificial skin, possible diffusion barrier and an absorbing material. The artificial skin and diffusion barrier would allow measurement of the time weighted average concentration of the contaminant on the skin surface, rather than its mass, with the units of measurement being mg/kg or similar.

It should, however, be remembered that although such a sampler would be an improvement on the samplers available, it would still be far from ideal. As the authors themselves point out, factors influencing uptake such as the integrity of the skin, variations in skin thickness over the body and the effect of exposure to substances other than the contaminant of interest are not accounted for. Dermal sampling on the outside of skin will never be able to take account of large inter-individual variation in e.g. skin thickness, skin hairiness, pore density and tissue perfusion or intra-individual variation e.g. the air temperature in the workplace, which will in turn influence the perfusion rate through the skin and the rate of sweating.

Although it is anticipated that the contaminant of interest would diffuse across the artificial skin in a similar manner to real skin, this uptake will continue at a similar rate throughout the monitoring period, regardless of how much has already passed through. This is clearly not the case with normal skin where uptake will be affected by the concentration in perfused tissue. In addition, such a sampler could only be constructed in patch form and would therefore be affected by non-uniform exposure and splashes.

Although this type of sampler would be appropriate for sampling liquids, sampling for particles would present problems. Before particles can permeate through the skin they must dissolve into the skin contaminant layer which will be composed of sweat, skin oil, any liquid contaminants and barrier cream where it is used. Uptake will at least partly depend on particle solubility. In general, particles are less likely to be absorbed across the skin than liquids and hence the current patch construction of surgical gauze is likely to lead to an overestimation of exposure.

CONCLUSIONS

If the aim of patch and whole body sampling techniques is to provide information on the risk to health from skin contact with various substances, then we must answer two primary questions. Firstly, is the health effect under investigation a local reaction such as irritant contact dermatitis, or is it a systemic effect mediated by increased blood concentrations of a substance able to pass through the epidermal barrier? Secondly, what is the relationship between the mass or concentration of the substance measured on the skin surface and the internalised dose and hence any resultant health effects? It is only by addressing these areas that quantitative measurements of dermal exposure can have meaningful results and be used for the basis of health based dermal occupational exposure limits.

In conclusion, dermal exposure sampling by means of patch and whole body sampling is currently a mixture of methods with little or no international consensus on what and how to sample. The model developed by Schneider et al. (1999) provides an excellent framework on which to build a strategy for standardised dermal exposure measurement, which will, in turn enable the health risks from this important exposure route to be assessed. Consideration of the principles involved in the model should lead to the development of more relevant sampling techniques, with the development of a more biologically relevant dermal sampler being a prerequisite.

REFERENCES


Cohen, B. S. M. and Popendorf (1989) A method for monitor-


