Fluorescent Tracer Evaluation of Chemical Protective Clothing during Pesticide Applications in Central Florida Citrus Groves

R. A. Fenske, S. G. Birnbaum, M. M. Methner, C. Lu, H. N. Nigg

Abstract

Chemical protective clothing (CPC) is often recommended as a method of exposure mitigation among pesticide applicators. This study evaluated four CPC regimens (cotton work shirts and work pants, cotton/polyester coveralls, and two non–woven garments) during 33 airblast applications of the organophosphorus insecticide ethion in central Florida citrus groves. CPC performance was determined by measurement of fluorescent tracer deposition on skin surfaces beneath garments with a video imaging analysis instrument (VITAE system), and by alpha–cellulose patches placed outside and beneath the garments.

Non–woven coveralls allowed significantly greater exposure than did traditional woven garments, primarily because of design factors (e.g., large sleeve and neck openings). The greatest exposure occurred on the forearms beneath the non–woven garments. Fabric penetration was detected for all test garments; 5% to 7% of the ethion measured outside the garments was found beneath the garments. The clothing materials tested were not chemically resistant under these field conditions. Exposure pathways that would probably be undetected by the patch technique were characterized effectively with fluorescent tracers and video imaging analysis. However, the patch technique was more sensitive in detecting fabric penetration. CPC garments have been improved since this study was conducted, but performance testing under field conditions is not widespread. Workers conducting airblast applications would be better protected by closed cab systems or any technology that places an effective barrier between the worker and the pesticide spray.

***Keywords**. Pesticides, Protective clothing, Orchard sprayers, Application, Pest control, Dermal exposure, Fluorescent tracers.*

Workplace chemical exposures can be controlled through engineering and administrative techniques, and through use of chemical protective clothing (Harris et al., 2000). Chemical protective clothing (CPC) remains

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a common control option in reducing occupational exposure to pesticides, since in many agricultural settings closed mixing systems, closed cabs, and other engineering control approaches are not feasible. Clothing and other personal protective equipment (PPE) that can substantially reduce pesticide contact with the skin and that can be worn comfortably during normal work activities is needed in the workplace (Easter and Nigg et al., 1992; Nielsen and Moraski, 1986).

The ability of chemical protective clothing to reduce dermal exposure is dependent both on low fabric penetration properties and proper design (DeJonge and Easter, 1989). Evaluation of protective clothing has traditionally been divided into two phases: laboratory testing and field performance testing. Laboratory testing can provide information regarding pesticide penetration through fabric, but only field testing under realistic exposure conditions can determine the overall efficiency of penetration reduction and design (Evans et al., 2001; Methner and Fenske, 1994; Nigg et al., 1993). Penetration characteristics of fabrics can be altered dramatically during field use by worker activities that may affect movement of dusts through fabric weave, by direct contact between the clothing and body that enhances movement of liquids through fabric, and by sweating that may change penetration rates in unpredictable ways. Design factors that enhance or reduce exposure are only evident during field use of the clothing.

Current methods used to evaluate protective clothing performance are most often laboratory–based simulations (Canning et al., 1998; Evans et al., 2001). In regard to field measurements, the patch technique places collection pads above and beneath clothing in close proximity to one another to estimate garment penetration. This approach assumes that exposure of the body region under study is relatively uniform, although this is not always the case (Fenske, 1990). Exposure may also occur in ways that patch sampling overlooks, e.g., at garment openings (Fenske, 1988a). The use of fluorescent tracers and video imaging provides an opportunity to examine patterns of exposure visually under realistic field performance conditions (Archibald et al., 1995; Bierman et al., 1998; Fenske et al., 1986a, 1986b; Kross et al., 1996; Methner and Fenske, 1994).

The objective of the study was to evaluate the performance of conventional and test garments in reducing pesticide exposure during airblast applications using both the patch and fluorescent tracer techniques. The work presented here is based on field studies conducted in 1988 and 1989 in central Florida citrus groves. A report of this work was prepared for the U.S. Environmental Protection Agency (U.S. EPA, 1993). Improvements have occurred in the quality of CPC fabrics and garment design since that time, but many garments currently available to pesticide applicators are similar to those tested in this study (Gempler’s, 2001). There remain no well–recognized or systematic procedures for chemical protective clothing evaluation under actual field use conditions.

Methods

Study Design

Four garment types were selected for study. Two were traditional garments used in agriculture (workshirt/workpants, woven coveralls) and two were made from nonwoven fabrics selected by U.S. EPA investigators based on their potential for providing both protection and comfort in hot environments. Eight replicate exposures of each garment were proposed based on a previous study that indicated statistical differences in garment performance with a similar sample size (Fenske, 1988b). Each applicator in the study wore each of the garments at least once to minimize potential confounding due to personal work practices. Equipment type, tank size, and amount of fluorescent tracer applied per tank were controlled for all applications. Uncontrolled variables included number of tanks applied, application time, and individual work practices.

Field Conditions

Field studies were conducted at two central Florida citrus cooperatives during the summer months (July, August). The pesticide formulation applied was Ethion 4 Miscibl (EPA Reg. No. 279–1254), a liquid concentrate formulation containing 4 lbs active ingredient (AI)/gal (46.5% AI by weight). The active ingredient is the organophosphorus insecticide ethion [0,0,0',0'–tetraethyl S,S'–methylene bisphosphorodithioate]. The procedures employed in the study were reviewed and approved by the Rutgers University Human Subjects Committee. All subjects were adult males who applied pesticides as part of their normal work duties. They read and signed a consent form prior to participating in the study and were paid a nominal sum for each day of participation. Each applicator was given a black cotton T–shirt, black athletic shorts, and one of the protective garments to wear. Mixers were not monitored during this study. All participants were provided with chemical resistant gloves during the study.

Four protective garments were evaluated:

- Cotton workshirt/workpants (woven) made of a 100% cotton twill material (twill woven construction); thickness = 19.0 mils; weight = 243 g/m^2; untreated; 23 cm sleeve circumference (when buttoned).
- Cotton/polyester coveralls (woven) made of a 65% cotton/35% polyester twill material (twill woven construction); thickness = 19.0 mils; weight = 243 g/m^2; untreated; 30 cm sleeve circumference.
- SMS coveralls (nonwoven, Kimberly Clark) made of a 100% polypropylene composite material with three–layered construction (thermally point–bonded laminate of spun–bonded, melt blown, spun–bonded fabric); thickness = 11.8 mils; weight = 62 g/m^2; treated with a repellent finish (Kimberly–Clark RF), exact commercial formulation unknown; 44 cm sleeve circumference.
- Sontara coveralls (nonwoven, DuPont) made of 50% polyester/50% wood pulp material with both point–bonded and spun–bonded construction (spunlaced composite); thickness = 12.6 mils; weight = 72 g/m^2; treated with a repellent finish (DuPont RF), exact commercial formulation unknown; 44 cm sleeve circumference.

These fabrics were chosen based on heat stress and pesticide protection potential (Nigg et al., 1992).

The Ethion 4 Miscible formulation was applied throughout the study according to label instructions. The amount of formulated ethion added to each 500 gal tank varied between the two cooperatives. Typically, the mixer measured the ethion formulation into a bucket and then poured this bucket into the mixing tank. The tank was filled with water, mixed by mechanical agitation, and pumped into the applicators' spray tank.

Cooperative A utilized a 1,000 gal mixing tank, allowing one mixer to supply two applicators. Cooperative B utilized 500 gal mixing tanks, requiring two mixers to supply two applicators. Both cooperatives utilized airblast sprayers with 500 gal tanks. The sprayers were pulled by tractors equipped with a top canopy for shade. The sides and back of the tractor were covered by a metal screen to protect the workers from branches. The front of the tractor was open. Several of the workers covered a portion of the side/back screens with a water–resistant cloth to block the spray (they found the spray mixture oily and sticky). Some of the workers from cooperative A used sprayers that utilized electronic photocells to detect the presence and size of trees. The sprayer would automatically turn nozzles off and on as needed. Workers from both cooperatives who used tractors that did not contain the electronic photocells could manually turn off the nozzles on the left, right, or top of the sprayer as needed. Each worker was monitored during application of four 500–gallon tanks. Spraying was occasionally terminated before all four tanks had been applied due to rain.

Fluorescent Tracer Sampling

A commercially available fluorescent whitening agent, 4–methyl–7–diethylaminocoumarin (Calcofluor RWP), was employed as a tracer of pesticide residue deposition. This compound has been used previously as a tracer in orchard airblast applications (Fenske et al., 1985; Fenske, 1988a). A pre–measured bag (300 g) of the fluorescent tracer was mixed into a bucket containing the ethion formulation. If no ethion was to be applied, then the tracer was instead mixed into a small amount of natural oil (93% vegetable oil, Stoller Inc., Houston, Texas). Thus, the tracer concentration in the spray mix was constant throughout the studies (300 g per 500 gal H_2O; 160 ppm), despite changes in ethion application rates.

A video imaging system (VITAE) was housed in a mobile laboratory. The design and function of the VITAE system has been described in detail elsewhere (Fenske and Birnbaum, 1997). Pre–exposure video images were acquired of each subject on the first day the subject was studied. At the end of spraying, the applicators were brought to the mobile laboratory where protective garments and T–shirts were removed by study staff, and post–exposure video images were acquired.

Video images were acquired of the hands, head, neck, forearms, upper arms, upper torso, and lower torso of each worker during each video imaging session. Four views (front, back, left, and right) were acquired of the head, both forearms, and the lower torso. Three views (front, back, and outer) were acquired for both upper arms. The inner view of this region was not collected due to difficulties in positioning subjects and due to previous observations that little or no exposure occurs on this area during pesticide applications (Fenske, 1988b). Two views (front and back) were acquired for the upper torso and both hands. An image of the front of the neck was acquired for several, but not all of the workers. Images of the legs were not acquired since some workers were reluctant to participate in the video imaging procedures for regions below the waist. Individuals who participated more than once in the study waited at least three days before repeating as subjects in order to ensure that tracer from a previous exposure did not remain on the skin. This waiting period was found to be adequate in a previous study (Fenske, 1988b). No residual tracer was observed on subjects used on a repeat basis during the study.

Fluorescent tracer deposition patterns were also evaluated and scored qualitatively for each body part/view according to a modification of a visual scoring system (Fenske, 1988c). Each view was assigned a score of 0 to 3 based on the intensity and extent of deposition on the skin, where 0 = no visually observed tracer; 1 = low–level tracer visible, near the imaging system's limit of detection; 2 = tracer clearly visible, detectable by imaging system; and 3 = tracer highly visible, easily detectable by imaging system. Scores for views were summed for each body part (i.e., face, forearms, upper arms, torso) to allow comparisons among workers and garments.

These scores were also employed as part of the quality assurance procedures for video imaging evaluation.

Patch Sampling

Dermal patches were not employed to estimate exposure by traditional methods (e.g., U.S. EPA, 1987). Rather, they were employed to estimate protective clothing penetration. Four 103.2 cm^2 (16 in^2) square alpha–cellulose patches were pinned to the protective clothing of each worker: two were attached at the front of the thighs (one per thigh) on the inside of the protective garment, and two were attached on the outside immediately adjacent to (but not overlapping) the inner patches. After the worker completed spraying his last tank, the patches were removed, immediately wrapped in foil, and placed in an ice–chest with ice for transport to the University of Florida Lake Alfred Experiment Station laboratory for storage.

Imaging Analysis

Two custom written C–language software programs (VITAE–Map and VITAE–Calc) were used to analyze the digital images. These analytical procedures are described in detail elsewhere (Fenske and Birnbaum, 1997). The accuracy and precision of the video imaging system were monitored continuously in the field throughout sample collection. Images of a standard target of known brightness were acquired immediately prior to and immediately following each imaging session for each worker. The imaging system performed in a very stable manner (<5% variability) throughout the entire data collection period. The limit of detection for image samples in this study was 35 ng of tracer per cm^2 of exposed skin surface.

Patch Analysis

Patch samples were extracted in an acetone/hexane solvent mixture, and analyzed for ethion at the University of Florida Lake Alfred Experiment Station laboratory by electron capture gas chromatography. Extraction efficiency of fortified patch samples (10 µg of ethion per patch) was 93% ±2% (n = 12). Recovery from patches fortified in the field was 90% ±2% (n = 28). Field blank samples (n = 30) were below the limit of detection (<0.0025 $\mu g/cm^2$). All laboratory blank samples were below the limit of detection. Storage stability of sample pads and extracts were tested, and no losses were noted.

Results

Thirty–three applications were monitored involving six workers: 9 in which Sontara was worn, and 8 each in which the other three garments were worn. The number of 500 gal tanks applied varied from 1.5 to 4, with one worker spraying 1.5 tanks, four workers spraying 3 tanks, and the remaining 28 workers spraying 4 tanks. Tracer concentration was maintained at 300 g/tank for all applications, but ethion concentration varied substantially. In 8 cases, no ethion was used (pest control practices dictated use of another insecticide or no insecticide on these days). In 14 cases, the rate was 5 pints (Ethion 4 Miscible)/tank, and in the remaining 11 cases the rate was 12 pints/tank. The total amount of tracer and ethion AI applied thus varied from 0.4 to 1.2 and from 0 to 10.9 kg, respectively. No effect was observed from using the same worker for several applications, so all applications were treated as independent events for statistical purposes.

Imaging Analysis

Fluorescent tracer exposure measurements produced by video imaging analysis were normalized to reflect a standard application of four tanks. These normalized values were then divided by 1.1 hr, the average time required to apply the four tanks. Examination of hourly exposure values (table 1) indicated that tracer exposure beneath protective clothing was greatest for the forearms in all cases. These data also indicated that the forearm exposure rate was lowest for the workshirt (34 µg/hr), and that the cotton/polyester coverall was lower than either of the nonwoven coveralls (64 µg/hr for C/P coveralls vs. 87 and 93 µg/hr for SMS and Sontara garments, respectively). A similar exposure pattern was observed for the upper arms, but was not evident for the torso. Variability within each garment group was very high for all body regions, with coefficients of variation ranging from 89% to 260%. Neither parametric (ANOVA) nor nonparametric (Kruskal–Wallis) tests between garment types yielded significant differences for any body region.

A substantial amount of the variability observed across garment types was believed to be due to differences in garment challenge (i.e., the amount of fluorescent tracer reaching the outside of the garments and the exposed skin surfaces). Head exposure provided an indication of the fluorescent tracer challenge that each worker received during application, since none of the workers wore personal protective equipment for this region. Exposure data for the forearms, upper arms, and torso were therefore normalized by a challenge adjustment factor (ratio of group mean head exposure and each individual's head exposure). Forearm, upper arm, and torso exposure values were multiplied by this adjustment factor to produce normalized

Table 1. Video imaging analysis of fluorescent tracer exposure (µg/hr).[a]

Body Region	Garment Type	N	Mean	Median	Range	CV (%)[b]
Forearm	WS/WP[c]	8	33.8	32.8	2 – 73	74
	C/P coverall[d]	8	64.4	70.1	2 – 170	89
	SMS[e]	8	86.7	39.9	4 – 214	102
	Sontara[f]	9	92.8	44.2	9 – 362	124
Upper arm	WS/WP	8	1.4	0.4	0 – 7	169
	C/P coverall	8	12.3	0.3	0 – 92	260
	SMS	8	17.9	7.9	0 – 100	88
	Sontara	9	21.5	7.5	1 – 96	149
Torso	WS/WP	8	19.7	9.9	0 – 82	140
	C/P coverall	8	37.2	12.1	2 – 168	155
	SMS	8	22.0	3.8	1 – 127	196
	Sontara	9	29.5	4.4	0 – 139	163

[a] Data have been normalized to application of 4 tanks per subject (exposure × 4/No. of tanks applied) and by time applied.

[b] CV = coefficient of variation (= standard deviation/mean × 100).

[c] WS/WP = 100% cotton work shirt and 100% cotton work pants.

[d] C/P coverall = 65% cotton/35% polyester coveralls.

[e] SMS = trade name for 100% polypropylene composite material with three–layer construction (thermally point–bonded laminate of spun–bonded, melt blown, spun–bonded fabric).

[f] Sontara = trade name for nonwoven 50% polyester/50% wood pulp material with both point–bonded and spun–bonded construction.

exposure data for these body regions. The adjustment resulted in a decrease in the coefficient of variation in 10 of 12 cases, with the range of CVs reduced from 74% to 260% (table 1) to 64% to 192% (table 2).

The pattern of exposure between woven and non–woven garments remained similar to that observed in the original data set, but the pattern within non–woven garments was altered such that the SMS garment exhibited higher adjusted exposure than the Sontara garment for all body regions. Statistical analysis of the challenge–adjusted data by the Kruskal–Wallis test (non–parametric analysis of variance) produced several findings (table 3). Forearm exposure was significantly higher for the SMS garment than for the other three garments. Forearm exposure was also significantly higher for the Sontara garment than for the woven garments. Upper arm exposure was significantly higher for the Sontara garment than for the two woven garments. Upper arm exposure was higher for the SMS garment than for the workshirt/workpants, with marginal statistical significance. No significant differences in torso exposure were observed. The detection of high levels of tracer on the forearms for the nonwoven garments suggests that dermal exposure occurred by spray entering through the sleeve opening. The detection of relatively high levels of tracer

Table 2. Challenge–adjusted fluorescent tracer exposure metric by garment type.[a]

Garment Type	N	Forearm		Upper Arm		Torso	
		Mean	CV (%)[b]	Mean	CV (%)	Mean	CV (%)
WS/WP[c]	8	46.2	64	1.7	149	30.9	97
C/P coverall[d]	8	56.3	108	4.1	192	24.5	70
SMS[e]	8	389	89	108	138	82.0	154
Sontara[f]	9	110	71	19.8	82	39.9	131

[a] Exposure metric has been calculated from data in table 1 normalized by group mean head exposure (unitless).

[b] CV = coefficient of variation (= standard deviation/mean × 100).

[c] WS/WP = 100% cotton work shirt and 100% cotton work pants.

[d] C/P coverall = 65% cotton/35% polyester coveralls.

[e] SMS = trade name for 100% polypropylene composite material with three–layer construction (thermally point–bonded laminate of spun–bonded, melt blown, spun–bonded fabric).

[f] Sontara = trade name for nonwoven 50% polyester/50% wood pulp material with both point–bonded and spun–bonded construction.

Table 3. Nonparametric analysis of variance of garment types by body region.

Garment Comparison[a]	Kruskal–Wallis P–Values		
	Forearm	Upper Arm	Torso
WS/WP = C/P coveralls	NSD[b]	NSD	NSD
SMS > WS/WP	0.001	0.09	NSD
SMS > C/P coveralls	0.002	NSD	NSD
SMS > Sontara	0.02	NSD	NSD
Sontara > WS/WP	0.03	0.004	NSD
Sontara > C/P coveralls	0.02	0.01	NSD

[a] Abbreviations for garment types: WS/WP = 100% cotton work shirt and 100% cotton work pants; C/P coverall = 65% cotton/35% polyester coveralls; SMS = trade name for 100% polypropylene composite material with three–layered construction (thermally point–bonded laminate of spun–bonded, melt blown, spun–bonded fabric); Sontara = trade name for nonwoven 50% polyester/50% wood pulp material with both point–bonded and spun–bonded construction.

[b] NSD = no significant difference; significance levels < 0.1 indicated in table.

on the upper arms for the Sontara garment suggests that both penetration and deposition through the sleeve opening contributed to exposure.

Visual Observations

Qualitative scores based on visual observations following application corresponded well to the imaging analysis results (figs. 1 and 2). Torso exposure was not significantly different across the garment types (ANOVA; $p < 0.05$), but both upper arm and forearm exposures were different. Qualitative scoring indicated even more pronounced differences between the woven and nonwoven garments for the arms, particularly the forearms. It was also apparent during visual observation that arm exposure decreased with increasing distance from the wrist (fig. 3), and that most torso exposure occurred beneath the garments near the neck (fig. 4). These observations suggest that, in the majority of cases, the tracer was transported to the skin by air movement *under* the garment rather than by passing through the fabric.

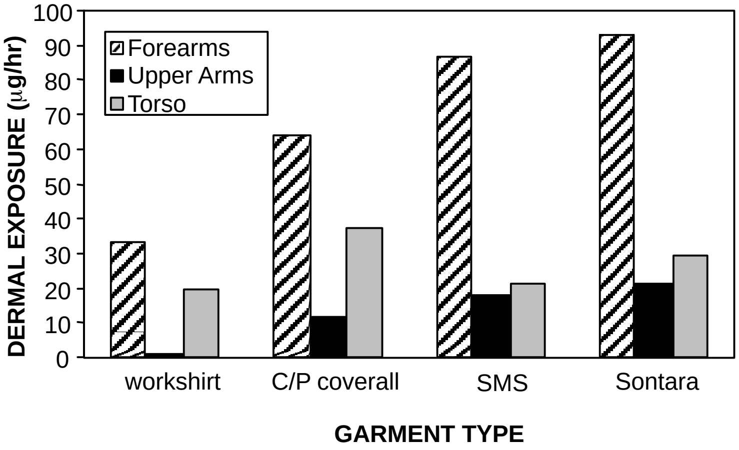

Figure 1. Video imaging analysis of fluorescent tracer exposure by garment type for three body regions.

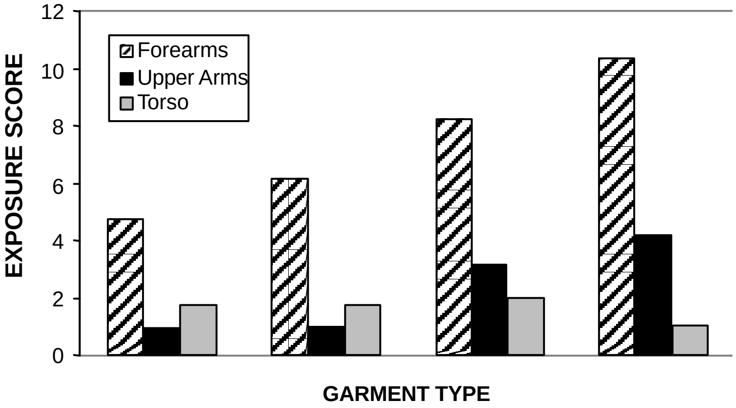

Figure 2. Qualitative evaluation of fluorescent tracer exposure by garment type for three body regions.

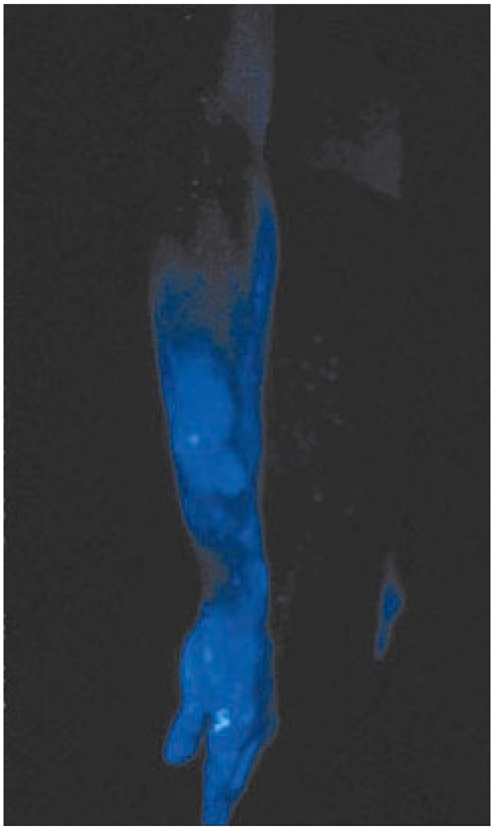

Figure 3. Fluorescent tracer deposition on the forearm beneath non–woven chemical protective garment. Tracer was transported to the skin by air movement under the garment due to large sleeve openings.

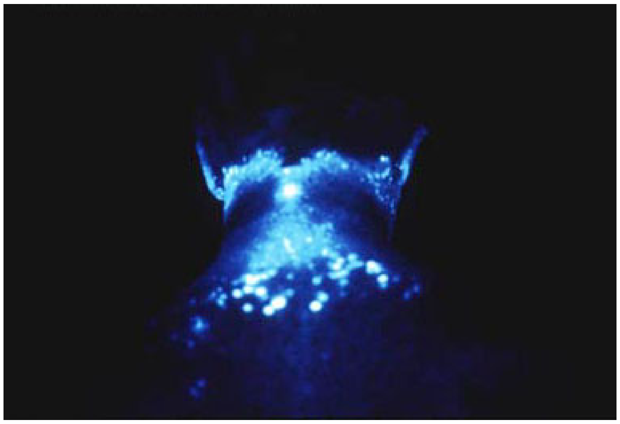

Figure 4. Fluorescent tracer deposition on neck and shoulders beneath chemical protective garment. Garment collar covered the neck and was unbuttoned in the front.

Ethion Penetration of Protective Clothing

Penetration of ethion through protective clothing was measured on the legs with inner and outer patch samplers (table 4). Mean ethion challenge (deposition on the outer patch sample) was similar for the three coverall garments, ranging from 14.0 to 32.3 μg/cm^2, but was much lower (1.44 μg/cm^2) for the workpants (Kruskal–Wallis; $p < 0.01$). Percent penetration was calculated by dividing the inner patch sampler value by the outer patch sampler value and multiplying by 100. Garment breakthrough occurred in all of the 23 applications for which complete data were available. Mean penetration values for the four garments ranged from 4.7% to 7.2% and did not differ significantly. Within each garment type the percent penetration was highly variable, suggesting that factors other than fabric content and construction contributed substantially to penetration under field conditions.

Discussion

Only a limited number of published studies have examined control strategies to prevent pesticide overexposure in workers (Keifer, 2000). The findings from this study demonstrate that field testing of CPC garments can provide useful information regarding CPC performance. Dermal exposures occurred due to both garment design and chemical breakthrough of fabric. No significant improvement in protection occurred when nonwoven garments were substituted for traditional woven garments. In this study, the nonwoven garments suffered from the most serious flaws in design and provided little, if any, increased resistance to chemical penetration. Improvements have been made in garment design and materials since the time of this study. Waterproof garments with hoods and sleeve closures are available, but they can be expensive (Gempler's, 2001). Garments with open neck and sleeve design are also available. It is not known whether any of these garments have been subjected to field testing under realistic use conditions.

The findings of this study are consistent with those of an earlier study of protective clothing performance during airblast applications (Fenske, 1988b). In that study, garment openings (neck and sleeves) were determined to be the major pathways for dermal exposure beneath coveralls. Findings regarding fabric penetration were also consistent with those of a study in which similar garments were tested with a similar applicator population (Nigg et al., 1992). In that study, no significant differences were demonstrated between woven and non–woven garments.

The use of fluorescent tracers and video imaging analysis clearly documented substantial exposure of the arms of workers wearing garments with large sleeve openings. When this design failure was rectified in follow–up studies (sleeve

Table 4. Ethion challenge and penetration to the legs (μg/cm^2).

		Challenge (μg/cm^2)[a]			% Penetration[b]	
Garment Type	N	Mean	Median	CV	Mean	Range
WS/WP	4	1.44[c]	1.22	77	7.2	2.6 – 19
C/P coveralls	4	14.0	6.74	110	4.7	0.5 – 9
SMS	7	32.3	19.6	104	4.8	0.1 – 12
Sontara	8	31.9	25.1	81	6.3	0.2 – 31

[a] Challenge = deposition on outer leg patch sampler (μg/cm^2).
[b] Percent penetration = inner patch / outer patch × 100.
[c] Challenge to workpants < all others (Kruskall–Wallis ANOVA: $p < 0.01$).

openings closed with tape), little tracer exposure could be detected on the protected body (U.S. EPA, 1993). It appears that the tracer/imaging analysis is most useful for measuring exposures occurring under rather than through the garments, and in detection of exposures that otherwise would have been undocumented by the patch technique.

The use of patches to detect fabric penetration was far more sensitive than tracer/imaging analysis. Low levels of tracer on skin were difficult to quantify by video imaging, while chemical analysis of patch extracts detected less than 10 ng/cm^2. The two techniques thus served complementary functions in documenting the limitations of chemical protective clothing performance. Fluorescent tracer measurement by video imaging analysis can be highly variable, and its accuracy has not yet been demonstrated (Fenske and Birnbaum, 1997). However, it does appear to be useful for comparative measurements (Methner and Fenske, 1994). In this study, the qualitative scoring system employed produced exposure patterns similar to those generated by imaging analysis.

Workplace chemical exposures are best controlled through engineering interventions, and personal protective equipment is normally viewed as a measure of ““last resort” (Harris et al., 2000). Thus, workers who conduct airblast applications would be best protected by closed cab systems or other technology that places an effective barrier between the worker and the pesticide spray. If CPC is used in lieu of such controls, then implementation of a CPC program should include procedures whereby employers and workers receive appropriate and ongoing education and training regarding its use.

Conclusion

Video imaging analysis or qualitative scoring of fluorescent tracer exposure can provide useful data regarding chemical protective clothing performance, in conjunction with the traditional patch technique. Deposition of pesticide spray through garment openings can be documented both visually and quantitatively with fluorescent tracers.

Protective garments designed and marketed for use by pesticide applicators should be field tested to determine performance. Traditional laboratory tests (e.g., permeability testing) cannot characterize the effects of garment design, and such tests may not be able to simulate the effects of field use on chemical breakthrough. Claims regarding the ability of garments to protect workers should be qualified unless performance has been demonstrated under realistic field conditions.

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