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Field evaluation of protective clothing against non-agricultural pesticides

Soutar A, Cherrie B, Cherrie JW

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Field Evaluation of Protective Clothing Against Non-agricultural Pesticides

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The effectiveness of three different types of protective overalls was investigated both in the laboratory and in the field during timber spraying. Polyester cotton overalls and two different types of disposable overalls were tested. In the laboratory, each type of protective overall was evaluated for penetration and permeation in accordance with European Standards. Following a pilot survey, a total of twelve field surveys were carried out, with each of the three types of protective overall being worn in four different surveys. Laboratory tests suggested that disposable overalls should be more effective than the polyester cotton overalls. However, field trials indicated that there was very little difference between the three types. Wide ranges of both potential exposure (i.e. the mass of pesticide collected on the outer patches) and the mass of pesticide under the protective overall were observed. Similarly, there was a wide range of penetration factors for the whole suit. It is therefore important to ensure that protective overalls be changed at frequent intervals. Safe working practices should be promoted regardless of the type of protective clothing worn.

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SUMMARY

The effectiveness of three different types of protective overalls when spraying pesticides for timber preservation was investigated both in the laboratory and the field. The three types of overalls tested were 65% polyester 35% cotton hooded overalls, a disposable garment made from low air-permeability non-woven fabric (Tyvek Pro Tech) and a disposable garment made from high air-permeability non-woven fabric (Kleenguard EP).

Each type of protective overall was tested in the laboratory in accordance with a number of European Standards to evaluate penetration and permeation. Following a pilot survey a total of twelve field surveys were carried out, with each of the three types of protective overall being worn in four different surveys. Two different types of pesticide were used in the surveys; for half of the surveys a permethrin-based product was used and for the remainder a boron-based product. The potential exposure was estimated from the mass of pesticide collected on patches placed on the outer protective overall. The amount of pesticide on each patch was extrapolated to provide an estimate of the amount on the section of suit it represented. The amount of pesticide penetrating the protective suits was assessed from the mass of pesticide collected on sampling suits worn underneath the protective clothing. Penetration factors both for the whole suit and for individual sections were estimated by dividing the mass on the inner sampling suit by the mass on the inner sampling suit plus the estimated mass on the protective suit and multiplying by 100. Contamination to the hands was assessed from the mass of pesticide collected on cotton sampling gloves worn underneath protective nitrile rubber gloves.

Laboratory tests suggested that the Tyvek and Kleenguard suits should be more effective than the polyester cotton overalls, but field trials indicated that there was very little difference between the three types of overall. Pesticide was detected underneath all types of protective overall, even when surveys were of very short duration. Wide ranges of both the potential exposure (i.e. mass of pesticide collected on the outer patches) and the mass of pesticide under the protective overall were observed. Similarly, there was a wide range of penetration factors for the whole suit. In addition, the penetration factors calculated for individual suit sections showed a great deal of variability, both within suits and across individual sections. However, there was a relationship between the amounts on the inner sampling suit sections and the estimated amounts on the corresponding outer protective suit sections, irrespective of the type of suit, with the amount on the inner suit sections increasing as the estimated amount on the outer suit section increased.

Contamination was, in most cases, observed below the protective gloves and is likely to have arisen when operators removed their gloves to adjust equipment or prime the pump, rather than from penetration through the gloves.

In summary, the study showed that penetration of protective clothing in field situations occurred regardless of the type of overalls worn and that it may occur after very short periods of time. It is therefore important to ensure that where protective overalls can be reused, that they be changed frequently and where they are disposable, that they be replaced at frequent intervals. Safe working practices should be promoted regardless of the type of protective clothing worn.

1. INTRODUCTION

Timber is subject to attack by fungi and wood-boring insects and treatment with pesticides is designed, both to control the existing infestation and to protect it from further attack. Most damage is carried out by the larvae (woodworm) of the common furniture beetle, the death watch beetle, the house-longhorn beetle and weevils. In the United Kingdom the common furniture beetle is responsible for most timber damage. The larvae of this beetle bore into wood where they pupate and emerge as adults, which lay eggs. The eggs hatch and larvae bore into the wood, completing the life cycle and so continuing the infestation. Since timber forms a major component of most buildings, swift eradication of wood damaging pests and subsequent protection from future infestation is of great importance.

Most treatment is now carried out using water-based solutions with products containing synthetic pyrethroids, for example, permethrin, cypermethrin and α-cypermethrin, are among the most commonly used treatments. Boron-based compounds are also popular and appear to becoming more extensively used. Such compounds are reputed to have a number of advantages including a wider spectrum of activity and deeper penetration into wood when compared with synthetic pyrehroid products and are also claimed to be more environmentally friendly. They are, however, more expensive than other products.

It is good occupational hygiene practice to reduce the hazards from harmful substances as far as is practicable. In general, it is preferable to implement controls when the process is in the design stage by eliminating the hazardous substances or substituting with materials which will reduce the risks. However, in practice this very rarely occurs and other methods of control have to be considered. These can include local ventilation, isolation or segregation from the sources of the hazardous substance or the use of personal protective equipment. Personal protective equipment is usually considered to be a last resort.

Although the pesticides used in timber preservation may be substituted with less harmful ones, the most practicable and primary method of control is the wearing of personal protective clothing. Operators typically wear protective overalls, gloves, safety boots and some form of respiratory protection. Dermal contact is the primary route of exposure and the whole body may potentially be exposed to contamination when treating timber. It is therefore imperative that the protective overalls provide adequate protection. A wide variety of clothing is typically worn, ranging from polyester cotton and cotton overalls to disposable suits made from synthetic fabrics.

When wearing a protective overall, dermal exposure may arise in a number of different ways:

- by penetration of the pesticide through the protective overall material, seams and closures by bulk flow;
- by permeation, whereby the pesticide moves through a material at a molecular level by a process of diffusion;
- direct deposition of the pesticide onto the skin through openings in the garment.

Penetration and permeation can be assessed in the laboratory, however, movement of the individual during the course of work may also affect the movement of the chemical through the fabric or its deposition beneath clothing. This can only be fully assessed by carrying out field tests.

There is very little information on the effectiveness of protective clothing against pesticides in field application situations and most existing reports relate to the use of agricultural pesticides

(Fenske, 1988, Fenske RA *et al*, 1990, Methner and Fenske, 1994, Nigg *et al*, 1992, Ojanen *et al*, 1992).

The most commonly employed methods to assess exposure over the whole body are the patch method, the whole body method and the fluorescent tracer method. For the patch method, exposure is measured by attaching a number of absorbent patches to various regions of the body. The amount of pesticide on each pad is determined and then used to estimate the mass of pesticide that would have deposited on the body or suit area. The major disadvantage of this method is that it assumes that contamination is uniformly distributed for a particular area. The patch represents only a relatively small proportion of a particular region and extrapolation could lead to under estimation, should, for example, droplets miss the patch when spraying, or overestimation, if a splash landed directly on the patch. In addition, the method requires considerable preparation prior to its use. Penetration through clothing can be measured by placing patches beneath the clothing, but the problems of non-uniform distribution are even greater under clothing. The method is, however, easy to use, not intrusive and relatively cheap, with straightforward analysis.

Some of the problems of the patch method can be overcome by using the whole body method where a lightweight overall is used to collect the pesticide landing on the whole of the covered area. They can be used to measure potential exposure, or by being worn under protective clothing, to measure the amount of contamination which ends up below the protective clothing. Exposure to various body regions can be determined by cutting the suit into sections before analysis. This method has the advantage that it does not rely on uniform distribution of pesticide deposition over the body. However, the analysis is more time consuming, involves the use of large volumes of solvents and is more costly (Roff, 1994).

Fluorescent imaging techniques involve the use of a tracer substance which is added to the pesticide formulation. Exposure is estimated from the intensity of ultra-violet fluorescence of the tracer, as measured from a computer image analysis system. This method has the advantage that it allows not only a quantitative analysis of exposure to be made, but also provides a visual analysis which can be useful in detecting non-uniform patterns of deposition. However, it assumes that tracer penetration and permeation is equivalent to that of the pesticide and quantification is expensive as it involves the use of a sophisticated exposure assessment chamber.

The disadvantage of all of these methods is that they do not necessarily correspond with the adsorption of pesticide through the skin, because this is determined by the concentration of the substance on the skin rather than the mass. In addition, there are no set guidelines for the type of material that patches or sampling suits should be made of, the only criteria being that they should be absorbent. It should also be noted that both the patch method and whole suit method assume that all contamination beneath the protective clothing occurs as a result of penetration or permeation and take no account of contamination as a result of direct deposition.

This study was designed to determine the efficiency of three different types of protective overalls under field conditions and a combination of the patch method and whole body method was used. Contamination to the outer surface of the protective overalls was assessed by the patch method, with the amount of pesticide on the patches being extrapolated to the corresponding suit area. A sampling suit, worn underneath the protective overall, was used to measure the amount of pesticide that may have actually been in contact with the skin.

2. AIMS OF THE STUDY

The main aims of the study were:

1. to compare the effectiveness of a selection of commonly used protective overalls in reducing transmission of sprayed non-agricultural pesticides to the skin;

2. to provide recommendations on the selection of overalls for protection against non-agricultural pesticides;

3. to undertake preliminary investigations of the field effectiveness of protective gloves.

3. METHODS

The effectiveness of three different types of protective overalls that are commonly worn by pesticide sprayers was investigated. The selected overalls were:

- polyester cotton hooded overalls (manufactured by Cosalt, weight = 245 g/m^3);
- a disposable garment made from low air-permeability non-woven fabric (Tyvek Pro Tech);
- a disposable garment made from high air-permeability non-woven fabric (Kleenguard EP).

With the exception of the polyester cotton hooded overalls, the other two types of overall were chosen at the planning stage. Originally cotton overalls were selected, but we found that it was now impossible to obtain these overalls with hoods. Discussions with a number of timber preservation companies suggested that polyester cotton overalls were used and we therefore decided to use these.

3.1 CHOICE OF PESTICIDES FOR USE IN MEASURING THE EFFECTIVENESS OF OVERALLS

The use of synthetic pyrethroid pesticides was considered to be widespread in the timber preservation sector and low levels can be easily measured by gas chromatography. It was intended to recruit companies who used either permethrin or cypermethrin-based products. However, as the study progressed it became clear that the use of pyrethroid products was becoming more limited and that boron-based pesticides were being more extensively used. Companies using such products were therefore recruited in the latter part of the study.

3.2 LABORATORY ASSESSMENT OF THE BARRIER PROPERTIES OF THE GARMENTS AND FABRICS

There are a number of European Standards that specify the performance of protective clothing (EN 368, 1992, EN 369, 1993, EN 468, 1994). Compliance with these standards provides some assurance about the initial integrity and potential performance of the clothing. Each of the three types of protective overalls was tested in the laboratory in accordance with the following European Standards:

1. EN 368 Protective clothing - protection against liquid chemicals - test method: resistance of materials to penetration by liquids ('gutter method')
2. EN 369 - Protective clothing - protection against liquid chemicals - test method: resistance of materials to permeation by liquids ('permeation cell method')
3. EN 468 Protective clothing – protection against liquid chemicals – test method: determination of resistance to penetration by spray ('spray test')

3.2.1 EN 368 Protective Clothing - Protection Against Liquid Chemicals - Test Method: Resistance Of Materials To Penetrations By Liquids ('Gutter Method')

Pieces of the material from each of the three types of suit were tested in accordance with the above method using the pesticide *Brunol Special P* which contains permethrin (working strength 0.2% by weight). A piece of test material 360 (± 2) mm by 235 (± 5) mm with 30 mm folded under was placed in the test apparatus on top of a pieces of absorbent paper and foil, 300 (± 2) mm by 235 (± 5) mm. A measured volume of test liquid (10 ml) was applied firstly with minimal force and secondly with higher force if appropriate, in the form of a fine stream or jet onto the surface of the test material resting in an inclined gutter. Any liquid that ran off was collected in a beaker. The pieces of test material, absorbent paper, foil, beaker and syringe were weighed before and after the test liquid was applied. The standard recommends that six pieces of a particular test material are tested. For woven materials, such as polyester cotton, three pieces were taken in the direction of the weave and three in the direction of the warp. For nonwoven materials such as the Tyvek and the Kleenguard, three pieces were taken in the direction of manufacture and three at right angles to it. The measurement of the respective proportions of the applied liquid which penetrate the test material and are repelled by its surface indicate the potential of the material for use in the field. The index of penetration (P) is defined as follows:

$$P = \frac{M_p \cdot 100}{M_t} \qquad \text{equation 1}$$

Where M_p = mass of test liquid deposited on the absorbent paper and foil
M_t = mass of test liquid discharged onto the test piece

The index of repellency (R) is defined as follows:

$$R = \frac{M_r \cdot 100}{M_t} \qquad \text{equation 2}$$

Where M_r = mass of test liquid collected in the beaker

An index of retention (R_t) was defined as:

$$R_t = \frac{M_{Rt} \cdot 100}{M_t} \qquad \text{equation 3}$$

Where M_{Rt} = mass of test liquid retained by the test material

3.2.2 EN 369 - Protective Clothing - Protection Against Liquid Chemicals - Test Method: Resistance Of Materials To Permeation By Liquids ('Permeation Cell Method')

Test pieces of the material from each of the three types of suit were tested in accordance with the above method using the pesticide *Remtox R8*, which contains permethrin (working strength 0.2% by weight). However, since it was difficult to detect permethrin in this test we measured a hydrocarbon component of the Remtox, trimethylbenzene. In doing this we assumed that the breakthrough time and permeation rate of the trimethylbenzene were the same as that for permethrin. The test material was placed between the two halves of the permeation cell and 10 ml of the test liquid rapidly discharged into the uppermost compartment of the permeation cell. A series of charcoal tubes were set up to collect trimethylbenzene from the permeation cell. Air was drawn through the charcoal tubes using pumps set to 100 ml/min. Samples were collected at one minute intervals, each for one minute. These were then desorbed in 1 ml of carbon disulphide and analysed by gas chromatography with a flame ionisation detector.

Breakthrough was taken to have occurred when a permeation rate of more than 1 µg/min/cm^2 was measured at the point where the applied liquid is detected on the other side of the material.

3.2.3 EN 468 Protective Clothing – Protection Against Liquid Chemicals – Test Method: Determination Of Resistance To Penetration By Spray ('Spray Test')

SGS United Kingdom Ltd carried out this test. It involved directing an aqueous spray containing a visible dye under controlled conditions at the chemical protective clothing worn by a volunteer. The inside surface of the overalls and the outside surface of absorbent clothing worn underneath were then inspected for any points of inward leakage. Three of each type of overall were tested.

3.3 FIELD SURVEYS OF THE EFFECTIVENESS OF PROTECTIVE OVERALLS

3.3.1 Study design

Field surveys were carried out to determine the degree of protection afforded by each of the chosen overalls. Thirteen surveys were planned, with up to three workers to be included in each survey. The first survey was designed as a pilot investigation to ensure that there were no problems with the methods. The remaining 12 surveys were intended to provide data from a variety of conditions with each of the suit types. Four different companies were to be recruited, with each company participating on three different occasions, wearing a different type of protective overall each time, giving a 4 x 3 design. The order of wearing of the protective overalls was randomised for each company as shown in Table 3.1 below.

Table 3.1
Random order of overall types by survey within company

Organisation	Survey		
	(i)	(ii)	(iii)
1	B	A	C
2	C	B	A
3	A	B	C
4	C	A	B

Where *A* *polyester cotton hooded*
B *disposable Tyvek Pro Tech hooded overalls*
C *disposable Kleenguard EP hooded overalls*

All tasks normally undertaken were included in the measurements. These included:

- dilution of the pesticide to working concentration;
- application of pesticide;
- cleaning of equipment after application and
- removal of personal protective equipment.

3.3.2 Company selection and recruitment

The British Wood preserving and Damp Proofing Association (BWPDA) was contacted and provided a list of their members in Scotland. In addition, they contacted all their members in Scotland, informing them about the study, indicating their support for it and encouraging organisations to participate should they be contacted. Organisations that had been involved in a previous study were contacted to see if they would be willing to participate in the present research (Tannahill *et al*, 1996). Additional companies were also selected from the Yellow Pages Directory.

In each case the company manager was contacted by telephone and given details of the study. Those who were interested in participating were asked for details of the pesticides used and about their normal work practices. Initially, those who indicated that they used permethrin or cypermethrin-based products were sent further details outlining the their involvement should they agree to become involved. Later, those who used boron-based pesticides were also recruited. These letters were followed up within two weeks by a further telephone call, firstly to establish if they were still willing to participate and secondly to discuss possible dates for carrying out the work. Those organisations that agreed to participate but who had no suitable work at that time were contacted at regular intervals.

3.3.3 Measurement techniques

Sampling suits (35% cotton, 65% polyester, manufactured by Cosalt) were worn underneath the selected protective overalls. Cotton sampling gloves (manufactured by ARCO) were worn under thick green nitrile gauntlets (also manufactured by ARCO). These protective gauntlets were chosen after discussion with various timber treatment companies who indicated that they would be prepared to participate in the study. The polyester cotton sampling suits and cotton sampling gloves were washed using a biological powder prior to use to increase their absorbancy.

Eleven 10 cm x 10 cm absorbent patches, made from the same material as the sampling suits, were attached to the outside of the protective overalls. These patches were backed by aluminium foil and reinforced with Tenza self-adhesive plastic. This provided the required robustness and also allowed for easy and quick removal of the backing at the end of the sampling period. Patches were attached to the overalls using safety pins, In addition, staples were also used to attach arm and leg patches to the overalls, since these were more likely to be dislodged during spraying.

The location of patches were as follows (Tannahill *et al*, 1996):

- right hand side of the hood;
- front torso, right hand side;
- back torso, between the shoulder blades;
- upper arms, midway between elbow and shoulder;
- lower arms, midway between the elbow and wrist;
- upper legs, mid thigh and
- lower legs, midway between the knee and ankle.

At the end of the survey, the gloves were first removed and the cotton sampling gloves placed in clean, labelled jars. The protective overall was then removed, followed by removal of the sampling suit. Both suits were hung up in an area away from the application area. Assistance was provided in order to minimise contamination.

Patches were removed from the protective suit, placed in jars and then sealed.
The sampling overalls were cut into eleven sections as follows:

- hood;
- front torso;
- back torso;
- upper arms, elbow to shoulder seam;
- lower arms, elbow to wrist;
- upper legs, knee to groin and
- lower legs, knee to ankle.

Each section was placed in a jar and sealed. The sections of the sampling overall had a corresponding patch on the outer protective overall.

3.3.4 Field surveys

An occupational hygienist and an assistant undertook each survey, with the hygienist being the same in all surveys to ensure consistency. Due to the nature of building preservation business, surveys were typically arranged at very short notice and were subject to change at the last minute; in some cases application sometimes depended on the completion of preparatory work.

The purpose of the study was fully explained to each worker prior to the start of the measurements. We also collected details about the nature of the timber treatment, including the intended working practices.

Each operator was provided with a new pair of jeans and T-shirt to ensure that there was no contamination from the operator's own clothing. The polyester cotton sampling suit was worn over these and beneath the selected protective test overalls for that survey. As far as possible, operators were encouraged to wear both hoods. Operators were permitted to remove the protective gloves when undertaking tasks such as preparing fresh pesticide solution if this was their normal practice. The inner cotton gloves, however, were kept on to ensure that a reliable estimation of hand contamination could be made.

Cotton fourchette gloves (manufactured by ARCO) were worn underneath protective nitrile gloves. New protective gloves were provided at the start of each survey. Any additional personal protective equipment, for example, respirators, visors, safety helmets and safety boots were worn as normal.

The operators were encouraged to wear the sampling suit, protective overalls and gloves for the entire duration of the survey, including formulation of the pesticide, application and cleaning of the equipment. Patches were replaced where there was judged to be a risk of them becoming saturated. Typically the same overalls were worn throughout a particular survey. However, they were changed during the course of the survey in line with the standard working practice for a particular company, if necessary.

Blank and spike samples

A small amount of the working strength pesticide was obtained from the operators prior to the start of spraying. Field recovery efficiencies were determined by spiking six 10 cm x 10 cm polyester cotton patches, half with 125 μl and half with 1250 μl, the levels being chosen to encompass the anticipated range of the field samples. Two blank patches were also taken on site and these were kept in sealed jars for the duration of the survey. Two small areas of the patch material were cut up during the survey and placed in jars, to determine whether or not any contamination had occurred during the handling of samples. These are termed "test" samples. Blank, test and spike samples were kept in an area distinct from where the preparation and application of the pesticide to minimise possible contamination.

3.4 RECORDING OBSERVATIONS

Details of the survey were recorded on a form based on that of Tannahill *et al* (1996), as shown in Appendix 1. Information recorded included general details of the company participating, where the survey was carried out, details of what was being treated and why, an estimate of the area treated and temperature and relative humidity. Information on the pesticide used, including its preparation, was recorded in detail. Details on the equipment used for spraying and the spray pressure were also recorded. Participant details were recorded, including tasks undertaken, time spent spraying, area sprayed, personal protective equipment, worn in addition to that supplied. Subjective assessments were made of the main routes of contamination and contamination of various parts of the protective suits. Finally, a short questionnaire was administered to each participant as to the acceptability of the protective suits and this is also shown in Appendix 1. Operators were asked four questions relating to comfort, thermal comfort, restriction of movement and overall comfort.

Detailed notes were also made during the survey and photographs were taken of the various working practices.

3.5 ANALYSIS OF FIELD SAMPLES

3.5.1 Permethrin based pesticides

Pesticide was extracted from cut suit samples, patches and cotton gloves with acetone. A known volume of acetone was added to each sample container, which was placed in an ultrasonic bath for 15 minutes. The volumes of solvent used ranged from 25 to 50 ml for the patches, up to 1500 ml for the larger suit sections (e.g. front and back torsos). A 1 ml aliquot of each sample was transferred to a septum-sealed glass vial and a known volume of diazinon was added as an internal standard. Calibration standards were prepared from known weights of the analyte in 1 ml of acetone, containing the internal standard solution. Blank patches were prepared similarly. Samples were analysed by gas chromatography/mass spectrometry (GC/MS) using a Varian Saturn II system. Concentrations were calculated by comparing the ratio of the analyte and the internal standard peak areas with the calibration curve. The GC/MS system software performed this. An electronic copy of all data was stored on tape. The mass of analyted on each suit section or patch was calculated using the relevant solvent extraction volume. A detection limit of 0.3 μg was achieved for the pilot investigation and with tuning, a detection limit of 0.1 μg was achieved for subsequent measurements.

The concentration of permethrin in the working strength solutions was also determined for each survey.

3.5.2 Boron based pesticides

The samples were prepared for analysis using a modification of OSHA ID121 (OSHA, 1991). Pesticide was extracted from cut sections of the sampling suits, patches and cotton gloves with water. A known volume of water was added to each sample container which were then placed on a hot plate and boiled for 5 minutes. The volume of water ranged from 50 ml for the patches to 1000 ml for the larger suit sections.

Samples were analysed for their boron content using Inductively Coupled Plasma/Atomic Emission Spectroscopy (ICP/AES). A detection limit of 6 μg was achieved. The concentration of boron in the pesticide solutions used was also determined.
As the polyester cotton material was found to contain about 0.2 $\mu g/cm^2$ boron, the amount of boron in the patches and suit sections was adjusted accordingly.

3.6 DATA ANALYSIS

The surface areas of each of the eleven sections of each type and size of protective overall were measured and the scaling factors calculated (Appendix 2). For example, the surface area of the 10 cm by 10 cm patches was 100 cm^2 and the surface area of a lower arm for an extra large Tyvek suit was 1422 cm^2. The scaling factor was therefore 14.22. The mass of pesticide on each patch was determined and the estimated mass for the corresponding section estimated by multiplying by the appropriate scaling factor. The total mass was obtained by summing the masses for each individual section. The penetration factor was calculated as described by OECD (1997). The penetration factor (*PF*) was defined as follows:

$$PF = \frac{m_{in}}{m_{in} + m_{out}} \text{ x } 100 \qquad \text{equation 4}$$

Where m_{in} was the mass of pesticide measured on the inner sampling suit and m_{out} the estimated mass on the outer protective overall.

These protection factors were calculated for each section separately and also for the whole suit.

It should be noted that the penetration factor provides a measure of the effectiveness of the protective suit from pesticide that bypasses the protective overall by any means, i.e. penetration or permeation. It may also give a spurious impression of the protective effect where the inner sampling suit is contaminated by direct contact, in which case there may be higher contamination on the inner suit than on the outer suit, i.e. the penetration factor would be greater than 50%.

Natural logs were taken of the amounts on the outer and inner suits for the individual sections of each suit and a graph drawn of the mass of pesticide inside a particular protective suit against the estimated mass on the outside of the protective suit. The relationship between the amounts of pesticide detected on individual sections of the inner sampling suit and that estimated on individual sections of the outer protective suit was estimated by regression analysis using SPSS for Windows v8.0. Due to the small numbers of measurements obtained in this study it was not possible to carry out any formal statistical analyses to compare the effectiveness of different suits.

The amount of fluid on the outer protective suits and the inner sampling suits was calculated by dividing the amount of active ingredient detected by the concentration of the working strength solution used. This allows a more direct comparison to be made between surveys and methods of application.

4. RESULTS

4.1 LABORATORY ASSESSMENT OF THE BARRIER PROPERTIES OF THE GARMENTS AND FABRICS

4.1.1 EN 368 Protective Clothing - Protection Against Liquid Chemicals - Test Method: Resistance Of Materials To Penetrations By Liquids ('Gutter Method')

The results of the penetration tests are given in table 4.1, as the average percentage penetration and the standard deviation (SD).

Table 4.1
Penetration tests

Fabric	Average Penetration and (SD)	Average Retention And (SD)	Average Repellency and (SD)
Polyester cotton	41% (3.1)	40% (14.6)	4% (3.8)
Tyvek Pro Tech	1% (1.0)	5% (1.0)	92% (1.6)
Kleenguard EP	4% (1.2)	6% (1.8)	84% (3.8)

Six pieces of fabric were tested for each overall, in accordance with EN 368. It can be seen that the polyester cotton fabric has much higher penetration and retention than either of the other suits. The Tyvek suit had the greatest repellency followed by the Kleenguard suit, with the polyester cotton suit demonstrating negligible repellency. It should be noted that the average figures in the above tables do not add up to 100%, which is probably due to evaporative or other losses.

4.1.2 EN 369 - Protective Clothing - Protection Against Liquid Chemicals - Test Method: Resistance Of Materials To Permeation By Liquids ('Permeation Cell Method')

All three suits had a breakthrough time of less than one minute. Using the method employed here it was not possible to calculation the permeation rate.

4.1.3 EN 468 Protective Clothing – Protection Against Liquid Chemicals – Test Method: Determination Of Resistance To Penetration By Spray ('Spray Test')

The results of this test are shown in table 4.2 below. The total area under the protective suit that was stained ranged from >31.5cm^2 to >500cm^2. All three types of overall failed the EN 468 test criteria, with the greatest amount of penetration occurring for the polyester cotton overalls.

Table 4.2
Determination of resistance to penetration by spray

	Criteria	Total stained area (cm^2)	Sites where spray has penetrated overall
Polyester cotton	Fail	> 500	Neck, hood, front fastening, side pockets, shoulders and legs
Tyvek	Fail	> 31.5	Seams and elastication
Kleenguard	Fail	> 31.5	Seams and elastication

There was wide spread staining for the polyester cotton, indicating that the test liquid had both penetrated the suit material and passed directly through gaps where there were fastenings etc. For the Tyvek and Kleenguard suits there was evidence of direct deposition through gaps at seams or the elasticated openings for arms and legs.

4.2 FIELD SURVEYS

4.2.1 Recruitment of companies

Eighteen companies were approached and asked to participate in the study. Three companies were not interested in being involved because of the perceived amount of work involved on their part. Nine companies indicated a willingness to participate but had no suitable work in the forseeable future, with one company having recently made some of their workers redundant. This was attributed to the small amount of timber preservation work typically carried out during the winter months. Three companies, two of whom had participated in a previous study carried out by Tannahill *et al* (1996) indicated their willingness to participate, but had ceased to use pyrethroid-based pesticide and were now using boron-based products.

4.2.2 Pilot study

The pilot study (survey 1) was carried out to ensure that the sampling methods and procedures were both feasible and practicable. The recording form was also tested. The test overall for this investigation was made from Tyvek, the type of overalls normally worn by this company who felt that the other test suits would provide less protection. In addition, operators wore the cotton sampling gloves underneath their own gauntlets since the Marigold blue nitrile gloves supplied by the Institute of Occupational Medicine, were not perceived by the contracts manager to provide adequate protection. These operators typically wore heavy duty PVC gauntlets and these were used during this survey.

This survey was carried out by two operators in an attic of an empty house. The purpose of the treatment work was to eradicate woodworm. The concentrated pesticide contained permethrin (2.45% by weight). One litre of the pesticide was added to a 25 l drum and diluted with 24 l of water to give a working solution of 0.1% by weight permethrin. The first batch of pesticide was prepared before the protective overalls were donned in line with normal working practice for this organisation.

The loft was brushed down and glass wool insulation was removed from a small area. The area was then sprayed, the insulation replaced and the procedure repeated. Spraying was therefore carried out in intermittent short bursts. The roof timbers were also sprayed, usually after a number of areas of floor had been treated. The entire attic was sprayed using a lance.

Both operators participated in the spraying, though the majority of the work was carried out by the first subject. Due to the structure of the loft, operator 1, spent a considerable amount of time crawling over timber, some of which had been treated. Operator 2 prepared a fresh batch of pesticide during the survey period. and he was also responsible for tidying the lance and tubing into plastic sacks when spraying was finished. The residual pesticide was disposed of since it had a limited shelf life. Around 38 l of pesticide was sprayed, with operator 1 spraying for around 30 minutes and operator 2 for approximately 10 minutes. The whole process lasted 80 minutes. The main routes of exposure for both operators was contact with treated timbers, spray bouncing back from surfaces and accidental direct spray.

The estimated amount of permethrin detected on the protective overalls and the amount inside, along with the calculated penetration factors are shown in table 4.3, below.

Table 4.3
Amounts of permethrin detected and penetration factors

Operator	Amount of permethrin (mg) Outside	Inside	Penetration factor (%)
1	107	3.3	3
2	63	2.8	4

Operator 1 spent more time spraying and in contact with treated timber. The estimated amount of permethrin on the protective overalls was greater for operator 1 than operator 2, i.e. 107mg -v- 63mg. The penetration factors were, however, very similar. No permethrin was detected inside the protective gloves although the cotton sampling gloves were observed to be stained and damp, probably as a result of sweating.

Both operators reported that they found the overalls restrictive, especially when stretching into corners. One operator commented that wearing two sets of overalls was a nuisance.

Samples spiked in the field showed low recovery rates: 38% (SD 7.4) for the low spikes and 63% (SD 8.5) for the high spikes, giving an average of 48% (SD 15.2). These were attributed to errors in spiking procedure and improvements were made as a consequence.

Patches were backed with aluminium foil, which was stapled to the polyester cotton patch. However, this was not found to be sufficiently robust, since on removal of the patches, the foil was often found to be crumpled up behind the patch, particularly in the case of the lower leg patches. For subsequent surveys the foil backing was reinforced with Tenza self-adhesive plastic backing. This provided the necessary strength and allowed easy removal of the backing at the end of the survey. Problems were also experienced with some patches which were stapled onto position, with the leg patches and also the arm patches becoming dislodged. This was overcome by using four safety pins to hold the patches in place. For the leg and arm patches staples were inserted between the safety pins. Based on the company's views on the supplied gloves it was decided to use nitrile gauntlets in subsequent surveys.

A number of minor changes were made to the recording form following the pilot investigation.

4.2.3 Blank and spike samples

With the exception of one survey, all blank and test samples for the permethrin-based surveys were below the limit of detection (appendix 4). In survey 2, for both of the blank samples and one of the test samples, values slightly higher than the detection limit were recorded. Since the blank samples are placed in the sample jars before being taken into the field and were not removed at any time it is difficult to see where this contamination arose. In any case the level contamination was much less than that detected on the samples from the survey. The majority of the blank and test samples for the boron-based surveys were observed to be just above the limit of detection (appendix 4). Since contamination did not occur in most of the permethrin-based surveys, it has been concluded that there were traces of boron in some of the reagents. These levels were insignificant in comparison with the levels found on our survey samples.

Samples spiked in the field exhibited variable recovery rates (table 4.4). Experimental difficulties caused the loss of all field spiked samples from survey 10 and the low spikes in surveys 8 and 9.

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. Our average recovery efficiencies were variable, ranging from 60% to 104% and in general were below the recommended 95%. In addition, recovery efficiencies varied widely within particular surveys as evidenced by the standard deviations. For example, for survey five, the three values for the low spikes were 114%, 65% and 91%. It is unclear what the reasons are for this wide range of values, although it seems probable that the difficulties in making up the spike samples in the field contribute to this variability. A small number of spike samples made up in the laboratory showed and average recovery of 87% (Standard deviation 8.3) It was therefore decided not to correct the sampled values and it is recommended that further work be carried out on recovery from patches in field situations.

Table 4.4
Mean field recovery efficiencies and (standard deviation) for spikes

	Percentage field recovery efficiencies (SD)	
Survey	Low (n=3)	High (n=3)
2	63 (3.1)	58 (5.7)
3	91 (2.1)	88 (4.4)
4	74 (33.9)	78 (22.6)
5	90 (24.4)	75 (4.0)
6	78 (12.6)	90 (0.2)
7	90 (6.8)	103 (6.0)
8 & 9	ND	71 (1.5)
10	Samples damaged	
11	108 (12.7)	101 (5.8)
12	55 (19.9)	90 (11.1)
13	53 (26.8)	97 (4.4)

4.2.4 General survey results

The numbers of each type of suit tested by each company and pesticide is shown in table 4.5 below.

Table 4.5
Number of each type of suit tested

Company	Polyester cotton	Tyvek	Kleenguard
	Permethrin-based pesticides		
A	1	1	2 [1]
B & D [2]	2	2	2
	Boron-based pesticides		
C	1	1	1
E	1	1	1

1 – two different surveys were carried out wearing Kleenguard overalls
2 – company B used Kleenguard overalls, the remaining two surveys were carried out by company D.

Originally it had been expected that two operators would normally be involved in each survey and so eight of each type of overall would have been tested. However, only in three of the permethrin-based pesticide surveys (excluding the pilot survey) were two operators present. Only one operator was involved in each of the boron-based pesticide surveys.

The purpose of the majority of treatments with permethrin-based pesticide was to eradicate woodworm. Only one of the surveys where permethrin used was preventative. Three of the surveys with boron-based pesticide, those carried out by company E, were for the treatment of dry rot. The remaining surveys were all carried out to treat woodworm.

The different application methods used are shown in table 4.6 below. A lance (fig. 4.1) was used for all of the permethrin-based surveys, whereas either a lance, a floor fogger (fig. 4.2) or a microblower (fig. 4.3) were used in the boron-based pesticide surveys.

Table 4.6
Applicator used

Company	Polyester cotton	Tyvek	Kleenguard
	Permethrin-based pesticides		
A	Lance	Lance	Lance
B & D	Lance	Lance	Lance
	Boron-base pesticides		
C	Lance	Lance	Floor fogger
E	Microblower	Microblower	Microblower

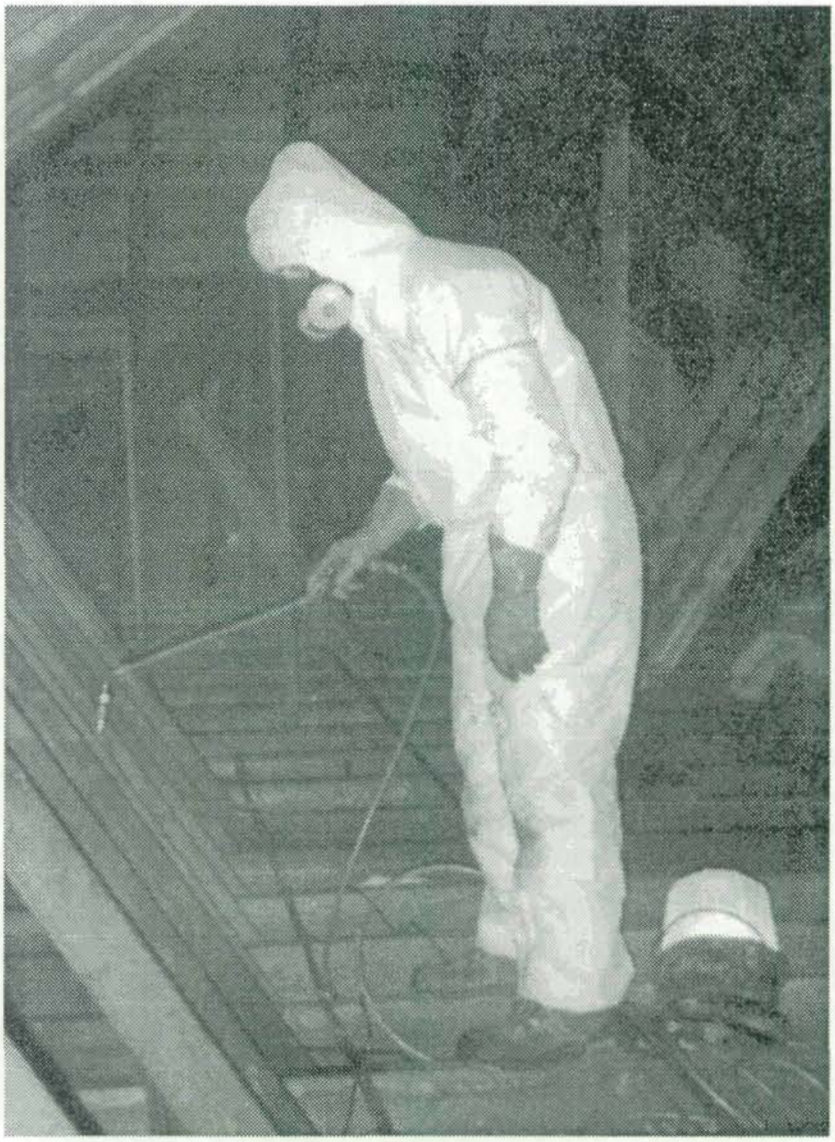


Figure 4.1
Application of pesticide using a lance

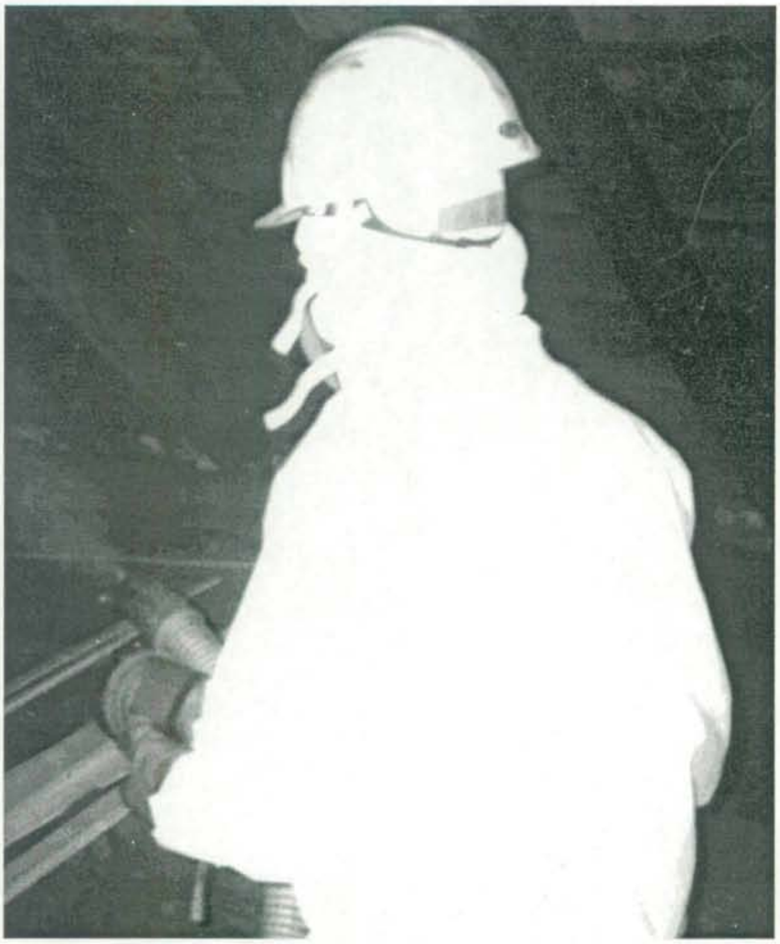


Figure 4.2
Application of pesticide using a floor fogger

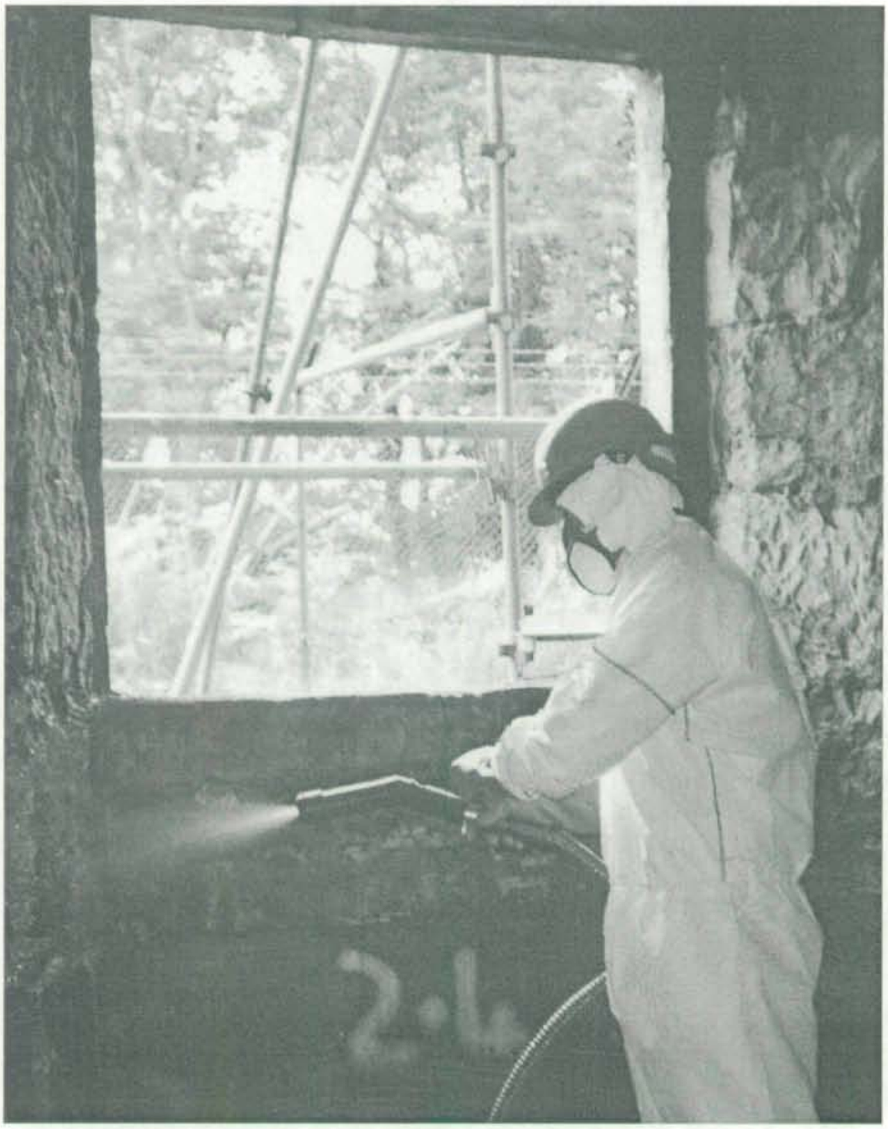


Figure 4.3
Application of pesticide using a microblower

Permethrin-based pesticide is normally applied by spraying with a lance. Pesticide is delivered to the lance at high pressure, typically between 5 and 7 bars using a mechanical pump driven by an electrical compressor. This pump requires priming prior to the start of spraying. Permethrin-based pesticides are supplied in concentrated form. They are generally poured from their original containers into a 25*l* drum and diluted to the correct working concentration.

With the boron-based compounds, new techniques are beginning to be employed. A floor fogger was used in one survey. This was filled with around 5*l* of fluid which was delivered as a fog with droplets of fluid depositing onto exposed timber surface. Using this method pesticide is distributed over a wider area than when using a lance. The method typically uses 60% less fluid than more conventional methods. Although there is less contact with treated timber, there is more fall out than when using a lance.

Company E used a microblower to apply a boron-based compound to masonary. A 25*l* drum was filled with pesticide and delivered to the microblower at high pressure using a mechanical pump driven by an electrical compressor. The spray pressure was 5 bars and the pump required priming before application of the pesticide, as with the lance.

Both of the boron-based compounds used by companies C and E were supplied at working concentration and therefore did not require dilution.

The treatment work was conducted under a wide range of conditions, ranging from wood work in small attic spaces to walls and floors in rooms, as shown in table 4.7.

Table 4.7
Site of application and approximate dimensions of working space

Company	Polyester cotton	Tyvek	Kleenguard
	Permethrin-based pesticides		
A	Room – floor 5 m x 2 m x 1.2 m	Attic 10 m x 5 m x 1.2 m	Rooms – floor, walls No dimensions, large attic + bits of rooms 10 m x 5 m x 1.2 m
B & D	Roof space over outside store 5 m x 1.2 m x 1.2 m	Attic 10 m x 5 m x 1 m	Attic 40 m x 10 m x 4 m
	Boron-based pesticides		
C	Attic 20 m x 5 m x 1.5 m	Attic 20 m x 5 m x 1.5 m	Attic 7 m x 5 m x 3 m
E	Room – walls 7 m x 6 m x 3 m	Room – walls 7 m x 6 m x 3 m	Room – walls 4 m x 3 m x 3 m

Where dimensions are arranged as length x width x height

Note, in the dimensions for the attic space the height of the roof was measured at the highest point.

In the majority of surveys it was judged that the main route of exposure was spray back (table 4.8). The exceptions to this are firstly three surveys carried out by company A where the lance was leaking and one operator from company D who carried out no spraying and who was responsible for preparing pesticide and attending the pump. Not surprisingly, his main route of exposure was spills and splashes during formulation. However, for those surveys that were carried out in attics, particularly small attics, contact with treated timber was also a major route of contamination.

Table 4.8
Main route of exposure

Company	Polyester cotton	Tyvek	Kleenguard
	Permethrin-based pesticides		
A	Spray back	Leaking nozzle	Leaking nozzle
			Leaking nozzle
B & D	Spray back	Spray back	Spray back
	Spray back	Spray back	Spills/splashes during formulation
	Boron-based pesticides		
C	Spray back	Spray back	Fall out
E	Spray back	Spray back	Spray back

The length of time taken to apply the pesticide ranged from 2 to 60 minutes, with a median time of 14 minutes (table 4.9).

Table 4.9
Time spent spraying

Company	Polyester cotton	Tyvek	Kleenguard
	Permethrin-based pesticides (mins)		
A	9	30	12
			22
B & D	4	14	60
	2	18	0
	Boron-based pesticides (mins)		
C	14	17	10
E	15	11	6

However, this does not represent the time that an operator takes to complete the whole job and hence the time possibly exposed to pesticide (see table 4.10). For example, although in the survey by company B there was 60 minutes was spent in spraying, the men wore their Kleenguard overalls for over one and a half hours, the remainder of the time was spent in moving and relaying insulation and covering up electrical equipment. Both operators were involved in this task. Similarly, for two of the boron surveys carried out by company C, although 14 and 17 minutes were spent in spraying, the overalls were worn for 77 and 78 minutes respectively. Again, the majority of time was spent moving and replacing insulation and ensuring that any electrical equipment was covered up before application of the pesticide.

Table 4.10
Total time spent in overalls

Company	Polyester cotton	Tyvek	Kleenguard
	Permethrin-based pesticides (mins)		
A	21	40	21
			34
B & D	8	40	151
	8	23	151
	Boron-based pesticides (mins)		
C	77	78	12
E	17	12	7

An estimate of the total area sprayed for each survey and the total quantity of pesticide mixture used are shown in tables 4.11 and 4.12 respectively.

Table 4.11
Estimate of total area sprayed (not broken down by operator)

Company	Polyester cotton	Tyvek	Kleenguard
	Permethrin-based pesticides (m^2)		
A	10	50	18
			37
B & D	7	110	880
	Boron-based pesticides (m^2)		
C	98	98	46
E	44	36	10

Table 4.12
Estimated quantity of pesticide mixture used

Company	Polyester cotton	Tyvek	Kleenguard
	Permethrin-based pesticides (l)		
A	23	25	12
			22
B & D	4.5	12	125
	2.5	18	0
	Boron-based pesticides (l)		
C	21	19	5
E	20	10	10

The concentration of permethrin in the working strength pesticide was similar over four surveys (table 4.13), generally being around 2 mg/ml. What is immediately apparent however, is that for two surveys, those carried out by company D, the concentration of permethrin was extremely low. We assume that the operators made an error in the formulation in these cases. It should be noted that one of the main differences between the permethrin and boron based pesticides is that whereas the permethrin-based products required dilution, the boron ones are supplied at working strength.

Table 4.13
Concentration of pesticide used

Company	Polyester cotton	Tyvek	Kleenguard
	Permethrin-based pesticides (mg/ml)		
A	1.8	1.1	2.0
			2.1
B & D	0.01	0.01	1.9
	Boron-based pesticides (mg/ml)		
C	17	17	18
E	22	21	22

4.2.5 Challenge and penetration concentrations and penetration factors

Estimated challenge masses ranged from 1.1 mg to 516 mg for permethrin surveys (table 4.14), although if the values from the two surveys where the concentration of permethrin was very low are disregarded (company D, wearing polyester cotton and Tyvek protective overalls), then the lower limit becomes 16 mg. These wide ranges are probably due to a number of factors including the location where the pesticide was applied, how long the survey lasted, the method of application and individual working practices.

A wide range of challenge masses was also observed for the boron-based pesticide surveys, with challenge concentrations ranging from 16 mg to 1090 mg. Although only two of each type of protective suits were tested, these values were generally very different. Conditions were very similar for each survey carried out by company E, where wall and floor masonary was sprayed. The main difference between them was that of the time taken to spray and this is reflected in the estimated amounts on the outside of the suits, with less boron being detected on the outside of the suit where spraying was carried out for the shortest period of time.

It should also be noted that it is not possible to directly compare the amounts of permethrin and boron, since the amount of boron in the preparations used was typically seven to ten times greater than that of permethrin in its respective preparations.

Table 4.14
Estimated amount on the outside of the protective overalls

Company	Polyester cotton	Tyvek	Kleenguard
	Permethrin-based pesticides (mg)		
A	16	160	20
			520
B & D	3.3	13	110
	1.8	1.1	36
	Boron-based pesticides (mg)		
C	210	1090	84
E	30	37	16

Table 4.15 shows that the range of pesticide masses under the protective suits, for both permethrin and boron-based surveys was again large. Interestingly, although the amount of active ingredient in the boron-based pesticide surveys was several orders of magnitude greater than that in permethrin-based surveys, this was not reflected either in the amounts found on the outside of the overalls or on the inner samples sampling overalls.

Table 4.15
Estimated amount on the inside of the protective overalls

Company	Polyester cotton	Tyvek	Kleenguard
Permethrin-based pesticides (mg)			
A	1.3	94	0.6
			32
B & D	0.5	ND	0.5
	ND	ND	7.4
Boron-based pesticides (mg)			
C	0.3	11	2.9
E	0.3	3.5	1.5

Where ND = none detected, i.e. < 0.1 μg for permethrin-based pesticides, < 6 μg for boron-based pesticides

Table 4.16
Penetration factors for whole suit

Company	Polyester cotton	Tyvek	Kleenguard
Permethrin-based pesticides (%)			
A	8	37	3
			6
B & D	13	-	0.5
	-	-	17
Boron-based pesticides (%)			
C	0.1	1	3
E	1	8	9

Where - = no penetration factor calculated

It is immediately apparent that there was a wide range of penetration factors for the whole overalls, ranging from 0.5 to 37% for permethrin and 0.1 to 9% for boron (table 4.16). The lower the penetration factor, the more effective a particular overall was. It is difficult to come to any clear conclusions about the effectiveness of the different types of overalls, firstly, because of the small numbers involved and secondly because of the variability of the other factors involved, for example, the different methods of application and the site of application. The most direct comparisons were for company E, where the three different types of overalls were tested under almost identical conditions. However, again it must be stressed that only one of each type of overall was tested and caution must be exercised in interpreting these figures.

Where the estimated amounts of pesticide are below the limit of detection of the analytical technique, the OECD (1997) method suggests that one half of the detection limit should be used in subsequent calculations, 0.00005 mg for permethrin and 0.003 mg for boron in this study. However, this procedure was not followed here since this could lead to erroneous results being obtained. For patches half the detection limit would have to be multiplied by the suit scaling factor. Therefore, if nothing is detected on both the patch and the suit section, because of the scaling factor it can appear that there was more on the outside than the inside and so a penetration factor of 1% or greater is obtained. On the other hand, if there is nothing on the patch but something on the inner section, then very high PFs of around 99% will be obtained.

More typically, there is nothing on the inner sections and so very small PFs are obtained - <1%. For two surveys, surveys 2 and 5, (Tyvek and the second Kleenguard survey, respectively) carried out by company A, breakthrough of the sampling suit was observed, in both cases at the lower part of the front torso and the upper and lower legs. As a consequence of this the amount of permethrin on the inner suit will be underestimated and hence the penetration factors will be lower.

Tables 4.17 to 4.19 show the penetration factors for each of the 11 sections of overall for polyester cotton, Tyvek and Kleenguard overalls respectively. Unfortunately, there was practically no information from surveys 8 and 9 (company D) due to the virtual absence of active ingredient in the pesticide used.

There was a great deal of variability in penetration factors, both within suits and across individual sections. It is perhaps not surprising that penetration factors vary from one part of a suit to another since not all sections of the suit will have been equally exposed. However, there was also no consistency for a particular operator over the three or four surveys (four for company A, three for company C and three for company E).

The magnitude of the penetration factor depends on the amount detected on the inner suit relative to the outer one. The mass of pesticide outside and inside the sampling suits for each survey and company are tabulated in appendix 5. Very low penetration factors indicate that the amounts on the inner suit were very low compared with the amount on the outer suit. Penetration factors near to 50% indicate that the amounts on the outer and inner suits were roughly equal. Those greater than 50% indicate that more pesticide was detected on the inner suit than the outer one. In tables 4.17 to 4.19, penetration factors greater than 50% were calculated on eight occasions. Four of these were for the hood and this can be easily explained since the hoods were in general ill-fitting, particularly those on the polyester cotton suits, and operators were often observed to push them back with their hands. It is therefore more likely than contamination on the sampling hood has come directly from the gloves. On two occasions a penetration factor greater than 50% was observed for the front torso, once with a polyester cotton overall and once when wearing a Tyvek protective overall. A possible explanation for this may be that pesticide is penetrating through the fastenings in the suits or there may be direct deposition through openings at the top of the suits. Penetration factors greater than 50% were also observed for the right lower arm of a polyester cotton suit and the right lower leg of a Kleenguard suit. Explanations for this are not immediately apparent. On another three occasions for which penetration factors could not be calculated, pesticide was detected on the inner sampling hood but not the outer protective one.

Table 4.17
Individual penetration factors for polyester cotton overalls

Section	Permethrin-based pesticides (%)			Boron-based pesticides (%)	
	A/3/1 *	D/8/1 *	D/8/2 *	C/7/1 *	E/12/1 *
Lower leg left	15	-	-	0.4	5
Upper leg left	4	-	-	-	2
Lower leg right	30	-	-	1	-
Upper leg right	-	-	-	-	-
Lower arm left	25	-	-	-	-
Upper arm left	-	-	-	-	-
Lower arm right	44	69	-	0.1	-
Upper arm right	-	-	-	-	-
Hood	-	-	-	3	-
Front torso	88	-	-	-	-
Back torso	-	-	-	-	-
Whole suit	8	13	-	0.1	1

*Where * company/survey/operator*
- = no penetration factor calculated

Table 4.18
Individual penetration factors for Tyvek overalls

Section	Permethrin-based pesticides (%)			Boron-based pesticides (%)	
	A/2/1 *	D/9/1 *	D/9/2 *	C/7/2 *	E/13/1 *
Lower leg left	15	-	-	38	16
Upper leg left	30	-	-	1	15
Lower leg right	17	-	-	2	18
Upper leg right	32	-	-	0.1	47
Lower arm left	28	-	-	0.2	1
Upper arm left	13	-	-	1	-
Lower arm right	37	-	-	0.5	-
Upper arm right	15	-	-	-	-
Hood	71	-	-	75	53
Front torso	83	-	-	1	17
Back torso	47	-	-	0.5	13
Whole suit	37	-	-	1	8

*Where * company/survey/operator*
- = no penetration factor calculated

Table 4.19
Individual penetration factors for Kleenguard overalls

Section	Permethrin-based pesticides (%)				Boron-based pesticides (%)	
	A/4/1 *	A/5/1 *	B/6/1 *	B/6/2 *	C/10/1 *	E/11/1 *
Lower leg left	-	2	0.7	24	28	8
Upper leg left	-	11	-	36	6	11
Lower leg right	-	3	-	19	52	6
Upper leg right	-	6	-	10	2	7
Lower arm left	-	2	-	35	6	-
Upper arm left	-	2	3	-	0.3	-
Lower arm right	-	26	-	25	6	0.2
Upper arm right	-	2	-	-	-	-
Hood	52	22	6	-	23	-
Front torso	-	21	-	-	1	2
Back torso	-	5	-	-	1	46
Whole suit	3	6	0.5	17	3	9

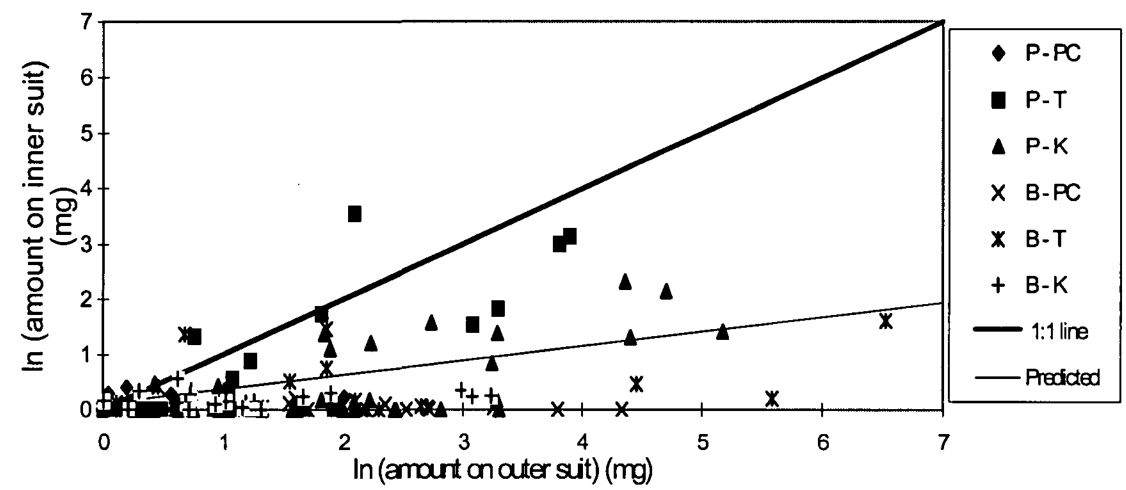
** company/survey/operator*
- = no penetration factor calculated

Surprisingly, although operator 1 in survey 6 (company B) sprayed for 60 minutes, by far the longest time in the whole study, penetration factors could only be calculated for three sections because very little permethrin was detected on the inner sampling suit (appendix 5). That a penetration factor could be calculated for the hood probably reflects the fact that it was observed to be regularly pushed back by the operator. The remaining penetration factors were calculated for the upper left arm and the lower left leg. This survey was carried out in an attic and although it was large, allowing the operator to stand upright at it's highest points, contact with treated timbers was to be expected. Contamination on the inner sampling suit and hence penetration factors could be calculated for operator 2, who was only involved in the preparation of pesticide and who attended the pump. Permethrin was found on six of the 11 sections, the legs and the lower arms. This may perhaps be partially explained by the fact that splashing with concentrated pesticide could have occurred when preparing the working strength pesticide.

Surveys 11, 12 and 13 (company E) were carried out by the same operator under virtually identical conditions – in large rooms in a derelict building and working practices were the same for each survey. Penetration factors in general appear to be lower for the polyester cotton suit, with no penetration factors being detected for the hood, front torso or back torso. Of the three surveys, spraying was carried for the longest period of time wearing the polyester cotton suit (17 minutes –v- 12 and 7 minutes), with an estimated amount of 30 mg being detected compared with 37 mg and 16 mg for the Tyvek and Kleenguard suits respectively. However, these results refer to only one of each type of suit and as such no definite conclusions can be drawn from them.

It should of course be remembered that the amounts of pesticide on the outer suits were only estimates and as such caution must be exercised when interpreting the results. An underestimate could result in penetration factors greater than 50% being observed. Similarly, overestimation of the amount on the suit will lead to lower penetration factors. In a previous study (Tannahill *et al*, 1996), the patch method was found to be more likely to overestimate exposure. At low masses random error may dominate and hence lead to misleading results. The penetration factor also assumes that everything detected on the inner suit has come through the outer suit, which is clearly not the case as evidenced by the hoods where pesticide was often detected on the inner suit was likely to arise as a result of pushing back the hood with contaminated gloves. As mentioned above, breakthrough of the sampling suit was observed on two occasions and as such the penetration factors for the sections affected – front torso and upper and lower legs – will be lower than expected.

It would, however, be misleading to consider penetration factors in isolation since very different amounts on the outer and inner suits can give rise to identical penetration factors. This can be illustrated by the following examples. In survey 5 (company A) a penetration factor of 5% was observed for the back torso, with 25 mg being estimated on the outer suit and 1 mg being detected on the inner suit. In survey 12 (company E) a penetration factor of 5% was observed for the lower leg left, with 4 mg being estimated on the outer suit and 0.2 mg detected on the inner suit (appendix 5).



Where P-PC = polyester cotton overalls exposed to permethrin based pesticides
P-T = Tyvek overalls exposed to permethrin based pesticides
P-K = Kleenguard overalls exposed to permethrin based pesticides
B-PC = polyester cotton overalls exposed to boron based pesticides
B-T = Tyvek overalls exposed to boron based pesticides
B-K = Kleenguard overalls exposed to boron based pesticides

Figure 4.4
Amount of active ingredient outside and inside protective overalls

In figure 4 the amount of pesticide detected on each section of the inner suit for each type of protective suit for both permethrin and boron based pesticides has been plotted against the estimated amount on the corresponding sections on the outer suit. The 1:1 line indicates where the amounts inside and outside are equal i.e. the penetration factor is equal to 50%. In general, the amounts on the outer suit are greater that those inside. On a few occasions the amount inside was greater than that outside leading to penetration factors greater than 50%. The reasons for this have been considered earlier. From the graph there are no apparent differences between suits or between permethrin and boron based pesticides. In general, higher amounts both outside and inside Kleenguard suits were detected, which, in part, reflects the dimensions of the working area, amounts of pesticide used and working practices.

Note, where no active ingredient was detected, a value of half the detection limit was used for the purposes of plotting this graph (permethrin = 0.05 μg, boron = 3 μg). However, the regression equation was calculated using only the 80 points for which active ingredient was detected both on the outer suit and the inner sampling suit.

When the points where active ingredient was detected on both sections only are considered, there is a suggestion of a relationship between the logarithims of the two variables, with the logarithim of the amount on the inner suit sections increasing as the logarithim of the amount on the outer suit sections increase. A significant correlation of 0.47 ($p < 0.001$) between the amounts was obtained and so 22% of the variability in inside measurements can be explained by the outside measurements.

The regression equation is:

$$\text{Ln (amount on inner suit section)} = 0.26 \text{ Ln (amount on outer suit section)} + 0.11$$

Only the slope was significant ($p < 0.001$).

Since the amount on the hood of the sampling suits was observed to be greater than that on the outer suits on a number of occasions for the reasons stated above, it was felt that it was justified to eliminate these points and repeat the analysis. A significant correlation of 0.50 ($p < 0.001$) was observed and so 25% of the variability in the logarithim of the inside measurements can be explained by the logarithim of the outside measurements. The regression equation is:

$$\text{Ln (amount on inner suit section)} = 0.28 \text{ Ln (amount on outer suit section)} + 0.05$$

Again, only the slope was significant ($p < 0.001$). Elimination of the measurements relating to the hood made little difference to the relationship between the two variables and resulted in only a very small increase in the amount of variability of inside measurements explained by the outside ones. This indicates that other factors play an important role in determining the amount of pesticide inside a suit, which is not surprising.

4.2.6 Quantity of fluid outside and inside protective overalls

The estimated quantity of fluid on the outside of the protective overalls is shown in table 4.20 and varied from less than 1 ml to 970 ml. It is interesting to note that for company D (where the operators wore polyester cotton and Tyvek suits), some of the highest quantities of fluid were on their outer overalls, which agrees with observations made during the survey. However, as the working strength pesticide was very dilute, no permethrin was detected on a number of occasions this could lead to the quantity of fluid being underestimated. Operator 2 of company B (who wore Kleenguard overalls) carried out no spraying, being responsible for the preparation of the working strength solution and for ensuring that the pump was kept supplied. It is likely that the majority of this operator's exposure would have been from the concentrated pesticide. As such, the quantity of fluid on his protective overalls may have been overestimated.

In general, less fluid was detected on the overalls in surveys where boron was the active ingredient. For three of these surveys, a microblower was used to apply the pesticide and for one a floor fogger was used and these lower quantities were probably, at least in part, due to these methods of application. The quantity of fluid using the lance varied from 12 to 970 ml, using a microblower it varied from under 1 ml to 2 ml and for the floor fogger 5 ml was detected on the overalls. However, it should be noted that there is only one result for the floor fogger and three for the microblower compared to 12 for the more traditional lance. The quantity of pesticide impinging on the protective overalls will also depend on many factors including the amount of pesticide applied, the area sprayed, the dimensions of the working space and hence the amount of contact with treated surfaces. The microblower, for example, was used in large rooms which will in itself lead to reduced amounts on the overalls. In an effort to allow for this the quantity of fluid on the overalls was multiplied by 1000 and divided by the amount of pesticide applied and the results presented in table 4.21.

Table 4.20
Estimated quantity of fluid on outside of protective overalls

Company	Polyester cotton	Tyvek	Kleenguard
	Permethrin-based pesticides (ml)		
A	9	150	10
			250
B & D	250	970	56
	140	85	19
	Boron-based pesticides (ml)		
C	12	66	5
E	1	2	1

Table 4.21
Estimated quantity of pesticide on protective overalls (x1000) adjusted by the amount applied

Company	Polyester cotton	Tyvek	Kleenguard
	Permethrin-based pesticides		
A	0.4	6	1
			11
B & D	56	81	0.5
	55	5	-
	Boron-based pesticides		
C	0.6	4	1
E	0.1	0.2	0.1

Table 4.22
Estimated quantity of fluid inside protective overalls

Company	Polyester cotton	Tyvek	Kleenguard
	Permethrin-based pesticides (ml)		
A	1	86	0.3
			16
B & D	39	-	0.3
	-	-	4
	Boron-based pesticides (ml)		
C	0.02	1	0.2
E	0.01	0.2	0.1

Key	*Lance used*	*Floor fogger*	*Microblower*

A wide range in the estimated quantity of penetration fluid was observed, although in the majority of cases this was less than 1ml. The quantity of fluid could not be detected on most occasions for company D (polyester cotton and Tyvek overalls) and, as stated previously, this was a consequence of the weak working strength solution being used.

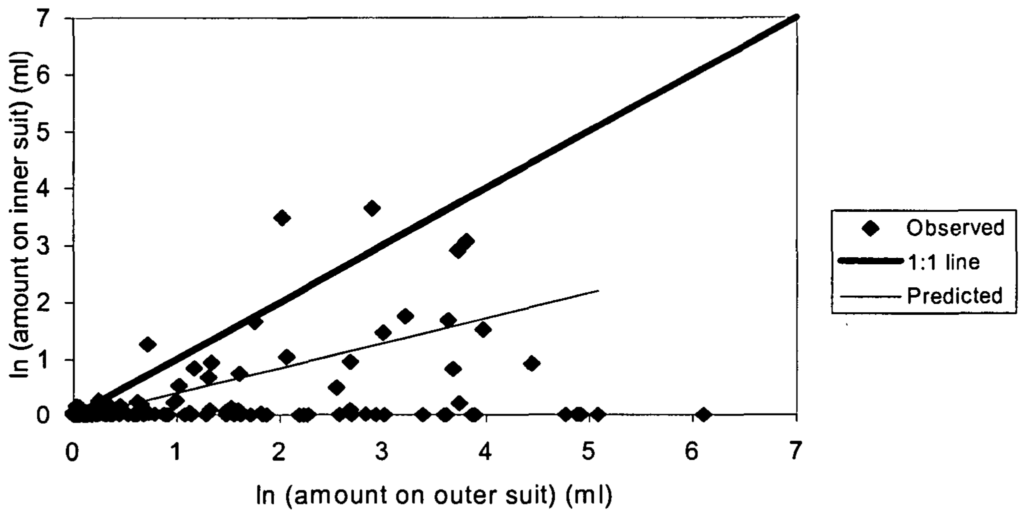


Figure 4.5
Amount of fluid outside and inside protective overalls

The quantity of fluid both outside and inside the protective overalls for each suit section are shown in appendix 6.

In figure 4.5 the quantity of pesticide detected on each section of the inner sampling suit has been plotted against the estimated quantity on the corresponding sections on the outer suit. The 1:1 line indicates where the amounts inside and outside are equal.

Note, where no active ingredient was detected, a value of half the detection limit was used to calculate the quantity of fluid and that value used when plotting the above graph. However, the regression equation was calculated using only the 80 points for which active ingredient was detected and hence the quantity of fluid could be calculated both on the outer protective suit and the inner sampling suit.

When the points where active ingredient was detected and hence quantity of fluid could be calculated for both outer and inner sections only are considered there is a suggestion of a relationship between the two variables, with the quantity on the inner suit sections increasing as the quantity on the outer suit sections increase. A significant correlation of 0.67 ($p < 0.001$) was obtained and so 45% of the variability in inside quantities can be explained by the outside quantities. The regression equation is:

Ln (quantity on outer suit section) = 0.44 Ln (quanti`ty on inner suit section) – 0.04

Only the slope was significant ($p < 0.001$).

If the values relating to the quantities on the hood are omitted, a significant correlation of 0.68 ($p < 0.001$) was observed, with 46% of the variability in inside quantities explained by the outside quantities.

The regression equation is:

Ln (quantity on outer suit section) = 0.45 Ln (quantity on inner suit section) - 0.06

Again, only the slope was significant ($p < 0.001$).

4.2.7 Assessment of comfort of overalls

This part of the study was not successful, which is perhaps not unexpected since operators were asked to wear two sets of overalls and it was therefore difficult to draw any conclusions from the results. Operators were asked four questions relating to comfort, thermal comfort, restriction of movement and overall comfort. The answers to the questions of comfort were clearly influenced in some cases when the operator was to hot, however, some operators reported that the overalls were comfortable despite the heat. Although the question relating to restrictiveness of the overalls was probably the most useful, this too had its problems with one operator reporting that his movement was restricted as a result of the sampling suit rather than the test overall. The main problem was one of heat, particularly in late spring and early summer. It was also noted that the Kleenguard overalls exhibited a tendency to rip easily.

4.2.8 Gloves

One of the original aims of the study was to undertake a preliminary investigation of the field effectiveness of gloves. It had been intended to use Marigold blue nitrile gloves as the test gloves. New gloves were to be issued to the operators of a particular company at the start of the first of the three surveys in which they were to participate. The gloves were to be given a unique reference number, stored at the end of the first survey and re-issued for the second and third surveys. However, there were a number of problems with this which were identified during the pilot survey. Firstly, the selected gloves were not thought to provide adequate protection by one company and secondly at least one other company indicated that gloves would not normally be reused for three surveys, particularly if a roof space was being treated. Consideration was given to the views of a number of companies and as a result heavy-duty green nitrile gauntlets (manufactured by ARCO) were selected. These were replaced at the start of each survey and so it was not possible to assess deterioration of the gloves over time. Gloves were usually removed when preparing fresh batches of pesticide or when priming the pump. On these occasions operators were encouraged to keep the cotton sampling gloves on.

Table 4.23
Amount of pesticide on sampling gloves

Company/ Survey	Amount Inside (mg)	Amount on sampling gloves (mg) Left	Right	Total	Gloves as % of total
		Permethrin-based pesticides			
A/2	94	0.4	0.4	1	1
A/3	1	7	6	13	91
A/4	1	0.1	ND	0.1	17
A/5	33	12	1	14	29
B/6	0.5	0.1	0.1	0.2	26
B/6	7	1	0.3	2	18
D/8	0.5	ND	ND	ND	0
D/8	ND	ND	ND	ND	-
D/9	ND	ND	ND	ND	-
D/9	ND	ND	ND	ND	-
		Boron-based pesticides			
C/7/1	0.3	0.3	1	1	73
C/7/2	11	0.3	0.3	1	5
C/10	3	2	1	2	42
E/11	2	1	0.2	1	38
E/12	0.3	1	0.4	1	77
E/13	4	1	1	1	29

Where ND = none detected, i.e. < 0.1 μg for permethrin-based pesticides

The amount of pesticide detected on the cotton sampling gloves is presented in table 4.23, along with the percentage of the total amount of pesticide detected under protective clothing. Not surprisingly, no pesticide was detected on the sampling gloves for either operator in both surveys 8 and 9 (company D), where the working concentration of the pesticide used was very low. Pesticide was detected on all sampling gloves from the remaining surveys. The amount on these gloves calculated as a percentage of the total amount of pesticide inside the protective clothing ranged from 0.9% to 91%, with a median of 34%. In survey 3 (company A), where exposure to the hands represented 91% of total dermal exposure, the operator had removed the outer protective gloves when preparing working concentration pesticide and the cotton gloves was seen to become contaminated when the operator pushed the nozzle from the concentrated pesticide back inside the container. This value is inflated due to the fact that very little contamination occurred to the inner suit, this being a short study where a room was sprayed. Rather surprisingly, very little contamination was observed to the sampling gloves in survey 2 (company A) where the operator was troubled by a leaking lance. At one point he removed both sets of gloves to dismantle and reassemble the lance to try and resolve the problem.

For all of the surveys with boron-based pesticide, the gloves were kept on for the entire survey period and so any contamination cannot be attributed to the removal of the gloves to attend to some other task. It is possible that the hands were already contaminated before the gloves were donned. In all of these surveys the sampling equipment complete with pesticide was set up before the protective clothing was put on. For survey 13 (company E) in particular, the pump required more priming than usual and hence there is more chance of contamination to the hands occurring, due to leakage of fluid, which could then be transferred to the sampling gloves.

Table 4.24
Estimated quantity of fluid on sampling gloves

Company/survey	Quantity of fluid on sampling gloves (ml) Left	Right	Total
	Permethrin-based pesticides		
A/2	0.4	0.4	1
A/3	4	4	7
A/4	0.1	ND	0.1
A/5	6	1	6
B/6	0.1	0.1	0.1
B/6	1	0.2	1
D/8	ND	ND	ND
D/8	ND	ND	ND
D/9	ND	ND	ND
D/9	ND	ND	ND
	Boron-based pesticides		
C/7/1	0.02	0.03	0.1
C/7/2	0.02	0.02	0.04
C/10	0.1	0.03	0.1
E/11	0.03	0.01	0.04
E/12	0.03	0.02	0.1
E/13	0.04	0.03	0.1

Where ND = none detected, i.e. < 0.01 ml for permethrin-based pesticides

The estimated quantity of fluid on the cotton sampling gloves is presented in table 4.24. In general, very small quantities of fluid were detected, particularly for the boron based surveys.

5. DISCUSSION

The laboratory tests suggested that Tyvek and Kleenguard suits should be more effective than overalls made from polyester cotton, with the average penetration of these overalls being over 40% compared with Tyvek and Kleenguard overalls with less than 5% penetration. However, the field trials indicated that there was very little difference between any of the overalls, with penetration factors varying widely. There was a relationship between the amount on the inner sampling suit sections and the estimated amounts on the corresponding outer protective suit sections, with the amount on the inner suit sections increasing as the amount on the outer suit sections increased. However, the amount on the outer overall sections only explained about 45% of the variability in the amounts detected on the inner suit sections and further explanations for this variability must be sought. As a consequence of the relatively small numbers of samples involved in the study it was not possible to undertake a more in-depth statistical analysis to investigate the influence of other factors such as the spraying time, the quantity of pesticide used, the type of applicator used, or how confined the working space was and hence the degree of contact with treated surfaces.

The results show that contamination occurs even after very short surveys lasting as little as six minutes, suggesting that duration of spraying is not an important variable. Typically, treatment of wood or masonary with preservative only comprises a very small proportion of an operator's time. When an attic is treated, for example, the majority of the time is spent in brushing down timber, covering junction boxes and removing and relaying insulation. When floors or walls are being treated the majority of the time may be spent in the removal of damaged timber and its replacement with new material.

The type of pesticides used in the treatment of domestic premises appears to be changing, with a number of companies who were contacted indicating that they were now using boron-based pesticides rather than permethrin or cypermethrin-based pesticides. With this change have come changes in the equipment used. Traditionally, a lance was used to apply pesticide. However, for the boron based pesticides, foggers and microblowers appear to be more typically used. This equipment applies the pesticide in a fine mist or fog rather than as a coarse spray. The floor fogger was used in an attic space and there was much less contact with treated timber than when a lance was used for similar applications. Despite this, there was still an appreciable amount of pesticide detected on the sampling suit. The microblower was used to treat masonary in large rooms and as such there was no contact with treated surfaces. Conversation with the operator in this case indicated that although their hands generally became wet, their overalls did not get wet. In this study contamination was found on all sampling suits, indicating that contamination occurs whether the operator perceives it or not. In such cases the operators could end up with greater skin exposure simply because they are unaware of any contamination.

It should, however, be remembered that the patch method only estimates the amount of pesticide on the outer suit. This approach assumes uniform distribution of exposure over each body region in order to directly compare inner and outer patches. However, direct deposition through openings in the clothing will result in non-uniform exposure, as will splashes. An overestimation of the amount on the outer suit would lead to lower penetration factors and an underestimation would result in higher penetration factors. In a study which compared the patch method with the whole suit method, Tannahill *et al* (1996) concluded that the patch method was an acceptable method for estimating potential dermal exposure, but that where a more accurate measurement was required, then a change of approach may be necessary.

It has been suggested that estimated whole suit exposure, calculated by summing the amount of pesticide found on each patch multiplied by a factor relating patch area to suit area divided by two provides a more accurate estimate than simply using the sum as an estimate (Llewellyn *et al,* 1996, Garrod *et al,* 1998). It is, however, not recommended that the estimated amount of pesticide for a particular suit area be divided by two (Garrod, personal communication). This presents problems for this study where penetration factors from both the whole suit and individual sections are of interest. In the interests of consistency estimated values, whether for the whole suit or individual sections, were not divided by two. Had the total amounts on the outer suits been divided by two, the calculated penetration factors would have almost doubled.

A number of studies have investigated the effectiveness of protective clothing (Fenske, 1988, Fenske and Methner, 1990, Methner and Fenske, 1994, Nigg *et al,* 1992, Ojanen *et al,* 1992), though all are subject to limitations. Other studies have investigated the performance of protective clothing by using patches placed outside and inside the clothing (Fenske *et al,* 1990, Nigg *et al,* 1992, Ojanen *et al,* 1992). Fenske (1988) also compared three different types of protective clothing using the fluorescent tracer technique. Although they assessed exposure underneath the protective clothing, no estimate of the challenge concentration to the clothing was made. Exposure was highly variable within each clothing group and there were no significant differences between types of clothing. A number of variables (mixing/loading and application activities, number of work cycles, mixing or applying the same amount of pesticide) were controlled in an attempt to create equal exposure. However, there were still variables which could not be controlled such as wind speed and direction, time worked, and individual working practices. All of these would have influenced the amount of pesticide on the protective clothing that in turn would have influenced the amount penetrating it. Other studies have demonstrated a wide range of challenge exposures when spraying pesticide (Methner and Fenske, 1994, Tilt *et al,* 1992, Garrod *et al,* 1998). As such, the Fenske (1988) paper provides information on skin exposure rather than the effectiveness of protective clothing.

In another study, Methner and Fenske (1994) again employed the fluorescent tracer method to assess potential exposure beneath four different types of protective clothing. In addition, they employed the patch method both to estimate potential exposure and exposure beneath the protective clothing. In this instance, only exposure to the thighs was considered. Estimated challenges were obtained by multiplying the amounts on the outer patches by the surface area of the front and outer surface of the thighs measured by video-imaging. Percent permeation (broadly equivalent to the term "penetration" used in the present study) through the protective overalls was determined by dividing skin deposition as measured by the fluorescent technique by the estimated challenge and multiplying by 100. They found a wide range of both estimated challenge mass and skin deposition rate and percent permeation values, both for different clothing and within clothing types.

Percent permeation was also estimated by using information from the patches alone. The amount of pesticide on each patch was determined and values from left and right patches pooled. Percent permeation was then defined as the inner patch rate divided by the outer patch rate multiplied by 100. The results were again highly variable and there was no relationship between challenge and inner patch deposition and there was generally a wide range in percent permeation within clothing types.

It is interesting to note that the percent permeations differ depending on the way in which they are calculated, with very different values being calculated by each method. For example, for one worker wearing a standard Tyvek suit, percent permeations were 16% and 2.1%. In general the values followed the same pattern, i.e. those with higher percent permeations calculated using the fluorescent tracer method tended to have higher percent permeations using the patch method, although this was not always the case.

The results from Methner and Fenske, clearly show that great care must be exercised when drawing conclusions about the relative effectiveness of different types of protective clothing since very different estimates can be obtained depending on the method used. There is clearly room for improvement in the way in which effectiveness is measured. Firstly, the accuracy of different methods of estimation should be established. For example, Tannahill *et al* (1996) when comparing the whole body method with the patch method 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, supplemented by a second patch or increased in size. Exposure estimation is an area which requires further investigation.

In all of the published studies relatively small numbers of comparisons were involved, which limits any conclusions which can be drawn. However, in common with this study, all other published research studies report a wide range of penetration (or permeation).

There were big differences between companies and operators with respect to their standards of housekeeping and maintenance of protective equipment. In general, respirators were kept in a box or bag, but gloves were placed anywhere, which could lead to further contamination and hence exposure. The policy on changing suits varied from one company whose operators changed suits at lunchtime to another organisation where operators wore suits until they became dirty. Similarly, for gloves, glove re-use varied from one company who replaced the gloves after being used twice to those who used them for some weeks until they felt it necessary that they be replaced.

Since there are many factors which may affect exposure, and hence the apparent effectiveness of a particular overall, it is difficult to draw any firm conclusions from this study, although there is no indication that the type of suit strongly affects the protection given. A better approach to investigate differences between suits might have been to carry out a simulation study. This would have allowed factors such as the amount of pesticide sprayed, area sprayed, method of application and nature of the area sprayed, i.e. attic or room, to be controlled. Although the application time and working practices cannot be controlled for, this approach could result in more similar exposure and hence allow a more direct comparison of the effectiveness of the protective overalls to be made.

Despite suitable protective gloves being worn, contamination was observed in most cases and occurred despite the careful working practices of some of the operators involved in the study. Contamination could have been due either to contamination of the hands prior to putting on the gloves or to contamination as a result of removing the gloves to prime the pump or to adjust equipment. Less likely, contamination may have been due to penetration through the gloves. Despite the fact that the hands comprise only 6% of surface area of the body, the median amount of contamination detected on the sampling gloves was over 30% It is therefore important that careful consideration be given to selection, use, reuse and storage of gloves. In addition, training should be given to operators on the correct way to remove gloves. It is our opinion that the care taken in selecting and maintaining respirators and protective clothing is not extended to the selection and maintenance of gloves, as evidenced by the state of the gloves which were being used by some operators and the way in which they were stored.

In conclusion, this study shows that penetration of protective clothing in field situations occurs regardless of the type of overalls worn and that it may occur after very short periods of time. It is important to ensure that both where protective overalls can be reused where they are disposable, that they be changed at frequent intervals, depending on the nature of the work. Regardless of the type of overalls worn, safe working practices should be promoted. Finally, hand exposure occurred despite the operators being issued with new protective nitrile gloves.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

EN 368. (1992). Protective clothing - protection against liquid chemicals - test method: resistance of materials to penetration by liquids ('gutter method'). Comité Européen de Normalisation: Brussels.

EN 369. (1993). Protective clothing - protection against liquid chemicals - test method: resistance of materials to permeation by liquids ('permeation cell method'). Comité Européen de Normalisation: Brussels.

EN 468. (1994). Protective clothing – protection against liquid chemicals – test method: determination of resistance to penetration by spray ('spray test'). Comité Européen de Normalisation: Brussels.

Fenske RA. (1988). Comparative assessment of protective clothing performance by measurement of dermal exposure during pesticide applications. Applied Industrial Hygiene; 3: 207-213.

Fenske RA, Blacker AM, Hamburger SJ, Simon GS. (1990). Worker exposure and protective clothing performance during manual seed treatment with lindane. Archives of Environmental Contamination and Toxicology; 19: 190-196.

Garrod ANI, Rimmer DA, Robertshaw L, Jones T. (1998). Occupational exposure through spraying remedial pesticides. Annals of Occupational Hygiene; 42: 159-165.

Llewellyn DM, Brazier A, Brown R, Cocker J, Evans ML, Hampton J, Nutley BP, White J. (1996). Occupational exposure to permethrin during its use as a public hygiene insecticide. Annals of Occupational Hygiene; 40: 499-509.

Methner MM, Fenske RA. (1994). Pesticide exposure during greenhouse applications, part II. Chemical permeation through protective clothing in contact with treated foliage Applied Occupational Environmental Hygiene; 9: 567-574.

Nigg HN, Stamper JH, Easter E, DeJonge JO. (1992). Field evaluation of coverall fabrics: heat stress and pesticide penetration. Archives of Environmental Contamination and Toxicology; 23: 281-288.

Occupational Safety and Health Administration. US Department of Labor. (1991). OSHA method ID121, Metals and metalloid particulates in workplace atmospheres.

OECD. (1997). Environmental Health and Safety Publications Series on Testing and Assessment No. 9. Guidance document for the conduct of studies of occupational exposure to pesticides during agricultural application. OCDE/GD (97) 148. Paris: OECD.

Ojanen K, Saranitila R, Klen T, Lotjonen A, Kangas J. (1992). Evaluation of the efficiency and comfort of protective clothing during herbicide spraying. Applied Occupational Environmental Hygiene; 7: 815-819.

Roff MW. (1994). A novel lighting system for the measurement of dermal exposure using a fluorescent dye and an image processor. Annals of Occupational Hygiene; 38: 903-919.

Tannahill SN, Robertson A, Cherrie B, Donnan P, MacConnell ELA, MacLeod GJ. (1996). A comparison of two different methods for assessment of dermal exposure to non-agricultural pesticides in three sectors. Edinburgh: Institute of Occupational Medicine. Edinburgh: Institute of Occupational Medicine. (IOM Report TM/94/04).

APPENDIX 1 – RECORDING FORM FOR FIELD STUDIES

FIELD EFFECTIVENESS OF PROTECTIVE CLOTHING AGAINST NON-AGRICULTURAL PESTICIDES

Institute of Occupational Medicine

8 Roxburgh Place, Edinburgh. EH8 9SU

1 Initial information

1.1 Date of survey ☐☐☐☐☐☐ Assessor ☐

1.2 Survey number ☐☐

1.1 Company no. ☐ Visit ☐ Test suit ☐

1.3

Company:	Contact:
Address:	
Post code:	☎:

2 Survey details

2.1

Application address
Site of application
Areas to which applied

Location of site application:

2.2 1 = Outside

2 = Inside building

3 = Tented enclosure

4 = Other, please specify ☐

2.3 For indoor facilities only:

1 = Natural ventilation

2 = Forced extraction

3 = Both

4 = None ☐

2.4 Plan of application site:

Dimensions of treated area: Dimensions of enclosed area:

2.5 Reason for treatment:

3 Environmental conditions

3.1 Temperature (°C)

3.2 Relative humidity (%)

4 Pesticide application

4.1 Product used

Manufacture

Trade name

Active ingredients:

1 = Permethrin

2 = Cypermethrin

Batch number

Dilutent

1 = Solvent

2 = Water

3 = Other, please specify

Dilution rate

Quantity used

4.2 (i) Applicator used for spraying ______________________

(ii) Spray pressure ______________________

(iii) Area sprayed ______________________

4.3 Describe procedure for application ______________________

____

5 Participant details

5.1 Individuals taking part in treatment application:

	Name	Task
1		
2		
3		

5.2 Individuals responsible for preparation of pesticide formulation:

1 ______________________

2 ______________________

3 ______________________

6 Time spent spraying

6.1 **Participant 1** - Name: ______________________

Total time spent spraying [ ]

Comments:

6.2 **Participant 2** - Name: ______________________________

Total time spent spraying [ ]

Comments:

6.3 **Participant 3** - Name: ______________________________

Total time spent spraying [ ]

Comments:

7 Approximate quantity of pesticide formulation used:

7.1 Participant 1 ______________________________ [ ]

7.2 Participant 2 ______________________________ [ ]

7.3 Participant 3 ______________________________ [ ]

8 Description of PPE

8.1 **Participant 1** - Name: ______________________

0 = Not worn

1 = Worn correctly

2 = Worn incorrectly

	Worn Y/N	Removed Y/N	Comments
Gloves			
Face protection			
Overalls			
Safety boots			
Wellingtons			
Respiratory protection			
Other			

8.2 **Participant 2** - Name: ______________________

0 = Not worn

1 = Worn correctly

2 = Worn incorrectly

	Worn Y/N	Removed Y/N	Comments
Gloves			
Face protection			
Overalls			
Safety boots			
Wellingtons			
Respiratory protection			
Other			

8.3 **Participant 3** - Name: ______________________________

0 = Not worn

1 = Worn correctly

2 = Worn incorrectly

	Worn Y/N	Removed Y/N	Comments
Gloves			
Face protection			
Overalls			
Safety boots			
Wellingtons			
Respiratory protection			
Other			

9 Contamination

9.1 **Participant 1** - Name: ______________________

Hand applicator held in ______________________

Routes of contamination:

0 = None	4 = Accidental direct spray
1 = Spills/splashes at formulation	5 = Spray back
2 = Leakage of spray nozzle during application	6 = Spills/splash at formulation
3 = Leakage of container during application	7 = Contact with treated timbers

(a) Main route of contamination ☐

Other routes of contamination ______________________

(b) Subjective assessment of contamination

0 = Dry 1 = Some wetness 2 = Soaked 3 = not applicable

		Following formulation	At end of treatment	At end of clean-up
(i)	Head/face	☐	☐	☐
(ii)	Hands/gloves	☐	☐	☐
(iii)	Arms	☐	☐	☐
(iv)	Legs (lower)	☐	☐	☐
(v)	Legs (upper)	☐	☐	☐
(vi)	Groin	☐	☐	☐
(vii)	Torso (front)	☐	☐	☐
(viii)	Torso (back)	☐	☐	☐

Comments:

9.2 **Participant 2** - Name: ____________________

Hand applicator held in ____________________

Routes of contamination:

0 = None	4 = Accidental direct spray
1 = Spills/splashes at formulation	5 = Spray back
2 = Leakage of spray nozzle during application	6 = Spills/splash at formulation
3 = Leakage of container during application	7 = Contact with treated timbers

(a) Main route of contamination ☐

Other routes of contamination ____________________

(b) Subjective assessment of contamination

0 = Dry   1 = Some wetness   2 = Soaked   3 = not applicable

		Following formulation	At end of treatment	At end of clean-up
(i)	Head/face	☐	☐	☐
(ii)	Hands/gloves	☐	☐	☐
(iii)	Arms	☐	☐	☐
(iv)	Legs (lower)	☐	☐	☐
(v)	Legs (upper)	☐	☐	☐
(vi)	Groin	☐	☐	☐
(vii)	Torso (front)	☐	☐	☐
(viii)	Torso (back)	☐	☐	☐

Comments:

9.3 **Participant 3** - Name: ______________________

Hand applicator held in ______________________

Routes of contamination:

0 = None

1 = Spills/splashes at formulation

2 = Leakage of spray nozzle during application

3 = Leakage of container during application

4 = Accidental direct spray

5 = Spray back

6 = Spills/splash at formulation

7 = Contact with treated timbers

(a) Main route of contamination ☐

Other routes of contamination ______________________

(b) Subjective assessment of contamination

0 = Dry 1 = Some wetness 2 = Soaked 3 = not applicable

		Following formulation	At end of treatment	At end of clean-up
(i)	Head/face			
(ii)	Hands/gloves			
(iii)	Arms			
(iv)	Legs (lower)			
(v)	Legs (upper)			
(vi)	Groin			
(vii)	Torso (front)			
(viii)	Torso (back)			

Comments:

9.4 Was personal washing water available during treatment sessions?

0 = None
1 = Cold water
2 = Hot and cold running water
3 = Shower facilities
4 = Other

Other, please specify

9.5 Frequency of washing:

1 = Always 2 = Occasionally 3 = Never 4 = Not applicable

(a) **Participant 1** - Name:

After contamination with pesticide
Before meal breaks
Before smoking
At end of treatment session(s)

(b) **Participant 2** - Name:

After contamination with pesticide
Before meal breaks
Before smoking
At end of treatment session(s)

(c) **Participant 3** - Name:

After contamination with pesticide
Before meal breaks
Before smoking
At end of treatment session(s)

10 Post treatment

Y/N

10.1 Was there any surplus pesticide formulation? ☐

If yes, describe how it was disposed/stored and by whom:

Y/N

10.2 Was the applicator cleaned after treatment was completed?

Participant 1 ☐

Participant 2 ☐

Participant 3 ☐

10.3 How was the applicator cleaned? ______________________

____

11 Additional information

12 Acceptability of overalls

12.1 **Participant 1** - Name: ______________________

Y/N

(a) Did you find the overalls comfortable? ☐

If no, why not? ______________________

____

Y/N

(b) Did you feel thermally comfortable? ☐

If no, why not? ______________________

____

Y/N

(c) Did you find that the overalls restricted your movement in any way? ☐

If yes, in which tasks did they restrict you? ______________________

____

Y/N

(d) Overall, did you find the overalls acceptable? ☐

If no, why not? ______________________

____

(e) Comments:

12.2 **Participant 2** - Name: ______________________

Y/N

(a) Did you find the overalls comfortable? ☐

If no, why not? ______________________

____

Y/N

(b) Did you feel thermally comfortable? ☐

If no, why not? ______________________

____

Y/N

(c) Did you find that the overalls restricted your movement in any way? ☐

If yes, in which tasks did they restrict you? ______________________

____

Y/N

(d) Overall, did you find the overalls acceptable? ☐

If no, why not? ______________________

____

(e) Comments:

12.3 **Participant 3** - Name: ______________________

Y/N

(a) Did you find the overalls comfortable? ☐

If no, why not? ______________________

____

Y/N

(b) Did you feel thermally comfortable? ☐

If no, why not? ______________________

____

Y/N

(c) Did you find that the overalls restricted your movement in any way? ☐

If yes, in which tasks did they restrict you? ______________________

____

Y/N

(d) Overall, did you find the overalls acceptable? ☐

If no, why not? ______________________

____

(e) Comments:

APPENDIX 2

Multiplication factors for individual suit sections for each size of suit

	Polyester cotton		Tyvek		Kleenguard	
Section	**44"**	**45.5"**	**Large**	**Extra large**	**Large**	**Extra large**
Lower leg	18.18	18.45	17.46	18.41	22.65	23.52
Upper leg	22.75	23.10	19.21	21.96	24.80	27.76
Lower arm	10.28	10.28	13.09	14.22	9.07	9.74
Upper arm	11.63	11.64	17.09	20.55	10.82	11.50
Hood	16.83	16.83	12.74	15.56	16.00	16.44
Front torso	46.46	48.54	61.17	65.10	62.63	65.75
Back torso	47.39	48.61	57.57	61.96	64.56	67.76

APPENDIX 3

Company identification and survey number

Company	Polyester cotton	Tyvek	Kleenguard
Permethrin (mg)			
A	3	2	4 5
B & D	8	9	6
Boron (mg)			
C	7/1	7/2	10
E	12	13	11

Note, surveys 7/1 and 7/2 were carried out on the same day on the same operator, in accordance with company policy the protective suit was changed at lunchtime and a different suit type of protective suit worn.

APPENDIX 4

Amount on blank and test patches for permethrin samples

Sample	Company/Survey	Amount (mg)
Blank	Pilot/1	-
Blank	Pilot/1	-
Test	Pilot/1	-
Test	Pilot/1	-
Blank	A/2	0.05
Blank	A/2	0.04
Test	A/2	0.11
Test	A/2	-
Blank	A/3	-
Blank	A/3	-
Test	A/3	-
Test	A/3	-
Blank	A/4	-
Blank	A/4	-
Test	A/4	-
Test	A/4	-
Blank	A/5	-
Blank	A/5	-
Test	A/5	-
Test	A/5	-
Blank	B/6	-
Blank	B/6	-
Test	B/6	-
Test	B/6	-
Blank	D/8	-
Blank	D/8	-
Test	D/8	-
Test	D/8	-

Where - = non detected or amount < 0.01 mg

Amount on blank and test patches for boron samples

Sample	Company/Survey	Amount (mg)
Blank	C/7	-
Blank	C/7	0.03
Test	C/7	0.01
Test	C/7	-
Blank	C/10	0.03
Blank	C/10	0.42
Test	C/10	0.01
Test	C/10	0.07
Blank	E/11	0.01
Blank	E/11	0.02
Test	E/11	-
Test	E/11	0.03
Blank	E/12	-
Blank	E/12	-
Test	E/12	-
Test	E/12	-
Blank	E/13	-
Blank	E/13	-
Test	E/13	0.01
Test	E/13	-

Where - = non detected or amount < 0.01 mg

APPENDIX 5

Mass outside and inside suits for each body part

Permethrin-based pesticides

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount inside (mg)	Penetration Factor
1	Pilot	Tyvek	1	Lower leg left	11	1.3	11
				Upper leg left	16	0.1	0.4
				Lower leg right	10	1.2	11
				Upper leg right	12	ND	-
				Lower arm left	9.1	0.1	1
				Upper arm left	12	ND	-
				Lower arm right	5.8	0.1	1
				Upper arm right	7.2	ND	-
				Hood	2.6	0.1	3
				Front torso	13	ND	-
				Back torso	8.2	0.4	4
				Left glove		ND	
				Right glove		ND	
1	Pilot	Tyvek	2	Lower leg left	1.9	0.5	23
				Upper leg left	22	0.3	1
				Lower leg right	2.1	0.2	10
				Upper leg right	5.8	0.4	7
				Lower arm left	3.7	ND	-
				Upper arm left	9.7	ND	-
				Lower arm right	0.4	ND	-
				Upper arm right	3.0	0.01	0.2
				Hood	0.7	0.8	55
				Front torso	11	0.1	1
				Back torso	2.7	0.4	13
				Left glove		ND	
				Right glove		ND	

Where ND = none detected, i.e. < 0.1 μg for permethrin-based pesticides
- = no penetration factor calculated

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount inside (mg)	Penetration Factor
2	A	Tyvek	1	Lower leg left	21	3.6	15
				Upper leg left	44	19	30
				Lower leg right	26	5.2	17
				Upper leg right	48	22	32
				Lower arm left	1.9	0.7	28
				Upper arm left	1.8	0.3	13
				Lower arm right	2.4	1.4	37
				Upper arm right	1.8	0.3	15
				Hood	1.1	2.7	71
				Front torso	7.1	34	83
				Back torso	5.2	4.7	47
				Left glove		0.4	
				Right glove		0.4	
3	A	Polyester cotton	1	Lower leg left	0.9	0.2	15
				Upper leg left	6.5	0.3	4
				Lower leg right	0.8	0.3	30
				Upper leg right	7.2	ND	-
				Lower arm left	0.1	0.04	25
				Upper arm left	ND	ND	-
				Lower arm right	0.1	0.05	44
				Upper arm right	ND	0.02	-
				Hood	ND	0.1	-
				Front torso	0.05	0.3	88
				Back torso	ND	ND	-
				Left glove		6.6	
				Right glove		6.4	

Where ND = none detected, i.e. < 0.1 μg for permethrin-based pesticides
- = no penetration factor calculated

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount Inside (mg)	Penetration Factor
4	A	Kleenguard	1	Lower leg left	0.9	ND	-
				Upper leg left	11	ND	-
				Lower leg right	1.6	ND	-
				Upper leg right	3.8	ND	-
				Lower arm left	1.1	ND	-
				Upper arm left	0.5	ND	-
				Lower arm right	0.5	ND	-
				Upper arm right	0.4	ND	-
				Hood	0.5	0.6	52
				Front torso	ND	ND	-
				Back torso	ND	ND	-
				Left glove		0.1	
				Right glove		ND	
5	A	Kleenguard	1	Lower leg left	180	3.1	2
				Upper leg left	77	9.2	11
				Lower leg right	81	2.7	3
				Upper leg right	110	7.6	6
				Lower arm left	8.2	0.2	2
				Upper arm left	7.1	0.2	2
				Lower arm right	5.6	2.0	26
				Upper arm right	4.4	0.1	2
				Hood	8.3	2.3	22
				Front torso	14	3.8	21
				Back torso	25	1.3	5
				Left glove		12	
				Right glove		1.1	

Where ND = none detected, i.e. < 0.1 μg for permethrin-based pesticides
- = no penetration factor calculated

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount inside (mg)	Penetration Factor
6	B	Kleenguard	1	Lower leg left	26	0.2	1
				Upper leg left	26	ND	-
				Lower leg right	6.4	ND	-
				Upper leg right	16	ND	-
				Lower arm left	10	ND	-
				Upper arm left	5.2	0.2	3
				Lower arm right	4.0	ND	-
				Upper arm right	1.8	ND	-
				Hood	1.7	0.1	6
				Front torso	2.8	ND	-
				Back torso	7.1	ND	-
				Left glove		0.1	
				Right glove		0.1	
6	B	Kleenguard	2	Lower leg left	1.6	0.5	24
				Upper leg left	5.3	3.0	36
				Lower leg right	1.7	0.4	19
				Upper leg right	26	3.0	10
				Lower arm left	0.2	0.1	35
				Upper arm left	0.3	ND	-
				Lower arm right	1.1	0.4	25
				Upper arm right	ND	ND	-
				Hood	ND	0.1	-
				Front torso	ND	ND	-
				Back torso	ND	ND	-
				Left glove		1.4	
				Right glove		0.3	

Where ND = none detected, i.e. < 0.1 μg for permethrin-based pesticides
- = no penetration factor calculated

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount inside (mg)	Penetration Factor
8	D	Polyester cotton	1	Lower leg left	ND	ND	-
				Upper leg left	ND	ND	-
				Lower leg right	ND	ND	-
				Upper leg right	1.7	ND	-
				Lower arm left	0.3	ND	-
				Upper arm left	0.2	ND	-
				Lower arm right	0.2	0.5	69
				Upper arm right	ND	ND	-
				Hood	0.4	ND	-
				Front torso	ND	ND	-
				Back torso	0.6	ND	-
				Left glove		ND	
				Right glove		ND	
8	D	Polyester cotton	2	Lower leg left	ND	ND	-
				Upper leg left	ND	ND	-
				Lower leg right	ND	ND	-
				Upper leg right	1.7	ND	-
				Lower arm left	0.1	ND	-
				Upper arm left	ND	ND	-
				Lower arm right	ND	ND	-
				Upper arm right	ND	ND	-
				Hood	ND	ND	-
				Front torso	ND	ND	-
				Back torso	ND	ND	-
				Left glove		ND	
				Right glove		ND	

Where ND = none detected, i.e. < 0.1 μg for permethrin-based pesticides
- = no penetration factor calculated

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount inside (mg)	Penetration Factor
9	D	Tyvek	1	Lower leg left	2.1	ND	-
				Upper leg left	1.8	ND	-
				Lower leg right	1.5	ND	-
				Upper leg right	0.2	ND	-
				Lower arm left	0.5	ND	-
				Upper arm left	0.2	ND	-
				Lower arm right	0.5	ND	-
				Upper arm right	ND	ND	-
				Hood	ND	ND	-
				Front torso	ND	ND	-
				Back torso	5.8	ND	-
				Left glove		ND	
				Right glove		ND	
9	D	Tyvek	2	Lower leg left	ND	ND	-
				Upper leg left	ND	ND	-
				Lower leg right	ND	ND	-
				Upper leg right	0.6	ND	-
				Lower arm left	ND	ND	-
				Upper arm left	ND	ND	-
				Lower arm right	0.4	ND	-
				Upper arm right	0.1	ND	-
				Hood	ND	ND	-
				Front torso	ND	ND	-
				Back torso	ND	ND	-
				Left glove		ND	
				Right glove		ND	

Where ND = none detected, i.e. < 0.1 μg for permethrin-based pesticides
- = no penetration factor calculated

Boron-based pesticides

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount inside (mg)	Penetration Factor
7	C	Polyester cotton	1	Lower leg left	4.1	0.02	0.4
				Upper leg left	43	ND	-
				Lower leg right	9.5	0.1	1
				Upper leg right	75	ND	-
				Lower arm left	14	ND	-
				Upper arm left	7.2	ND	-
				Lower arm right	25	0.03	0.1
				Upper arm right	7.6	ND	-
				Hood	3.7	0.1	3
				Front torso	4.5	ND	-
				Back torso	11	ND	-
				Left glove		0.3	
				Right glove		0.5	
7	C	Tyvek	2	Lower leg left	5.4	3.3	38
				Upper leg left	680	4.0	1
				Lower leg right	7.2	0.2	2
				Upper leg right	270	0.2	0.1
				Lower arm left	14	0.03	0.2
				Upper arm left	4.2	0.03	1
				Lower arm right	13	0.06	0.5
				Upper arm right	6.0	ND	-
				Hood	1.0	2.9	75
				Front torso	85	0.6	1
				Back torso	6.2	0.03	0.5
				Left glove		0.3	
				Right glove		0.3	

Where ND = none detected, i.e. < 6 µg for boron-based pesticides
- = no penetration factor calculated

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount inside (mg)	Penetration Factor
10	C	Kleenguard	1	Lower leg left	1.1	0.4	28
				Upper leg left	5.7	0.3	6
				Lower leg right	0.4	0.4	52
				Upper leg right	19	0.4	2
				Lower arm left	2.5	0.2	6
				Upper arm left	2.7	0.01	0.3
				Lower arm right	4.3	0.3	6
				Upper arm right	2.7	ND	-
				Hood	1.1	0.3	23
				Front torso	24	0.3	1
				Back torso	21	0.3	1
				Left glove		1.5	
				Right glove		0.6	
11	E	Kleenguard	1	Lower leg left	1.8	0.2	8
				Upper leg left	1.0	0.1	11
				Lower leg right	2.3	0.1	6
				Upper leg right	1.6	0.1	7
				Lower arm left	1.1	ND	-
				Upper arm left	0.2	ND	-
				Lower arm right	2.4	0.01	0.2
				Upper arm right	2.3	ND	-
				Hood	ND	0.2	-
				Front torso	2.2	0.04	2
				Back torso	0.9	0.8	46
				Left glove		0.7	
				Right glove		0.2	

Where ND = none detected, i.e < 6 µg for boron-based pesticides
- = no penetration factor calculated

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount inside (mg)	Penetration Factor
12	E	Polyester cotton	1	Lower leg left	4.0	0.2	5
				Upper leg left	6.0	0.1	2
				Lower leg right	7.7	ND	-
				Upper leg right	1.5	ND	-
				Lower arm left	0.8	ND	-
				Upper arm left	0.7	ND	-
				Lower arm right	4.3	ND	-
				Upper arm right	2.2	ND	-
				Hood	ND	ND	-
				Front torso	2.6	ND	-
				Back torso	0.9	ND	-
				Left glove		0.6	
				Right glove		0.4	
13	E	Tyvek	1	Lower leg left	1.8	0.4	16
				Upper leg left	3.7	0.7	15
				Lower leg right	1.8	0.4	18
				Upper leg right	0.6	0.5	47
				Lower arm left	2.8	0.03	1
				Upper arm left	2.4	ND	-
				Lower arm right	9.0	ND	-
				Upper arm right	8.0	ND	-
				Hood	0.1	0.1	53
				Front torso	5.4	1.1	17
				Back torso	1.7	0.3	13
				Left glove		0.9	
				Right glove		0.6	

Where ND = none detected, i.e. < 6 μg for boron-based pesticides
- = no penetration factor calculated

Appendix 6

Quantity of fluid outside and inside suits for each suit section

Permethrin-based pesticides

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount inside (mg)
1	Pilot	Tyvek	1	Lower leg left	8.5	1.0
				Upper leg left	12	0.1
				Lower leg right	7.7	1.0
				Upper leg right	9.5	ND
				Lower arm left	7.0	0.1
				Upper arm left	9.0	ND
				Lower arm right	4.4	0.1
				Upper arm right	5.6	ND
				Hood	2.0	0.1
				Front torso	10	ND
				Back torso	6.3	0.3
				Left glove		ND
				Right glove		ND
1	Pilot	Tyvek	2	Lower leg left	1.4	0.4
				Upper leg left	17	0.2
				Lower leg right	1.6	0.2
				Upper leg right	4.5	0.3
				Lower arm left	2.9	ND
				Upper arm left	7.4	ND
				Lower arm right	0.3	ND
				Upper arm right	2.3	0.00
				Hood	0.5	0.6
				Front torso	8.3	0.1
				Back torso	2.1	0.3
				Left glove		ND
				Right glove		ND

Where ND = none detected, i.e. < 0.1 μg for permethrin-based pesticides

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount Inside (mg)
2	A	Tyvek	1	Lower leg left	19	3.3
				Upper leg left	40	17
				Lower leg right	24	4.8
				Upper leg right	44	20
				Lower arm left	1.8	0.7
				Upper arm left	1.6	0.3
				Lower arm right	2.2	1.3
				Upper arm right	1.7	0.3
				Hood	1.0	2.5
				Front torso	6.5	31
				Back torso	4.8	4.3
				Left glove		0.4
				Right glove		0.4
3	A	Polyester cotton	1	Lower leg left	0.5	0.09
				Upper leg left	3.6	0.1
				Lower leg right	0.4	0.2
				Upper leg right	4.0	ND
				Lower arm left	0.1	0.02
				Upper arm left	ND	ND
				Lower arm right	0.03	0.03
				Upper arm right	ND	0.01
				Hood	ND	0.1
				Front torso	0.03	0.2
				Back torso	ND	ND
				Left glove		3.7
				Right glove		3.6

Where ND = none detected, i.e. < 0.1 μg for permethrin-based pesticides

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount inside (mg)
4	A	Kleenguard	1	Lower leg left	0.4	ND
				Upper leg left	5.3	ND
				Lower leg right	0.8	ND
				Upper leg right	1.9	ND
				Lower arm left	0.6	ND
				Upper arm left	0.3	ND
				Lower arm right	0.2	ND
				Upper arm right	0.2	ND
				Hood	0.3	0.3
				Front torso	ND	ND
				Back torso	ND	ND
				Left glove		0.1
				Right glove		ND
5	A	Kleenguard	1	Lower leg left	84	1.5
				Upper leg left	37	4.4
				Lower leg right	39	1.3
				Upper leg right	52	3.6
				Lower arm left	3.9	0.1
				Upper arm left	3.4	0.1
				Lower arm right	2.7	1.0
				Upper arm right	2.1	0.05
				Hood	4.0	1.1
				Front torso	6.9	1.8
				Back torso	12	0.6
				Left glove		5.9
				Right glove		0.5

Where ND = none detected, i.e. < 0.1 µg for permethrin-based pesticides

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount inside (mg)
6	B	Kleenguard	1	Lower leg left	14	0.1
				Upper leg left	14	ND
				Lower leg right	3.4	ND
				Upper leg right	8.3	ND
				Lower arm left	5.5	ND
				Upper arm left	2.7	0.1
				Lower arm right	2.1	ND
				Upper arm right	1.0	ND
				Hood	0.9	0.1
				Front torso	1.5	ND
				Back torso	3.7	ND
				Left glove		0.1
				Right glove		0.1
6	B	Kleenguard	2	Lower leg left	0.8	0.3
				Upper leg left	2.8	1.6
				Lower leg right	0.9	0.2
				Upper leg right	14	1.6
				Lower arm left	0.1	0.05
				Upper arm left	0.2	ND
				Lower arm right	0.6	0.2
				Upper arm right	ND	ND
				Hood	ND	0.05
				Front torso	ND	ND
				Back torso	ND	ND
				Left glove		0.7
				Right glove		0.2

Where ND = none detected, i.e. < 0.1 μg for permethrin-based pesticides

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount inside (mg)
8	D	Polyester cotton	1	Lower leg left	ND	ND
				Upper leg left	ND	ND
				Lower leg right	ND	ND
				Upper leg right	130	ND
				Lower arm left	19	ND
				Upper arm left	12	ND
				Lower arm right	17	37
				Upper arm right	ND	ND
				Hood	28	ND
				Front torso	ND	ND
				Back torso	47	ND
				Left glove		ND
				Right glove		ND
8	D	Polyester cotton	2	Lower leg left	ND	ND
				Upper leg left	ND	ND
				Lower leg right	ND	ND
				Upper leg right	130	ND
				Lower arm left	8.7	ND
				Upper arm left	ND	ND
				Lower arm right	ND	ND
				Upper arm right	ND	ND
				Hood	ND	ND
				Front torso	ND	ND
				Back torso	ND	ND
				Left glove		ND
				Right glove		ND

Where ND = none detected, i.e. < 0.1 μg for permethrin-based pesticides

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount inside (mg)
9	D	Tyvek	1	Lower leg left	160	ND
				Upper leg left	140	ND
				Lower leg right	120	ND
				Upper leg right	18	ND
				Lower arm left	35	ND
				Upper arm left	18	ND
				Lower arm right	36	ND
				Upper arm right	ND	ND
				Hood	ND	ND
				Front torso	ND	ND
				Back torso	450	ND
				Left glove		ND
				Right glove		ND
9	D	Tyvek	2	Lower leg left	ND	ND
				Upper leg left	ND	ND
				Lower leg right	ND	ND
				Upper leg right	48	ND
				Lower arm left	ND	ND
				Upper arm left	ND	ND
				Lower arm right	28	ND
				Upper arm right	7.9	ND
				Hood	ND	ND
				Front torso	ND	ND
				Back torso	ND	ND
				Left glove		ND
				Right glove		ND

Where ND = none detected, i.e. < 0.1 μg for permethrin-based pesticides

Boron-based pesticides

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount Inside (mg)
7	C	Polyester cotton	1	Lower leg left	0.2	<0.01
				Upper leg left	2.6	ND
				Lower leg right	0.6	0.01
				Upper leg right	4.5	ND
				Lower arm left	0.9	ND
				Upper arm left	0.4	ND
				Lower arm right	1.5	<0.01
				Upper arm right	0.5	ND
				Hood	0.2	0.01
				Front torso	0.3	ND
				Back torso	0.7	ND
				Left glove		0.02
				Right glove		0.03
7	C	Tyvek	2	Lower leg left	0.3	0.2
				Upper leg left	41	0.2
				Lower leg right	0.4	0.01
				Upper leg right	16	0.01
				Lower arm left	0.8	<0.01
				Upper arm left	0.3	0.00
				Lower arm right	0.8	0.00
				Upper arm right	0.4	ND
				Hood	0.1	0.2
				Front torso	5.1	0.04
				Back torso	0.4	<0.01
				Left glove		0.03
				Right glove		0.02

Where ND = none detected, i.e. < 6 μg for boron-based pesticides

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount inside (mg)
10	C	Kleenguard	1	Lower leg left	0.1	0.02
				Upper leg left	0.3	0.02
				Lower leg right	0.02	0.02
				Upper leg right	1.1	0.02
				Lower arm left	0.1	0.01
				Upper arm left	0.2	<0.01
				Lower arm right	0.2	0.02
				Upper arm right	0.2	ND
				Hood	0.1	0.02
				Front torso	1.4	0.02
				Back torso	1.2	0.02
				Left glove		0.09
				Right glove		0.03
11	E	Kleenguard	1	Lower leg left	0.1	0.01
				Upper leg left	0.05	0.01
				Lower leg right	0.1	0.01
				Upper leg right	0.1	0.01
				Lower arm left	0.05	ND
				Upper arm left	0.01	ND
				Lower arm right	0.1	<0.01
				Upper arm right	0.1	ND
				Hood	ND	0.01
				Front torso	0.1	0.00
				Back torso	0.04	0.03
				Left glove		0.03
				Right glove		0.01

Where ND = none detected, i.e. < 6 μg for boron-based pesticides

Survey	Company	Suit	Subject	Section	Amount outside (mg)	Amount Inside (mg)
12	E	Polyester cotton	1	Lower leg left	0.2	0.01
				Upper leg left	0.3	0.01
				Lower leg right	0.3	ND
				Upper leg right	0.1	ND
				Lower arm left	0.04	ND
				Upper arm left	0.03	ND
				Lower arm right	0.2	ND
				Upper arm right	0.1	ND
				Hood	ND	ND
				Front torso	0.1	ND
				Back torso	0.04	ND
				Left glove		0.03
				Right glove		0.02
13	E	Tyvek	1	Lower leg left	0.1	0.02
				Upper leg left	0.2	0.03
				Lower leg right	0.1	0.02
				Upper leg right	0.03	0.02
				Lower arm left	0.1	<0.01
				Upper arm left	0.1	ND
				Lower arm right	0.4	ND
				Upper arm right	0.4	ND
				Hood	0.01	0.01
				Front torso	0.3	0.1
				Back torso	0.1	0.01
				Left glove		0.04
				Right glove		0.03

Where ND = none detected, i.e. < 6 μg for boron-based pesticides

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