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FLUORESCENT TRACER EVALUATION OF PROTECTIVE CLOTHING PERFORMANCE

by

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FOREWORD

Today's rapidly developing and changing technologies and industrial products frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency is charged by Congress with protecting the nation's land, air, and water resources. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This publication describes a research project that investigated occupational exposure to pesticides and the role that personal protection can play in reducing such exposures. Fluorescent tracer analysis of dermal exposure was able to document significant problems associated with the design of chemical protective clothing currently available for agricultural workers, and provided guidance for design improvements.

Risk Reduction Engineering Laboratory
E. Timothy Oppelt, Director

ABSTRACT

Chemical protective clothing (CPC) is often employed as a primary control option to reduce occupational exposures during pesticide applications, but field studies evaluating CPC are limited. This study was designed to evaluate several protective garments and to determine the ability of specific CPC components to reduce worker exposure. The studies, conducted in central Florida during citrus applications of Ethion 4 Miscible™, examined cotton workshirts and workpants, cotton/polyester (C/P) coveralls, SMS coveralls, and Sontara coveralls. CPC performance was evaluated by fluorescent tracers and video imaging analysis and by the patch technique. Nonwoven coveralls allowed significantly greater exposure than did traditionally woven garments primarily because of design factors (*e.g.*, large sleeve openings). Fabric penetration occurred with high frequency for all test garments, and none can be considered chemically resistant under these field conditions. Improved coverall garments would, however, provide only a small further reduction in exposure. Faceshields would reduce the exposure approximately three times more than would improved coveralls. Exposure pathways that would probably be undetected or inaccurately quantified by the patch technique were measured by fluorescent tracers and imaging analysis. The patch technique, however, was far more sensitive in detecting fabric penetration.

Workers conducting airblast applications would be better protected by closed cab systems or any other technology that places a well-defined barrier between the worker and the pesticide spray. Personal protective equipment (PPE) requirements should consider the potential for heat stress, and conditions under which PPE is not to be used should be defined and enforced to reduce the risk of illness related to heat stress. Protective garments designed and marketed for use by pesticide applicators should be field tested to determine performance, and users should be provided with accurate information regarding the chemical resistance of such garments.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

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SECTION 1

INTRODUCTION

Chemical protective clothing (CPC) is a major control option in reducing occupational exposure to pesticides. In many agricultural settings closed mixing systems, closed cabs and other engineering control approaches are not feasible. Clothing and other personal protective equipment (PPE) which can substantially reduce pesticide contact with the skin and which can be worn comfortably during normal work activities is needed in the workplace (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. The U.S. Environmental Protection Agency has provided substantial support recently for research aimed at identifying appropriate protective garments for agricultural workers. 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. Penetration characteristics of fabrics may be altered dramatically during field use: 1) worker movements may affect movement of dusts through fabric weave, 2) direct contact between the clothing and body may enhance movement of liquids through fabric, 3) sweating may change penetration rates in unpredictable ways. Design factors which enhance or reduce exposure are only evident during field use of the clothing.

The methods currently employed to evaluate protective clothing performance in the field are limited. The patch technique places collection pads above and beneath clothing to estimate garment penetration. This approach can produce highly variable measurements, since pesticide exposure during applications is not uniform (Fenske *et al.* 1985; Fenske 1990). In many cases the patch will either be "hit" or missed altogether, producing misleading results regarding clothing performance. Exposure may also occur by means which patch sampling overlooks. Recent work has shown that a substantial portion of exposure to mixer/applicators wearing coveralls occurs through the garment openings; *i.e.*, sleeves and collar (Fenske 1988a). Exposure may also occur at seams, and through secondary contact (*e.g.*, deposition on the skin from a contaminated glove or hand). The use of fluorescent tracers and video imaging provides an opportunity to conduct realistic field performance evaluations (Fenske *et al.* 1986a; b). The fluorescent tracer allows visualization of exposure patterns on the skin. The imaging system records the pattern of exposure and calculates

the corresponding pesticide deposition on the skin. This approach allows direct evaluation and comparison of different protective clothing options, and serves to complement both laboratory testing and field methods such as biological monitoring.

SECTION 2

CONCLUSIONS

1. The nonwoven coveralls tested in Year 01 of this study performed less effectively than traditional woven garments due to garment design factors. Significantly greater exposure was measured on the arms of workers wearing the SMS and Sontara garments compared to either a cotton/polyester coverall or a cotton workshirt. This difference was attributable to the large sleeve openings of the nonwoven garments. When the sleeve openings were reduced in Year 02, no significant difference in exposure beneath coveralls was observed between Sontara and cotton garments.

2. Fabric penetration occurred with high frequency for all test garments. No significant differences in percent penetration were found between woven and nonwoven garments. None of the test garments can be considered chemically resistant under the field conditions evaluated in this study.

3. Properly designed garments (woven or nonwoven) such as those evaluated in this study provide a substantial reduction in exposure when compared to a theoretical "unprotected" worker, but improvement in the chemical resistance of coverall garments will provide only a small further reduction in exposure. Faceshields could provide approximately three times the exposure reduction resulting from improved coverall garments. The hands, even when protected by chemical resistant gloves, contribute a substantial proportion of total dermal exposure, as does the unprotected face/head region.

4. The inhalation route of exposure was estimated to contribute 20% of the total absorbed dose under these study conditions if a worker were to wear gloves and coveralls but no respiratory protection. Proper use of a respirator or use of a faceshield would result in similar reductions in absorbed dose; a combination of these two PPE options would reduce absorbed dose by nearly 40%. Either of these measures would be more effective in reducing dose than improving the chemical resistance of coveralls.

5. The use of fluorescent tracers and video imaging analysis allows measurement of exposure which occurs by pathways which would likely be undetected or inaccurately quantified by the patch technique (*e.g.*, exposure through openings in garments). The patch technique was far

more sensitive in detecting fabric penetration. The techniques appear to play complementary roles in documenting the performance of chemical protective clothing under realistic field conditions.

SECTION 3

RECOMMENDATIONS

1. Dermal and respiratory exposures under the work conditions studied were relatively high for pesticide applicators. Workers conducting airblast applications would be better protected by closed cab systems or any other technology which places a well-defined barrier between the worker and the pesticide spray.

2. Personal protective equipment (PPE) options must be considered if engineering controls are not feasible. PPE requirements or recommendations should take into account the potential for heat stress and should be designed to strike a balance between protection and comfort. Conditions under which PPE shall not be used should be defined and enforced to reduce the risk of illness related to heat stress.

3. Implementation of PPE requirements or recommendations should include procedures whereby employers and workers receive appropriate and ongoing education and training regarding PPE use.

4. Important factors to be considered in developing PPE requirements or recommendations include the following:

   a. Woven or nonwoven coveralls similar to those tested in this study provide substantial protection to most of the body; improvements in the chemical resistance of such garments will probably not reduce total dermal exposure significantly.
   b. The hands, even when chemical resistant gloves are worn, contribute a substantial proportion of total dermal exposure under the use conditions studied. Further reduction in hand exposure will be achieved only by more effective employer and worker education and training.
   c. The unprotected head represents a substantial proportion of total dermal exposure; use of a hood covering the back of the neck and most of the head would reduce exposure significantly; addition of a faceshield would further reduce exposure.

d. The respiratory route of exposure represents a substantial proportion of total dose under the use conditions studied. Respirator use will, in theory, eliminate this exposure. Under current use conditions, further employer and worker education and training will be required to insure that respirators are properly fitted, tested and used. The use of an air-supplied respirator covering the entire head would obviate the need for the hood, faceshield and respirator, and appears to be the best available alternative.

5. 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 effects of garment design and appear to be inadequate measures of potential chemical breakthrough.

6. Users should be provided with accurate information regarding garments designed and marketed for pesticide handlers. Claims regarding the ability of garments to protect workers should be accurate. In particular, garments should not be referred to as "chemical resistant" or "liquid proof" unless these qualities have been demonstrated under realistic field use conditions.

SECTION 4

PROTECTIVE CLOTHING PERFORMANCE STUDY

4.1 OBJECTIVES

This study involved field testing of protective clothing under controlled, but realistic pesticide application conditions. The objectives of the study were as follows:

1. Evaluate the performance of test garments in reducing exposure using the fluorescent tracer technique

    a. Compare dermal exposure measurements of workers wearing test garments to the exposure of workers wearing traditional protective clothing.
    b. Compare the results of the fluorescent tracer technique with those of the traditional patch technique to determine the scientific validity and feasibility of employing the fluorescent tracer technique as an alternative or complementary evaluation method.

2. Determine the role of garment design in reducing exposure.

    a. Establish the relative importance of exposure by clothing penetration versus exposure through openings in clothing.
    b. Determine whether significant reductions in exposure can be obtained by modifying neck, sleeve and leg closures.

4.2 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 studies which 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 personal application procedures. Equipment type, tank size and amount of fluorescent tracer applied per tank were controlled for all applications in Year 01. Uncontrolled variables included number of tanks applied, application time and individual work practices.

4.3 METHODS

4.3.1 Field Conditions

Field studies occurred during the summer application (July through early August) of Ethion 4 Miscible™ [EPA Reg. No. 279-1254]. Ethion 4 Miscible™ is a liquid concentrate formulation containing 4 lbs active ingredient (AI)/gal and is 46.5% AI by weight. The active ingredient is the organophosphorus insecticide, ethion [0,0,0',0'-Tetraethyl S,S'-methylene bisphosphorodithioate]. Participants were employed by two citrus cooperatives in central Florida. 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 (Appendix III), and were paid a nominal sum for each day of participation. Each morning, a mixer and two pesticide applicators were either met at their citrus cooperative headquarters and followed to the citrus grove or were met directly in the grove. Each applicator was given a black, cotton T-shirt and one of the protective garments to wear. The mixers were not monitored during this study. All participants were provided with chemical resistant gloves during the study.

Protective Garments: Four types of protective garments were tested. Each participant wore each type of protective garment at least once during the course of the study. Fabric descriptions and characteristics are drawn from DeJonge and Easter (1989) and Nigg *et al.* (1992):

1) SMS coverall (nonwoven): 100% polypropylene composite material with three-layered construction (thermally point bonded laminate of spunbonded, melt blown, spunbonded fabric); thickness = 11.8 mils; weight = 62 gm/m^2; treated with Kimberly-Clarke RF™, a repellent finish, exact commercial formulation unknown; 44 cm sleeve circumference.
2) Sontara coverall (nonwoven): 50% polyester, 50% wood pulp material with both point bonded and spun bonded construction (spunlaced composite); thickness = 12.6 mils; weight = 72 gm/m^2; treated with DuPont RF™, a repellent finish, exact commercial formulation unknown; 44 cm sleeve circumference.

3) Cotton/Polyester coverall (woven): a 65% cotton /35% polyester twill material (twill woven construction); thickness = 19.0 mils; weight = 243 gm/m^2 weight; untreated; 30 cm sleeve circumference.
4) Cotton workshirt/workpants (woven): a 100% cotton twill material (twill woven construction); thickness = 19.0 mils; weight = 243 gm/m^2; untreated; 23 cm sleeve circumference (when buttoned).

Application Procedures: 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, agitated mechanically, and pumped into the applicators' spray tank. Natural oil and other agricultural chemicals (*e.g.*, copper, Benlate, Kocide) were frequently added to the spray mixture. In some cases no ethion was included in the spray mix; *i.e.*, pest control practices dictated that another insecticide or no insecticide be used on those days.

Cooperative A utilized a 1000 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 open air tractors 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 which utilized electronic photocells to detect the presence and size of trees. The sprayer would automatically turn off/on nozzles as needed. Workers from both cooperatives who used tractors which 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 gal tanks. Spraying was occasionally terminated before all four tanks had been applied due to rain .

Fluorescent Tracer: A commercially available fluorescent whitening agent, Calcofluor RWP (4-methyl-7-diethylaminocoumarin), 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 gm) of the fluorescent tracer was mixed into a bucket containing the ethion formulation. If no ethion was to be applied, the tracer was mixed into a small amount of natural oil instead. Thus, the tracer concentration in the spray mix was constant

throughout the studies (300 gm per 500 gal H_2O; 160 ppm), despite changes in ethion application rates.

4.3.2 Sampling

Video Image Sampling: The mobile laboratory utilized in this project was a 1965 Dodge Travco recreational vehicle which was provided by the U.S. EPA. Prior to the study, extensive modifications and repairs were made to the interior and exterior of the vehicle as well as the engine. In addition, a new generator and air conditioner were installed. The interior of the mobile laboratory was painted black, a dark carpet was laid on the floor and black curtains were fabricated to cover all windows, vents and the back passageway. A video imaging system was placed in the mobile laboratory and secured for transport.

The general design of the second generation instrument used in this study is similar to that of the original VITAE system (Fenske *et al.* 1986a). The major improvements on the original system include 1) increased resolution and grey level scale, 2) increased processing speed, 3) replacement of the touch screen with a mouse for image outlining, and 4) replacement of floppy disks with a tape back-up system for data storage (Fenske *et al.* 1993). Hardware components used in this study were a DOS-based microcomputer (Compaq 286), imaging analysis board (Data Translation DT2851), television camera (RCA T2000), television monitor (Ikegama), data storage tape unit (Mountain Computer Filesafe Model 7060), optical mouse (Mouse Systems Corporation serial mouse), UV-A lamps (custom, with 4 F40 BLB bulbs/lamp + UV-passing glass filters), and subject examination frame (custom, 70 x 70 cm interior dimension). Custom software programs used in the study were VITAE-PIC (image acquisition), VITAE-MAP (outlining and overlay of pre- and post-exposure images, and VITAE-CALC (calculation of exposure) The accuracy of the exposure calculations produced by this system are discussed in detail elsewhere (Fenske *et al.* 1993). The distance from the UV lights to the frame (subject-light distance) was 90 cm. The distance from the camera to the frame (subject-camera distance) was either 75 cm (head, hands and neck images) or 85 cm (all other images). UV-A readings and standard target readings were collected prior to and following each subject examination.

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, upperarms, 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, and much of the leg surface area was covered both by the inner patch samplers (200 cm^2 total) and by tall rubber boots extending up to the knee All video images were acquired using VITAE-PIC, saved onto the microcomputer's hard drive, and transferred to a storage tape at the end of each session. At least one full set of pre-exposure video images were recorded for each worker. Individuals who participated more than once in the study waited at least three days before repeating as subjects in order to insure that tracer from a previous exposure did not remain on the skin. This waiting period had been found to be adequate previously (Fenske 1988b). No residual tracer was observed on subjects used on a repeat basis during the study.

Qualitative Scoring Procedure: Fluorescent tracer deposition patterns were 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 0-3 based on the intensity and extent of deposition on the skin:

0 no visually observed tracer
1 low-level tracer visible; near imaging system limit of detection
2 tracer clearly visible; detectable by imaging system
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.*, USEPA 1987). Rather, they were employed to estimate protective clothing penetration, and to measure the proportion of ethion and tracer reaching the outside of the garment. Six 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; the fifth patch was attached at the right upper chest (outside the garment) and the sixth was pinned to the front of the worker's hat in a vertical position. For workers who did not wear hats the sixth patch was attached at the left upper chest. 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 where they were transferred to a -20°C freezer for storage until analysis.

4.3.3 Analysis

Video Image Samples: Two custom written C-language software programs (VITAE-MAP and VITAE-CALC) which utilize subroutines contained in Data Translation's DT-Iris library were used to analyze each image. The first program, VITAE-MAP, used a mouse to outline the portion of each post-exposure image which was to be analyzed. Two reference points in both images were then identified using the mouse. These two points were used to transpose the outline onto the pre-exposure image. The outline information was saved onto a floppy diskette. The portions of the post-exposure images which had been outlined were then quantified using the program VITAE-CALC (Fenske *et al.* 1993). Several adjustments are automatically made to the images during analysis. Each image (pre and post-exposure) is adjusted for distortion due to lens vignetting. Any change in the lights or camera sensitivity between the pre and post-exposure imaging sessions are corrected. A histogram of the number of pixels within the outlined area at each gray level (0 through 255) is generated and compared for the pre and post-images. If either the total brightness or the maximum gray level (gray level containing at least 10 pixels) of the post-image is greater than the pre-image, the computer considers the post-image to be exposed, and the amount of the exposure is then quantified.

An anthropometric model is used to adjust both the pre and post-images for the effects of non-planar surfaces (changes in the brightness and the surface area represented by each pixel). The unexposed pixels within the image (background skin) are removed by subtracting the histogram of the pre-image from the histogram of the post-image. All remaining pixels are considered to be exposed. The total mass of tracer within the outlined image is then quantified using a standard curve (Fenske *et al.* 1993). The data for the standard curve was collected in the laboratory at New Jersey. Several concentrations of tracer in acetone were spotted onto subjects' skin. Images were acquired of these spots and a line which related the mass of tracer spotted verses the brightness of the spot was determined. This information is input into the VITAE-CALC program to quantify the mass of tracer in the post-exposure images.

Patch Samples: The patch samples were extracted and analyzed for ethion at the University of Florida Lake Alfred Experiment Station laboratory, under the supervision of Dr. Herbert Nigg. The samples were center cut into a 40.32 cm^2 square using a paper cutter. This square was then

quartered. All four quarters were placed into a 225 ml jar with 50 ml of a 30% acetone/70% hexane solvent mixture and shaken on a flat top rack shaker (New Brunswick Scientific, Model R-2) for 5 min at 350 RPM. The solvent was decanted into a 250 ml round-bottom flask and the procedure was repeated. The two extracts were combined. An aliquot of the patch extracts (approximately 10 ml) was transported on dry-ice to New Jersey for analysis of the fluorescent tracer. The remainder of the extract was evaporated to dryness on a rotaty evaporator at 40°C and then brought back up in 10 ml hexane. These samples were analyzed for ethion content by gas chromatography using electron capture Ni^{63} detection and a fused silica capillary column.

Extracts received from Florida were analyzed for tracer at the Rutgers University Department of Environmental Sciences laboratory. A Turner 430 spectrofluorometer was zeroed on a cuvette containing solvent only (30% acetone/70% hexane). Six standards (calcofluor in 30% acetone/70% hexane), ranging from 0.0016 to 0.32 ppm, were read. All samples were placed in the same cuvette and read on the most sensitive scale possible. A blank (cuvette filled with solvent only) was read approximately every 5 samples to ensure stability of the machine. Linear regression of the six standards was used to quantify the samples.

4.3.4 **Quality Assurance/Control**

Quality assurance studies for ethion on patches were conducted under the supervision of Dr. Herbert Nigg at the University of Florida Lake Alfred Experiment Station laboratories, and were reported to USEPA previously in his final report. Procedures and results are summarized here. Extraction efficiency studies were conducted by spiking pads with 10 ug of ethion. Average recovery was 93 ± 2% (n=12). Field spike samples were prepared by spiking 10 ug of ethion onto each alpha-cellulose pad. Pads were taken to the field throughout the course of the study. Average recovery was 90 ± 2% (n=28). Field blank samples (n=30) were prepared at the same time and exposed to the same environmental conditions. The mean amount of ethion recovered was substantially below the limit of detection (<0.0025 ug/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.

Patch samples were analyzed for the fluorescent tracer, Calcofluor RWP, at the Rutgers University Department of Environmental Sciences. Extraction efficiency (n=8) was tested by spiking pads with either 50 ug (n=4) or 5 ug (n=4). The extraction efficiency at the 50 ug level was 96 ± 3.2%. The extraction efficiency at the 5 ug level was 82 ± 2.4%. Field spike samples (n=15) were prepared by spiking 50 ug of calcofluor onto each alpha-cellulose pad. Three pads were kept as controls. The remaining 12 were placed in filtered sunlight at midday (11:00-15:00)

for times ranging from 1-4 hr. Average temperature was 90° F in the shade and relative humidity was 55-60%. Mean recovery after 1-2 hr was 85 ± 4%. Mean recovery after 3-4 hr was 75 ± 10%. These results correspond with previous observations that the tracer can be degraded by sunlight (Fenske *et al.* 1985). Field blank samples (n=4) were prepared at the same time and exposed to the same environmental conditions. Three samples were at or below the limit of detection (0.00016 ppm, equivalent to 0.40 ng/cm^2). The fourth sample measured 1.4 ng/cm^2. Laboratory blank samples (n=4) were center-cut, quartered, extracted and analyzed in the same manner as field patches. Three were below the limit of detection. The fourth sample measured 0.69 ng/cm^2. Storage stability of sample extracts (n=8) was tested by spiking 500 ug of calcofluor into 50 ml of solvent (30% acetone / 70% hexane) and storing at -20° C for six months. Mean recovery was 95 ± 1.8%.

The accuracy and precision of the video imaging system were monitored continuously in the field throughout sample collection. Images of a standard target were acquired immediately prior to and immediately following each imaging session for each worker. Since each worker had two imaging sessions (pre- and post-exposure), four standard target samples were collected for each worker dataset. The standard target was a 36 cm^2 square of standard photocopy paper covered with 70% shading paper (Letratone), attached to a black board so that the standard target could be placed in the center of the frame. The percent differences across pre-exposure sessions, post-exposure sessions and worker evaluation sessions averaged 1.8%, 1.9% and 3.7%, respectively. Thus, 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 square centimeter of exposed skin surface.

4.4 YEAR 02 MODIFICATIONS

Preliminary analysis data from Year 01 indicated that the Sontara garment provided greater protection than the SMS garment. In an effort to narrow the focus of the study and increase sample sizes, only two protective garments were studied in Year 02: the treated Sontara coverall and a woven coverall made of 100% cotton denim material (twill woven construction); 0.66 mm thickness; 274 gm/m^2 weight; untreated. This type of woven coverall had been determined in laboratory studies to be the most effective among available woven garments (E. Easter; personal communication). The cotton coverall was pre-washed with water softener (most laundry detergents contain fluorescent whitening agents) to remove any available fluorescing compounds.

Field observations and preliminary analysis of Year 01 data indicated that exposure to the forearms, upper arms and in some cases the torso was due primarily to material being blown up the sleeves rather than penetrating through the protective garment. The Sontara garment design was therefore altered from Year 01, with the circumference of the sleeve at the wrist reduced from 44 cm to 32 cm. An effort was also made to tape the sleeves of the Sontara garment with masking tape in Year 02, although this was not accomplished in all cases. Additionally, it was decided to collect images of the worker's legs during the second year of this project. Since the legs of the garments were tucked into work boots, the only exposure pathway for the legs, especially the upper legs, would be penetration through the protective clothing. Applicators were given a pair of black athletic shorts to wear under the protective garment in addition to the black T-shirt . The level of fluorescence observed on regions which were covered by protective clothing were low during Year 01. Even lower levels were anticipated in Year 02 due to alterations in the garment openings. Thus, the mass of tracer mixed into each spray tank was increased to 400 gm per 500 gal spray mixture.

4.4.1 Field Conditions

The mobile laboratory utilized in Year 02 was a 1985 Chevrolet truck which was provided by the U.S. EPA. During the first day of the field study, surging of the generator was noticed. The surging became more pronounced the longer the generator was used. As the video equipment, especially the camera and lights, are sensitive to electrical voltage, these surges made data collection unreliable. The field study was discontinued until the problem could be resolved. Several mechanics were contacted in an attempt to correct the problem. The problem was finally resolved when a mechanic in Tampa, FL replaced the condensor which had been recalled by the manufacturer 6 months earlier. After data had been collected from several subjects, a very light, diffuse exposure (below the detection limits of the imaging system) was noted on the torso of a worker wearing Sontara (Worker #8). Further inspection of the Sontara garment revealed that it fluoresced weakly under the UV lights (No fluorescence had been osbserved with this fabric in Year 01.) A question arose as to whether the observed exposure was due to penetration of tracer through the protective garment or leaching of a fluorescing agent from the Sontara garment. In order to determine whether the fluorescence was due to garment breakthrough the tracer concentration was increased from 400 gm to 1200-1600 gm per tank (Worker #9 - 18).

4.4.2 Sampling

A new Cohu Charge Coupled Device (CCD) camera equipped with a 12.5 75 mm zoom lens was used in place of the RCA camera. The zoom lens was fixed at a 12.5 mm focal length. The subject-camera distance was changed to 110 cm due to the new lens, and this distance was

fixed for all images to simplify the image acquisition process. An additional 12 images were acquired of the upper and lower legs of each worker. Seven alpha cellulose patches backed with a polyethylene layer (to prevent sweat from entering the patch) were employed rather than six. The additional patch was attached to the inside of the protective clothing at the chest. Concern that residue might be transferred from the alpha-cellulose to the aluminum foil wrapping led to the use of a cover patch (a second patch placed on top of the sample prior to wrapping). The cover patch was extracted and analyzed with the sample patch.

4.4.3 Analysis

Analysis of video images revealed several problems. First, images for Workers 1 and 2 were collected while the generator was providing inadequate current to the imaging system. Fluctuations in the instrument's performance appeared to affect the brightness of the images, making quantification of the images unreliable. Second, workers 4 and 17 had detectable tracer on their skin prior to pre-image collection. It is not certain how this exposure occurred. Most likely it was the result of contacting equipment that had been used the previous day in the study. Third, the pre-images of workers 5, 6 and 7 appeared much darker than expected. This problem is most likely to have been caused by use of an incorrect f/stop on the camera when the images were collected or an error in the acquisition of the image used to correct all subsequent images for system noise. These images could not be used as pre-exposure images, and thus the post-exposure images could not be quantified. Fourth, worker 11 applied only 0.5 tanks of ethion/tracer (due to 2 sequential flat tires on his tractor); thus no post-images were collected. In sum, images from a total of 17 workers (no post-images for worker 11) were collected before the study was terminated. Elimination of the seven workers listed above left a final data set of 10 subjects. The qualitative examination revealed that exposure was very low for the body parts covered by the protective clothing. An attempt to increase detectable fluorescence beneath clothing by adding 1200 or 1600 gm of tracer rather than 400 gm of tracer to each tank indicated that the observed exposure was due to garment penetration, but at levels so low that they would not be quantifiable by the video imaging system. In light of these circumstances, video images collected during Year 02 were not quantified.

All chemical analyses were conducted at the Rutgers University Department of Environmental Sciences laboratories. Both the sample patch and the cover patch were center cut to a 25.81 cm^2 (4 in^2) square. The plastic backing of each patch was removed. Each patch and its associated cover were placed into a 4 ounce glass jar with 30 ml of toluene and shaken at high speed on a shaker table (100 cpm) for one hour. The patch extracts were analyzed for ethion content by gas chromatography (Hewlett-Packard 5890A, electron capture detector) using the

following conditions: nitrogen carrier gas flow rate = 83 ml/min, oven/column temperature 205° C, injection port temperature 225° C, detector temperature 300° C. The detector was reconditioned during the analysis; the nitrogen flow rate was changed to 85 ml/min and the injection post temperature was reduced to 215°C at this time. The glass column (6 ft., 0.635 cm (0.25 inch) outer diameter, 4 mm inner diameter) was packed with 20 gm 5% 2401 Supelcoport, 100/120 mesh. A 1.0 ul injection was made for each sample. An internal standard (100 pg Dieldren) was used to quantify the field samples.

4.4.4 Quality Assurance/Control

Patch extraction and analysis in Year 02 were conducted at the Rutgers University Department of Environmental Sciences. Extraction efficiency (n=6) was determined by spiking 5.08 x 5.08 cm alpha-cellulose pads with either 2.7 ug or 54 ug of ethion in toluene. Each pad was paired with a cover pad and then extracted and analyzed as described for the field samples. Three controls were prepared at each level by spiking the same amounts into toluene. The extraction efficiency for the two spiking levels was 100.3% ± 4.3 and 99.0% ± 2.4, respectively. Field spike recovery was determined from patches which had been spiked with either 100 ul or 1 ml of a 150 ppm ethion formulation in toluene standard (70 µg ethion active ingredient/ml toluene). The samples were transported and analyzed in the same manner as the field samples. Average recovery for these samples was 86.7% ± 5.8%. Field blank samples (n=3) were prepared and exposed to field conditions. All were below the limit of detection. Laboratory blank samples (n=3) were center-cut, quartered, extracted and analyzed in the same manner as field patches, and were below the limit of detection. Calcofluor extraction efficiency (n=10) was determined by spiking 5.08 x 5.08 cm alpha-cellulose pads with either 0.25 ug or 2.50 ug of calcofluor in toluene. Samples were allowed to dry under a fume hood for 1 hour. Each pad was then paired with a cover pad and extracted and analyzed as described for the field samples. Ten controls were also prepared by spiking calcofluor directly into 30 ml of toluene. The extraction efficiencies for the low and high spiking levels was 99.1 ±2% and 94.6 ± 2.5%, respectively. Field blank samples (n=3) were prepared and exposed to field conditions. All were below the limit of detection. Laboratory blank samples (n=3) were below the limit of detection.

4.5 RESULTS

In the Year 01 study 33 applications were monitored involving six workers: nine in which Sontara was worn and eight each in which the other garments were worn. The number of 500 gal tanks applied varied from 1.5-4, 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

gm/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 pt (Ethion 4EC)/tank, and in the remaining 11 cases the rate was 12 pt/tank. The total amount of tracer and ethion AI applied thus varied from 0.4-1.2 and 0-10.9 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.

In the Year 02 study 18 applications were monitored involving ten workers: nine in which Sontara coveralls were worn and nine in which 100% cotton coveralls were worn. The number of 500 gal tanks applied varied from 1.5-4, with one worker spraying 1.5 tanks, four workers spraying 3 tanks, and the remaining 13 workers spraying 4 tanks. Tracer concentration was purposely increased, as discussed previously. Ethion concentration again varied substantially: in 2 cases no ethion was used, in 7 cases the rate was 5 pt (Ethion 4EC)/tank, and in the remaining 9 cases the rate was 12 pt/tank. The total amount of tracer and ethion AI applied thus varied from 0.8-4.8 and 0-10.9 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.

4.5.1 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 1.113 hr, the average time required to apply the four tanks. This application time value was derived from data collected in the Total Exposure Distribution Study (Section 5), in which application time was carefully monitored. Due to staff time constraints total work time rather than application time was recorded during the Year 01 study and could not be used as a reliable adjustment factor. Examination of hourly exposure values (Table 4.1) indicated that tracer exposure beneath protective clothing was greatest for the forearms in all cases. These data also indicated that forearm exposure 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 89-260%. Neither parametric (ANOVA) nor nonparametric (Kruskal-Wallis) tests between garment types yielded significant differences for any body region.

Table 4.1 Video Imaging Analysis of Fluorescent Tracer Exposure (µg/hr)*

Body Region	N	Mean	Median	Range	C.V. (%)
FOREARM					
WS/WP	8	33.8	32.8	2 - 73	74
C/P Coverall	8	64.4	70.1	2 - 170	89
SMS	8	86.7	39.9	4 - 214	102
Sontara	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

*Data have been normalized to application of 4 tanks per subject (exposure x 4/# tanks applied) and by time applied.

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 provides an indication of the fluorescent tracer challenge which each worker received during application, since none of the workers wore personal protective equipment for this region (Fenske 1988). Exposure data for the forearms, upper arms and torso were therefore normalized by the average head exposure (96.7 µg/hr) for the entire study group as follows: a challenge adjustment factor was calculated by dividing the group mean head exposure by each individual's head exposure; each individual's forearm, upper arm and torso exposure values were then multiplied by this adjustment factor to produce normalized exposure data for these body regions. If differences in individual challenge are contributing to the variability observed within garment groups, then this adjustment should

reduce within-group variability and allow a more direct assessment of the effect of garment type on exposure to protected regions. The adjustment resulted in a decrease in the coefficient of variation in 10 of 12 cases, with the range of CVs reduced from 89-260% to 64-192% (Table 4.2). The pattern of exposure between woven and nonwoven garments remained similar to that observed in the original data set, but the pattern within nonwoven 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 (KW: non-parametric analysis of variance) indicated the following (Table 4.3): 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 probably higher for the SMS garment than for the workshirt and woven coveralls, but differences were not statistically significant; 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 on the upper arms for the Sontara garment suggests that both penetration and deposition through the sleeve opening contributed to exposure.

4.5.2 Visual Observations

Qualitative scores based on visual observations following application corresponded well to the imaging analysis results (Figures 4.1 and 4.2). Torso exposure was not significantly different across the garment types (ANOVA: $p<.05$), 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, and for the forearms in particular. It was also apparent during visual observation that arm exposure decreased with increasing distance from the wrist, and that most torso exposure occurred at or near the neck. These observations suggest that in the majority of cases the tracer was being deposited on skin by movement *under* the garment rather than through the fabric.

Table 4.2 Challenge - Adjusted Tracer Exposure Values by Garment Type*

Garment Type	FOREARMS		UPPER ARMS		TORSO	
	Mean	CV (%)	Mean	CV(%)	Mean	CV(%)
WS/WP	46.2	64	1.7	149	30.9	97
C/P Coverall	56.3	108	4.1	192	24.5	70
SMS	388.9	89	107.8	138	82.0	154
Sontara	109.8	71	19.8	82	39.9	131

* These values have been normalized by group mean head exposure.

Table 4.3 Nonparametric Analysis of Variance of Garment Types by Body Region

Garment Comparison	KRUSKAL-WALLIS P-VALUES Forearm	Upper Arm	Torso
WS/WP = C/P Coveralls	NSD*	NSD	NSD
SMS > WS/WP	.001	.09	NSD
SMS > C/P Coveralls	.002	.16	NSD
SMS > Sontara	.02	NSD	NSD
Sontara > WS/WP	.03	.004	NSD
Sontara > C/P Coveralls	.02	.01	NSD

* NSD = no significant difference

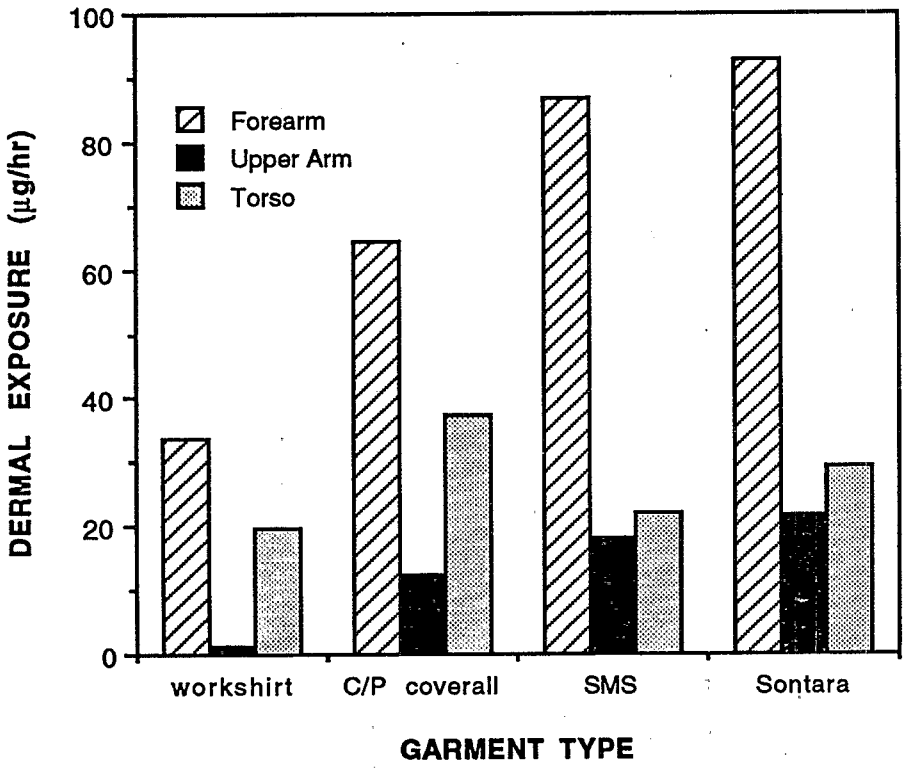

Figure 4.1 Video imaging analysis of fluorescent tracer exposure

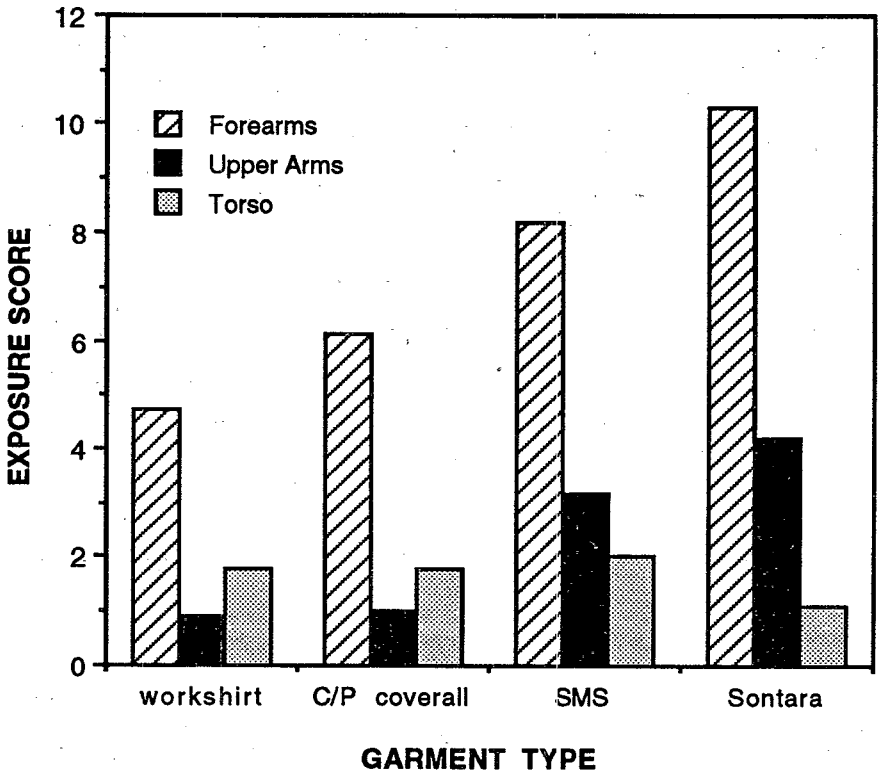

Figure 4.2 Qualitative evaluation of fluorescent tracer exposure

4.5.3 **Estimated Ethion Exposure to Protected Regions**

Ethion exposure (Table 4.4) was estimated by multiplying the fluorescent tracer exposure data in Table 4.1 by the average ratio of ethion and tracer deposited on outer patch samplers on the upper region of the body (chest (chest, shoulder and head). Since workers appliedwidely varying amounts of ethion, average ethion/tracer ratios were calculated for applications with 5 pt Ethion 4 Miscible™/tank and 12 pt/tank. These ratios averaged 8.90 $\pm$ 4.4 and 21.34 $\pm$8.4 for 5 pt and 12 pt tank concentrations, respectively. Despite a broad range of ratio values within each group (4-19 and 9-35, respectively), the proportion of the average ratios was virtually identical to the 2.4 proportion of pt/tank (12pt/5pt).

4.5.4 Ethion and Tracer Penetration of Protective Clothing

Penetration of ethion through protective clothing in Year 01 was measured on the legs with inner and outer patch samplers (Table 4.5). Mean ethion challenge (deposition on the outer patch sampler) was similar for the three coverall garments, ranging from 14.0-32.3 $\mu g/cm^2$, but was much lower (1.44 $\mu g/cm^2$) for the workpants (Kruskal-Wallis; $p<.01$). Percent penetration was calculated 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 were quite similar, ranging from 4.7 - 7.2%, and did not differ significantly. Within each garment type the percent penetration was highly variable, suggesting factors other than fabric content and construction contributed substantially to penetration under field conditions.

Penetration of the tracer through the garments was also monitored in Year 01 (Table 4.6). Mean challenge values followed a pattern similar to that of ethion (nonwoven coveralls>C/P coveralls>workpants). The difference between the Sontara garment and the workpants was significant (KW: $p<.04$), and the challenge to the SMS garment was marginally higher than to the C/P coveralls ($p<.07$) and to the workpants ($p<.09$). Garment breakthrough was measured in all 27 applications for which complete data were available. Mean penetration values for the four garments exhibited a broader range (0.7 - 7.6%) than for ethion. The high SMS penetration value was marginally greater than both the Sontara ($p<.06$) and workpants values ($p<.09$). As with ethion, percent penetration for each garment type was highly variable.

In Year 02 ethion challenge and penetration was measured at the chest and upper legs for cotton and Sontara coveralls (Table 4.7). Challenge was consistently higher for the legs when compared to the chest, but for each region no significant difference was observed between the two garment types. Penetration at the legs was greater for the cotton coveralls than for the Sontara coveralls (2.7 *vs.* 0.8; KW: $p<.02$). The same pattern was observed for the chest but was not statistically significant due to high variability within each garment type (5.4 vs. 1.4; KW: $p=.17$). Tracer challenge and penetration values were not calculated for Year 02 due to the high variability in the amount of tracer applied. Ethion penetration of the Sontara garment was much lower in Year 02 than in Year 01 (0.8% *vs.* 6.3% penetration at the legs). Comparing the woven coverall garments across years indicated that the 100% cotton coveralls performed more effectively than the cotton/polyester coveralls (2.7% *vs* 4.7% penetration at the legs).

Table 4.4 Ethion Exposure Estimates for Protected Body from Video Imaging Analysis (µg/hr)*

		5 PT		12 PT	
Body Region	N	Mean	Range	Mean	Range
FOREARM					
WS/WP	8	300.8	18 - 650	721.3	43 - 1558
C/P Coverall	8	573.2	18 - 1513	1374.3	43 - 3628
SMS	8	771.6	36 - 1905	1850.2	86 - 4567
Sontara	9	825.9	80 - 3222	1980.4	192 - 7725
UPPER ARM					
WS/WP	8	12.5	1 - 62	29.9	0 - 149
C/P Coverall	8	109.5	1 - 819	262.5	0 - 1963
SMS	8	159.3	1 - 890	382.0	0 - 2134
Sontara	9	191.4	9 - 854	458.8	21 - 2049
TORSO					
WS/WP	8	175.3	0 - 730	420.4	0 - 1750
C/P Coverall	8	331.1	18 - 1495	793.8	0 - 1963
SMS	8	195.8	9 - 1130	469.5	21 - 27104
Sontara	9	262.6	0 - 1237	629.5	0 - 29669

*Fluorescent tracer data (Table 4.1) has been multipled by the ethion / tracer ratio for each Ethion 4 Miscible application rate (8.90 for 5 pt/500 gal; 21.34 for 12pt/500 gal)

Table 4.5 Ethion Challenge and Penetration to the Legs - Year 01 (µg/cm^2)

		CHALLENGE[A]			PERCENT PENETRATION[B]	
Garment	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
B Penetration = inner patch / outer patch * 100
C Challenge to workpants < all others (KW: p < 01)

Table 4.6 Tracer Challenge and Penetration to the Legs - Year 01 (µg/cm^2)

		CHALLENGE[A]			PERCENT PENETRATION[B]	
Garment	N	Mean	Median	CV	Mean	Range
WS/WP	7	0.95	0.46	103	2.6	.02 - 17
C/P Coveralls	7	1.55	0.56	154	1.7	.01 - 8
SMS	5	3.36[C]	1.16	128	7.6[E]	.1 - 14
Sontara	8	3.27[D]	2.64	89	0.72	.2 - 4

A Challenge = deposition on outer leg patch sampler
B Penetration = inner patch / outer patch * 100
C Challenge to SMS > WS/WP (KW: $p < .09$) and > C/P coveralls ($p < .07$)
D Challenge to Sontara > WS / WP ($p < .04$)
E Pentration of SMS > Sontara ($p < .06$) and > WS/WP ($p < .09$)

Table 4.7 Ethion Challenge and Penetration to the Chest and Legs - Year 02 ($\mu g/cm^2$)

Garment	Location	N	CHALLENGE[A] Mean	Median	CV	PERCENT PERETRATION[B] Mean	Range
Cotton Coverall	Chest	8	8.48	2.32	182	5.36	.3 - 18
Sontara	Chest	8	9.00	4.40	105	1.43	.1 - 5
Cotton Coverall	Leg	8	42.2	16.5	193	2.74[C]	.6 - 12
Sontara	Leg	8	19.7	17.5	80	0.75[C]	.2 - 2

A Challenge = deposition on outer leg patch sampler
B Penetration = inner patch / outer patch * 100
C Pentration of cotton coverall > sontara coverall (KW: p <.02)

SECTION 5

TOTAL EXPOSURE DISTRIBUTION STUDY

5.1 OBJECTIVES

This study was designed to examine distribution of dermal exposure across body regions and the contribution of respiratory exposure relative to dermal exposure during routine pesticide applications in citrus orchards. The objectives of the study were as follows:

1. determine the relative contributions of hand exposure, face/neck exposure, exposure to regions protected by coveralls, and respiratory exposure to total exposure.
2. determine the effectiveness of woven and nonwoven coveralls in reducing total exposure.
3. determine appropriate techniques for estimating face exposure.
4. construct scenarios in which the effectiveness of interventions with personal protective equipment could be evaluated quantitatively.

5.2 STUDY DESIGN

Participants conducted replicate applications of the insecticide, Ethion 4 Miscible™, under normal field conditions. Two protective coveralls (cotton and Sontara) were assigned to applicators on a random basis. In one-half of the replicate applications protective gloves were worn, also assigned on a random basis. All applicators wore plastic face shields and air sampling equipment.

5.3 METHODS

5.3.1 Field Conditions

The study occurred during one week of a summer application of ethion in central Florida citrus groves. All applicators applied Ethion 4 Miscible™ at a rate of 5 pts/500 gal. Initial applications involved two tanks, but the research staff found that this schedule did not allow sufficient time for proper collection and storage of samples. The remaining applicators applied

three 500 gal tanks. Participants were three adult male employees from Cooperative A who applied pesticides as part of their normal work activities. Each read and signed a consent form and was paid a nominal sum for each day of participation.

Protective Clothing Two types of protective coveralls were tested. Fabric descriptions and characteristics are drawn from DeJonge and Easter (1989) and Nigg *et al.* (1992):

1) Cotton coverall (woven): a 100% cotton denim material (twill weave construction); 0.66 mm thickness; 274 gm/m^2 weight; untreated.
2) Sontara coverall (nonwoven): 50% polyester, 50% wood pulp nonwoven material with both point bonded and spun bonded construction (spunlaced composite); 0.2 mm thickness; 43 gm/m^2 weight; treated with DuPont RF™, a repellent finish, exact commercial formulation unknown.

Twelve replicates of each garment were conducted, with each participant wearing each type of garment four times.

5.3.2 Sampling

Patch Sampling: The traditional patch technique recommended for applicator exposure assessment (USEPA 1987) was employed with minor modifications. Twenty alpha cellulose patches (see Section 4.2.2) were positioned on each worker. The outer patches were pinned with two safety pins so that the polyethylene layer backing the patch was adjacent to the protective garment. The inner patches were pinned to the inside of the protective garment so that the polyethylene layer faced the subjects' skin. Patches were positioned so that the outer patches were adjacent to, but not overlapping the inner patches. A pair of patches (one outer and one inner patch) were attached in the following locations: upper legs (4), lower legs (4), upper arms (4), and lower arms (4), chest (2), and back (2). In addition, a patch was attached to the front of the hat (positioned vertically) for the16 cases in which a hat was worn.

On the first day (Workers 1-6) patches were attached to the inside and the outside of the protective garments while the worker was wearing the garment. On subsequent days the patch locations were measured from garments used on the first day and the patches were positioned on the clothing before the garment was given to the applicator. This allowed substantial reduction in the amount of time required to prepare each volunteer for spraying. Outer patches were removed immediately after the worker completed spraying. Patches were placed onto aluminum foil with the plastic side facing down. A blank piece of alpha-cellulose was placed on top as a cover. The

patch and cover were then wrapped in the foil and placed in a cooler with dry-ice. The inner patches were removed after the worker had removed his garment and were stored in the same manner as the outer patches.

Handwash Sampling: After a worker was suited in a protective garment, both hands were washed with ethanol (reagent grade, Fisher Scientific) by the following procedure:

1. the hand was placed in a plastic bag containing 250 ml ethanol
2. the mouth of the bag was wrapped tightly around the wrist
3. the participant was instructed to relax the hand
4. a staff member shook the hand in the solution for 30 sec.

This procedure was repeated twice for each hand. The pre-handwash solutions were discarded. After the worker had completed spraying his tanks, the handwash procedure described above was repeated. All workers' hands were washed regardless of whether they were bare-handed or wearing gloves. The handwashes from both hands (1000 ml total volume) were combined immediately in a large mason jar and mixed well. An aliquot (approximately 100 ml) of this solution was poured into a glass jar and frozen in the cooler with dry ice.

Faceshield Wipe Sampling: All workers wore face shields (Protecto-Shield, Willson, 17 x 31 cm cellulose acetate, 0.102 cm thick) which extended from their forehead to chin. The shield was open at the top, bottom and sides and was suspended approximately 5 cm in front of the worker's face. The shields were pre-wiped with ethanol. When the worker returned from spraying, his faceshield was removed by the field staff. A gauze pad was moistened with 4 mists from a spray bottle of ethanol. The entire face of the shield was then wiped with the pad using three horizontal strokes. This procedure was repeated with a second pad. Both pads were stored in a single sample jar.and placed in the cooler with dry ice.

Air Sampling: Aerosol samples were collected on glass fiber filters (Gelman type A/E) using 10M Personal Inspirable Dust Samplers (Rotheroe and Mitchell) attached to the collar and positioned in the breathing zone. ORBO-44 tubes containing Supelpak 20 (Supelco, Inc.) were placed in line behind the samplers to collect volatilized ethion. Gilian pumps were adjusted to maintain an air flow of 2 L/min through the samplers. The airflow of each sampler was standardized with a rotameter just prior to placement on the worker. Air sampling began after the pre-handwash and ended when the spray activities were completed. Air sampling times were affected by the number of tanks applied, spray equipment problems, and variations in the size and density of the trees being sprayed. At the end of sampling the glass fiber filter was removed from the sampler with tweezers and placed in a 4 oz glass jar. The ORBO-44 tube was capped on both ends and wrapped

in foil. Samples were placed in a cooler with dry ice.

5.3.3 Analysis

All field samples were stored in a cooler with dry-ice. At the end of the day, samples were transferred to a freezer (approximately 0^{o} C) for overnight storage, and then transferred to a -10^{o} C freezer the following morning. At the end of the field study, all samples were packed in a cooler with dry-ice and transported overnight to New Jersey where they were stored in a -20^{o} C freezer until analysis.

Patch Samples: The outer patch samples were analyzed in the same manner described in Section 4.3.3, with an injection volume of 1 ul. The inner patches from several workers were analyzed using the same procedure, but most were below the analytical limit of detection. To improve detectability the cover portion for each remaining patch was discarded, and the patch was center cut to 5.08 x 5.08 cm and then quartered. These four pieces were placed into a glass jar with 10 ml of toluene and were extracted and analyzed according to the procedures for the outer patches.

Handwash Samples: The handwash samples were removed from the freezer and allowed to warm to room temperature. The ethion content of the samples was analyzed directly by gas chromatography (Hewlett-Packard 5890A, electron capture detector) under the following conditions: Alltech RSL-200 capillary column (15m x 0.32mm); oven temperature 215^{o} C, injection port temperature 230^{o} C, detector temperature 300^{o} C, column flow 2.0 ml/min He, auxilary gas 35 ml/min N. The retention time for ethion was 3.9 min under these conditions. Two 1.0 ul injections were made for each sample and averaged.

Faceshield Wipe Samples: The gauze faceshield wipes were removed from the freezer, allowed to warm to room temperature for 2 hr, and then placed in sample jars with 30 ml of toluene. The jars were placed on a shaker table at high speed (100 cpm) for 1 hr. The gauze wipes were removed from the jar and discarded. The extracts were stored in the freezer (-20^{o}C) until analysis.

Air Samples: Toluene (25 ml) was added to the jars which contained the glass fiber filters. These jars were placed onto a mechanical shaking table (100 cpm) for 30 min. The filters were discarded. The extracts were analyzed by gas chromatography. The contents of the Orbo-44 tubes were removed from the glass tubes and placed into vials with 10 ml of toluene. These were placed on the mechanical shaking table for 5 min. The vials were allowed to sit for 30 min after shaking to allow the granular contents to seperate from the extract. The granules were discarded and the extracts were analyzed by gas chromatography.

5.3.4 Quality Assurance/Control

The patch samples collected in this part of the Year 02 study were handled in a manner to those discussed in Section 4.4.4. Thus, the quality assurance/control information presented there pertain to these samples. This study included a number of sample media which were not a part of the Protective Clothing Performance Study; i.e., handwashes, faceshield wipes, and air samples. Handwash samples were quantified in ethanol, obviating the need for an extraction. However, it was determined that the ethion analytical standard, which had been prepared in toluene, produced a higher response factor than ethion in ethanol. Therefore, the relative response of the GC to ethion in these two solvents was measured. Ethion in ethanol produced a response which was 62.1 $\pm$ 2.9% of the ethion/toluene standard response. All field sample values were thus adjusted (increased) by this factor. Handwash removal efficiency (i.e., the fraction of pesticide on the skin which is removed by the handwash procedure) was not determined for ethion. Three replicate handwash field spikes were prepared at two concentrations by adding 20 ug or 100 ug of ethion formulation to 100 ml of the ethanol handwash solution. The same amounts of ethion formulation were spiked in duplicate directly into toluene as controls. Mean recoveries of ethion for the low and high spikes were 113 $\pm$ 9.6% and 88 $\pm$ 1.0%, respectively, with an overall mean value of 100.5 $\pm$ 15.2%. Field blank samples were prepared by placing ethanol into a plastic handwash bag, pouring the contents into a mason jar, then pouring the contents into a sample jar for storage and analysis. None of the handwash field blanks contained detectable ethion.

Faceshield wipe extraction efficiency samples (n=6) were prepared by spiking surgical gauze pads with either 2.3 ug or 6.9 ug of ethion. Each sample consisted of two gauze pads which were extracted and analyzed together. Samples were allowed to dry under the fume hood for 1 hr, and were then extracted and analyzed in the same manner described previously for the field samples. Control spikes were prepared by the same amounts of ethion directly into 30 ml toluene. Mean recoveries at the low and high spike levels were 104 $\pm$6.0% and 109 $\pm$1.6%, with an overall recovery of 106 $\pm$ 4.5%. Laboratory blank samples (n=2) were prepared by placing gauze wipes under the fume hood for 2 hrs and as above. One sample contained no ethion and the other contained <0.3 ug. To determine the removal efficiency of the faceshield wipe procedures shields were spiked with either 100 µg or 300 µg of ethion (n=6 in each case). The faceshields were then wiped according to the sampling procedure described in Section 5.3.2 and analyzed as described in Section 5.3.3. Average removal efficiency (amount removed from shield by wipe divided by amount on shield times 100) was 53.0 $\pm$ 10.4%. This average value was used to adjust the faceshield wipe data.

Air filter extraction efficiency samples (n=6) were prepared by spiking 4.8 ug of ethion onto each glass fiber filter. The filters were allowed to dry under the fume hood for 1 hr, and then each was placed in a glass jar with 25 ml of toluene and extraced. Three controls were prepared by spiking the same amount of ethion directly into jars with 25 ml of toluene. Mean recovery was 98 ± 8.6%. Field spike samples (n=2) were prepared by spiking 0.1 ug of the ethion formulation directly onto the glass fiber filters. Controls were prepared by spiking the same amount of ethion into 100 ml of toluene. The recovery for these samples was 107 ± 4.4%. Field blank samples (n=4) were prepared by using tweezers to place glass fiber filter into sample jars. No ethion was detected on these samples.

5.4 RESULTS

Twenty-four applications were monitored: 12 in which the cotton coverall was worn and 12 in which the Sontara coverall was worn. The first six applications consisted of two 500 gal tanks, while the remaining 18 consisted of three tanks. Ethion concentration was maintained at 5 pt/500 gal for all tanks. The total amount of ethion AI applied thus varied from 2.3-3.4 kg. All data have been normalized to three tanks (ethion AI applied = 3.4 kg). All exposure data are expressed as hourly rates (µg/hr) based on a measured application rate of 17 min/tank. Worker 17 appeared as an extreme outlier throughout the data set (very high values), and has therefore been excluded from statistical calculations.

5.4.1 Respiratory Exposure

Measureable ethion was found in all glass fiber filter samples. No ethion was detected in the back-up ORBO tubes samplers. Respiratory exposure was calculated by multiplying the air concentration measured in the worker's breathing zone ($\mu g/m^3$) by a standard factor respiratory volume rate of 1.5 m^3/hr (USEPA 1989). This rate is the maximum rate for light work, and appears appropriate for workers conducting orchard applications. Respiratory exposure averaged 31.2 µg/hr, ranging from 1-207 µg/hr (Table 5.1).

Table 5.1 Respiratory, Hand, Face, and Head Exposure to Ethion (µg/hr)

Body Region	N	Mean	Median	Range	CV(%)
Respiratory	22	32	18	1 - 207	140
Hands					
Gloves	12	1,762[C]	805	193 - 9370	154
No Gloves	12	13,812[C]	12,213	2040 - 23570	43
Face[A]					
Torso estimate	21	965[D]	858	26 - 2305	76
Hat estimate	13	228[D]	135	37 - 684	84
Head[B]					
Torso estimate	21	1,752[E]	1,557	47 - 4184	76
Hat estimate	13	413[E]	246	67 - 1242	84

A Mean torso patch rate or hat patch rate x 650 cm^2
B Mean torso patch rate or hat patch rate x 1180 cm^2
C Significantly different (ANOVA: $p < .0001$)
D Significantly different (ANOVA: $p < .002$)
E Significantly different (ANOVA: $p < .002$)

5.4.2 Hand Exposure

Hand exposure without gloves averaged 13,812 µg/hr, ranging from 2000-23,000 µg/hr (Table 5.1). When nitrile gloves were worn exposure decreased nearly 8-fold to 1,762 µg/hr, with a range of 193-9,370 µg/hr (ANOVA: $p<.0001$). Variability in hand exposure was substantially higher among workers who wore gloves, indicating that such exposures are probably the result of intermittent events (*e.g.*, glove removal) rather than chemical breakthrough. Clearly use of gloves substantially reduced, but did not eliminate hand exposure.

5.4.3 Face and Head Exposure

Face and head exposure have traditionally been calculated by determining the average of four torso patch samplers (left and right upper arms, chest, back) and multiplying it by an

appropirate standard factor for surface area (650 cm^2 for face, 1180 cm^2 for head; USEPA 1989). This calculation yielded an average face exposure value of 965 µg/hr, and an average head exposure value of 1,752 µg/hr (Table 5.1). Alternatively, it is considered acceptable to employ a hat or head patch sampler in lieu of the torso patches (USEPA 1987). Using this approach, face exposure was 228 µg/hr and head exposure was 413 µg/hr, significantly lower than the torso patch extrapolations (ANOVA: $p<.002$).

The faceshield provided to workers was also sampled for ethion deposition. As discussed in Section 5.3.4, spike/recovery studies indicated that only 53% of deposited ethion was removeable by the wipe sampling technique employed. Thus, data from the faceshield wipes have been divided by a .53 removal efficiency factor. Estimated face exposure based on faceshield sampling averaged 105 µg/hr (Table 5.2). When hat and torso patch extrapolations were applied to the faceshield surface area (527 cm2), the respective face exposure estimates averaged 176 µg/hr and 782 µg/hr. The torso patch estimate was significantly higher than the faceshield estimate (ANOVA-SNK: $p<.0001$), while the difference between the head patch estimate and the faceshield estimate was not statistically significant (ANOVA-SNK: $p<.09$). The discrepancy between the faceshield/hat patch estimates and torso patch estimate of face exposure suggests that deposition on the torso patches was not representative of deposition either at the location of the hat patch (above forehead) or at the face itself. Thus, face and head exposure estimates derived from torso patch extrapolation appear to overestimate exposure by a 7-fold or 11-fold factor.

Table 5.2 Comparative Estimates of Face Exposure to Ethion (µg/hr)

Face Estimate	N	Mean	Median	Range	CV
Faceshield[A]	23	105[DE]	84	2 - 321	93
Hat Estimate[B]	21	176[E]	105	29 - 530	84
Torso Estimate[C]	13	782[D]	695	29 - 1869	76

A Faceshield wipe values have been adjusted for 53% removal efficiency (value/.53)
B Hat patch rate x 527 cm^2 (faceshield surface area)
C Mean torso patch rate x 527 cm^2 (faceshield surface area)
D Significantly different (ANOVA: $p < .0001$)
E Marginally different (ANOVA: $p < .09$)

5.4.4 Exposure beneath Coveralls

Deposition rates on outer patch samplers were similar for the cotton and Sontara coveralls, with the exception of the upper legs (Table 5.3). The rate at this region for the Sontara coveralls was nearly twice that for the cotton coveralls (ANOVA: $p<.02$). Total deposition rates on the outside of the clothing were calculated by multiplying the outer patch sampler values by the appropriate standard surface areas for the body regions (USEPA 1989). The total deposition rate for the Sontara coveralls was 48% greater than the corresponding rate for the cotton coveralls, but this difference was not statistically significant.

Table 5.3 Ethion Deposition Rates on Cotton and Sontara Coveralls

Garment/Region	N	Patch Deposition Rate[A] (µg/cm²/hr)	TOTAL DEPOSITION (mg/hr) Mean	Median	RATE[B] Range	CV (%)
COTTON						
Upper arm	12	1.39	1.99	1.76	0 - 6.3	82.4
Lower arm	11	2.98	3.40	2.97	0.5 - 11.0	86.7
Chest	11	1.15	3.27	1.48	0.2 - 9.9	109.6
Back	12	0.74	2.10	1.48	0 - 9.6	127.2
Upper leg	12	5.71[D]	11.30	12.20	2.3 - 18.0	44.8
Lower leg	11	5.48	11.34	9.39	1.0 - 38.1	93.7
TOTAL	10	--	34.23	35.49	6.7 - 65.4	55.8
SONTARA[C]						
Upper arm	10	2.08	2.97	3.42	0.1 - 5.1	62.6
Lower arm	11	8.31	9.47	6.35	0.6 - 53.1	157.3
Chest	11	2.14	6.09	4.58	0.2 - 18.3	103.3
Back	11	1.01	2.86	2.01	0.3 - 9.7	102.7
Upper leg	11	10.26[D]	20.31	21.01	4.1 - 45.8	52.9
Lower leg	11	3.90	8.06	6.78	1.5 - 20.2	76.7
TOTAL	10	--	50.59	54.43	14.1 - 86.7	44.6

A Mean value
B Patch deposition rate x body region surface area (USEPA 1988)
C One subject excluded (W-17) due to very high deposition rates
D Sontara > Cotton (KW: $p < .02$)

Inner patch samplers were categorized as either 1) quantifiable (>0.84 µg/sample), 2) trace (0.24-0.84 µg/sample), or 3) unexposed (<0.24 µg/sample). In the majority of cases garment breakthrough occurred leading to exposure to the body regions protected by coveralls (Table 5.4). For cotton coveralls 34% of the inner patch samplers had quantifiable ethion and an additional 29% had trace levels, resulting in a breakthrough frequency of 63%. For the Sontara coveralls 26% of the inner patch samplers had quantifiable ethion and an additional 43% had trace levels, resulting in a breakthrough frequency of 69%. Since breakthrough frequencies for the two garments were similar, these data were pooled to examine breakthrough frequency by body region (Table 5.5). Quantifiable ethion was measured most frequently on the lower arm (forearm) samplers (43%) and the upper leg samplers (43%). For all body regions breakthrough frequency (quantifiable and trace) was >50%.

Table 5.4 CPC Breakthrough Frequency by Garment

Garment	Total Patches	Quantifiable[A] Ethion	Percent	Trace[B] Ethion	Percent	Q + T[C] Ethion	Percent
Cotton Coverall	114	39	*34.2*	33	*28.9*	72	*63.2*
Sontara[D] Coverall	96	25	*26.0*	41	*42.7*	66	*68.8*

A Quantifiable = > 28 pg/µl; > 0.84 µg/sample
B Trace = < 28 pg/µl and >8 pg/µl; .24 - .84 µg/sample
C Frequency of quantifiable + trace breakthrough
D One subject excluded (W17) due to very high deposition rates

Table 5.5 CPC Breakthrough Frequency - by Body Region (both Garments)

Body Region	Total Patches	Quantifiable[A] Ethion	Percent	Trace[B] Ethion	Percent	Q + T[C] Ethion	Percent
Chest	20	5	*25.0*	6	*30.0*	11	*55.0*
Back	23	3	*13.0*	11	*47.8*	14	*60.9*
Up Arm	47	10	*21.3*	17	*36.2*	27	*57.4*
Lo Arm	47	20	*42.6*	14	*29.8*	34	*72.3*
Up Leg	46	20	*43.5*	19	*41.3*	39	*84.8*
Lo Leg	46	13	*28.3*	17	*37.0*	30	*65.2*

A Quantifiable = > 28 pg/µl; > 0.84 µg/sample
B Trace = < 28 pg/µl and >8 pg/µl; .24 - .84 µg/sample
C Frequency of quantifiable + trace breakthrough

Exposure to regions beneath protective garments was calculated by multiplying the inner patch sampler deposition rate by the appropriate standard surface area (Table 5.6). Only quantifiable ethion and trace values were used, with trace values being assigned one-half the limit of detection (.007 µg/cm^2); unexposed samples were assigned values of zero. Total exposure to these regions was then determined for each worker and average "protected body" exposure determined (protected body is defined here as all regions beneath coveralls.) Exposure beneath cotton coveralls appeared to be lower than that beneath Sontara coveralls, based on inspection of both the mean and median protected body exposure values. However, this difference was not significant statistically due to high variability within each garment group. If the difference observed in these mean values were significant, it would in part be attributable to the greater challenge (deposition rates) received by the Sontara garment.

Table 5.6 Ethion Exposure beneath Cotton Coveralls and Sontara Garments (µg/hr)

Garment/Region	Mean	Median	Range	CV (%)
COTTON (N = 12)				
Upper Arm	11.4	6.6	0 - 61	150
Lower Arm	37.6	12.1	0 - 243	184
Chest	20.5	0	0 - 121	173
Back	13.2	13.2	0 - 26	104
Upper leg	31.6	26.1	0 - 85	74
Lower leg	112.4	12.0	0 - 1,214	309
Protected Body	226.7	104.0	5 - 1,540	187
SONTARA (N = 11)				
Upper arm	13.9	13.3	0 - 40	92
Lower arm	80.2	10.6	0 - 571	212
Chest	44.4	26.4	0 - 147	111
Back	29.2	26.4	0 - 147	143
Upper leg	44.7	28.8	9 - 154	98
Lower leg	45.7	19.2	0 - 308	192
Protected Body	258.1	152.4	9 - 1,272	136

5.5 EXPOSURE DISTRIBUTION ASSESSMENT

The distributional characteristics of exposure are important in that they indicate the effectiveness of specific interventions for reducing exposure, and provide data for recommending additional interventions. Numerous applicator exposure studies have reported the distribution of dermal exposure across body regions, and the relative contribution of respiratory exposure to total exposure, but most often these studies have lacked specificity regarding methods of calculations, use of personal protective equipment (PPE), and underlying assumptions. Furthermore, traditional sampling techniques may have underestimated exposure beneath protective clothing due to deposition through garment openings, as documented in Section 4. As a result, generalizations which are sometimes cited regarding exposure distribution may be inaccurate. Based on the data collected in this study a series of exposure scenarios has been developed to identify the role of PPE in exposure reduction. It is believed that these data are representative of airblast applicator exposure in citrus orchards, and may be representative of orchard airblast exposure in general.

They are not, however, applicable to other types of pesticide applications (e.g., groundboom, backpack), nor do they reflect exposure patterns of pesticide mixers or mixer/applicators.

Label requirements for Ethion 4 Miscible™ (January 1991 label) require that a worker wear the following personal protective equipment (PPE) during application:

- Protective suit of one or two pieces covering all parts of the body except the head, hands and feet;
- Chemical resistant gloves and shoes
- NIOSH or MESA approved respirator

In practice, these requirements are not followed consistently during summer spraying of citrus in Central Florida. Indeed, there is substantial evidence to suggest that such requirements place an undue burden on workers and may contribute to physiological conditions related to heat stress (Nigg *et al.* 1992). It is not uncommon for workers applying under high temperature and high humidity conditions to forego the use of a respirator, and to alter protective suits in a manner that allows greater air circulation to the body.

5.5.1 Dermal Exposure Scenarios

In light of the realities of actual field use of PPE cited above the following scenarios have been constructed to assess the role of specific PPE combinations in reducing dermal exposure. Exposure estimates generated by these scenarios are presented in Table 5.7. Since this study did not measure exposure to the feet, the use of chemical resistant shoes or boots is not discussed, and exposure to this body region is assumed to be zero in subsequent calculations. Unfortunately, one PPE option -- chemical resistant hoods -- was not investigated in this study. Hoods would appear to provide substantial protection for all portions of the head except the face; however, no published studies are available to demonstrate the effect of hoods on head exposure.

Table 5.7 Dermal Exposure Reduction by Personal Protective Equipment (PPE)

PPE Scenario	PERCENT EXPOSURE REDUCTION vs Scenario 1	vs Scenario 2	vs Scenario 3	Total Dermal Exposure µg/hr)	PERCENT Hands	TOTAL EXPOSURE Head	Body
1 Unprotected Worker[A]	0	---	---	57,974	23.8	3.0	73.2
2 Cotton or Sontara Coverall Only[B]	72.7	0	---	15,806	87.4	11.1	1.5
3 Cotton or Sontara Coverall[C] + Gloves	93.5	76.2	0	3,756	46.9	46.6	6.4
4 Cotton or Sontara Coverall [D] + Gloves + Faceshield	94.9	81.2	20.8	2,974	59.2	32.6	8.2
5 Chem-Resistant Coveralls[E] + Gloves	93.9	77.8	6.4	3,514	50.1	49.9	0
6 Chem-Resistant Coveralls + Gloves + Faceshield	95.3	82.7	27.3	2,732	64.5	35.5	0

A Deposition to outside of coveralls + hand + head exposure (torso patch estimate)
B Deposition beneath coveralls (mean of cotton and Sontara) + hand + head exposure
C Gloves reduced exposure from 13,182 to 1,762 µg/hr (Table 5.1)
D Assumes faceshield protects 44.7% of head (527/1180 cm^2)
E Assumes chemical-resistant coveralls replace cotton or Sontara and provide 100% protection

SCENARIO 1: *The unprotected worker.* This scenario assumes that workers use virtually no PPE or that PPE is used in a manner which provides little protection. Thus, the hands, face and Protected Body regions (regions beneath coveralls) are considered unprotected. Deposition rates measured on the outside of coveralls have been used to estimate exposure to the Protected Body; the mean exposure to the outside of coveralls has been used, since no significant difference was noted between cotton and Sontara coveralls. The mean torso patch value (Table 5.1) has been used to estimate head exposure here and throughout the scenarios to provide consistency with the extrapolation procedures used for other body regions. However, it should be noted that data presented previously (Section 5.4.3) suggest that use of this value may overestimate the contribution of head exposure to total dermal exposure.

SCENARIO 2: *Cotton or Sontara Coveralls only.* Use of a protective coverall is added to Scenario 1. The mean exposure value for cotton and Sontara coveralls extrapolated from inner patch samplers was used to estimate exposure to the Protected Body (Table 5.6). Hand and Head estimates remain unchanged. This scenario assesses the effect of the coveralls used in this study, but assumes that the worker does not follow label requirements regarding gloves.

SCENARIO 3: *Cotton/Sontara Coveralls + Gloves.* Use of chemical resistant gloves has been added to Scenario 2. Measured exposure beneath gloves was used to estimate Hand exposure (Table 5.1). Head and Protected Body estimates remain unchanged. This scenario assesses the effect of chemical resistant gloves on hand exposure, and is consistent with label requirements.

SCENARIO 4: *Cotton/Sontara Coveralls + Gloves + Faceshield.* Use of a 527 cm^2 faceshield has been added to Scenario 3. The exposure calculation assumes that the faceshield protects 44.7% of the head surface area (527/1180 cm^2). Hand and Protected Body estimates remain unchanged. This scenario assesses the effect of the faceshield when a worker is following label requirements.

SCENARIO 5: *Chemical Resistant Coveralls + Gloves.* Chemical resistant coveralls have been substituted for the cotton or Sontara coveralls used in the study, and the faceshield has been removed. It has been assumed that these coveralls are 100% effective and that no exposure occurs on Protected Body regions. Head exposure is that used in Scenarios 1-3. Hand exposure remains unchanged from Scenario 4. This scenario assesses the effect of a truly chemical resistant coverall on total exposure when a worker is wearing label-required protective clothing. It should be noted

that no field studies to date have documented that commercially available coveralls perform in this manner.

SCENARIO 6: *Chemical Resistant Coveralls + Gloves + Faceshield.* Faceshields have been added to the PPE in Scenario 5 to create a scenario in which all PPE options are combined.

Dermal exposure to the unprotected worker (S-1) was primarily to the Protected Body regions (73%), with hand exposure contributing nearly one-quarter (24%) of total exposure. The use of cotton or Sontara coveralls (S-2) reduced total dermal exposure by 73%, and exposure to unprotected hands became the primary contributor to total dermal exposure (87%). Thus, coveralls play the most important role of any PPE in reducing exposure during citrus airblast applications. The addition of chemical resistant gloves (S-3) further reduced dermal exposure to 94% of that received by the unprotected worker. When compared with workers wearing coveralls the use of gloves reduced total dermal exposure by 76%. Under this scenario the contributions of protected hands and unprotected head were equal, accounting for more than 90% of total dermal exposure. The addition of faceshields (S-4) produced further, but slight decreases in exposure (to 95% compared to the unprotected worker; to 81% compared to workers with coveralls), and hands again became the predominant source of exposure. When compared to Scenario 3, however, in which workers followed label requirements, exposure was reduced by 21%.

In light of the partial failure of the coveralls evaluated in this study to prevent exposure, it seems reasonable to ask whether improved coveralls would provide substantially greater protection. If 100% effective coveralls had been worn with gloves (S-5), only a slight decrease in exposure (to 94% compared to the unprotected worker; to 78% compared to workers with coveralls; only 6% compared to coveralls + gloves) would have occurred, with remaining dermal exposure distributed equally between the protected hands and unprotected head. Thus, use of faceshields would provide greater exposure reduction under these conditions than further efforts to provide truly chemical resistant coveralls. The final scenario (S-6) indicates use of faceshields and improved coveralls would reduce exposure by 27% when compared with the label-required PPE used in this study.

5.5.2 Dermal and Respiratory Dose Scenarios

Estimation of absorbed dose from dermal and respiratory exposure values requires quantitative absorption factors for each exposure route. The dose estimate produced here assumed that oral exposure was negligible. While this assumption is probably correct under these study conditions, oral exposure may occur when workers who have not washed their hands thoroughly

handle food and cigarettes or place other materials in their mouths. An absorption factor of 1.0 (100%) was assumed for respiratory exposure. This factor likely overestimated respiratory dose since some fraction of the inhaled aerosol may have been exhaled, and an additional fraction may have been deposited in the airways, bound to mucous, and swallowed, thereby contributing to oral exposure. Notwithstanding these considerations, the lack of an experimentally generated absorption factor for ethion inhalation makes the assumption of 100% absorption the valid estimate of dose at present.

An absorption factor of 0.033 (3.3%) was assumed for dermal exposure, based on controlled percutaneous absorption experiments in humans (Feldmann and Maibach 1974). The use of a single percent absorption value for dermal exposure is probably not accurate for several reasons: 1) percent absorption varies with skin loading and can be affected by the vehicle in which the toxicant is administered; in the experiment cited above loading was 4 $\mu g/cm^2$ in acetone, whereas in the field study ethion loading in a water vehicle was much higher in some cases (*e.g.*, hands, unprotected head) and much lower in others (*e.g.*, regions beneath coveralls); 2) percutaneous absorption varies across body regions and across individuals; 3) workers' skin may not have stratum corneum barrier properties intact relative to volunteers in controlled experiments. Despite these concerns the 3.3% absorption value is the best available information regarding dermal absorption of ethion.

Absorbed dose estimates (µg/hr) have been generated by multiplying these absorption factors by the mean exposure estimates calculated in this study (Table 5.8). Four scenarios have been created to estimate the impact of PPE options on total absorbed dose. In all scenarios workers wear the cotton or Sontara coveralls and nitrile gloves. This PPE combination serves as Scenario 1. In Scenario 2 a respirator only is added. In Scenario 3 a faceshield only is added. In Scenario 4 an idealized chemical resistant coverall only is added.

In Scenario 1 the total aborbed dose was 156 µg/hr, with the following distribution: hands, 37%; head, 37%; inhalation, 20%; protected body, 5%. Thus, addition of a respirator (S-2) reduced dose by 20%, roughly equivalent to the 17% reduction produced by use of a faceshield (S-3). Use of completely effective coveralls reduced dose by only 5%. Label requirements for respirator use appear justified by these calculations, since the respiratory route was responsible for a substantial proportion of absorbed dose despite an extremely low exposure estimate relative to total dermal exposure. Gains in reduction of total absorbed dose could also be made by providing greater protection for the face and head.

Table 5.8 Ethion Dose Estimates and Reduction by Personal Protective Equipment [A]

	PPE Scenario	PERCENT EXPOSURE REDUCTION (vs. Scenario 1)	ABSORBED DOSE RATE (µg/hr)	PERCENT ABSORBED DOSE Protected			
				Hands	Head	Body	Respiratory
1	Cotton or Sontara Coveralls + Gloves	---	156	37.3	37.1	5.1	20.5
2	+ Respirator[B]	20.5	124	46.9	46.6	6.5	0
3	+ Faceshield[C]	16.7	130	44.7	24.6	6.1	24.6
4	+ Chem Resistant[D] Coveralls	5.1	148	39.3	39.1	0	21.6

A Dose estimates based on dermal absorption factor of 3.3% (Feldmann and Maibach 1974) and a respiratory absorption factor of 100%

B Assumes respirator provides 100% protection

C Assumes faceshield protects 44.7% of head (527/1180 cm^2)

D Assumes chemical - resistant coveralls replace cotton or Sontara and provide 100% protection

SECTION 6.

DISCUSSION

These studies have demonstrated that coverall garments similar to those used routinely by pesticide applicators did not provide the levels of protection expected. Dermal exposures occurred both due to garment design and chemical breakthrough of fabric. No significant improvement in protection occurred when nonwoven garments were substituted for traditional woven garments. Indeed the nonwoven garments suffered from the most serious flaws in design, and provided little if any increased resistance to chemical penetration.

The use of fluorescent tracers and video imaging analysis clearly documented substantial exposure to the arms of workers wearing garments with large sleeve openings. When this design failure was rectified, little tracer exposure could be detected on the protected body. 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, whereas chemical analysis of patch extracts detected <10 ng/cm2. The techniques thus served complementary functions in documenting the limitations of chemical protective clothing performance.

Analysis of exposure distribution revealed that further improvements in protective coveralls would do little to reduce total dermal exposure or total absorbed dose of applicators under the field conditions tested. Proper use of such personal protective equipment as gloves, respirators and faceshields could provide greater exposure reduction than more chemically resistant coveralls. It should be noted that hand exposure may have been even higher than the values reported here. Recent studies in our laboratory indicated that only about 30% of the organophosphorous insecticide, chlorpyrifos, in a liquid formuation, was removed from hands by the ethanol handwash procedure used in this study (Fenske and Lu 1993). Further efforts should be directed at establishing accurate hand exposure assessments methods.

The findings of this study are consistent with those of an earlier study of protective clothing performance during airblast applications (Fenske 1998a; b). In that study exposure through

garment openings (neck and sleeves) was determined to be the major pathway for dermal exposure beneath coveralls. Findings regarding fabric penetration were also consistent with those of a recent study in which similar garments were tested with a similar applicator population (Nigg *et al.* 1992). In that study no significant differences ($p<.05$) were demonstrated between woven and nonwoven garments. The further finding by Nigg *et al.* that shoulder and hat patch deposition rates were similar was not supported by data in this study. Indeed use of patch values from these different locations produced dramatically different estimates of head exposure. Evidence from faceshield sampling indicated that torso patches may have overestimated head exposure by an order of magnitude.

The most important finding of Nigg *et al.* (1992) concerned the role of chemical protective clothing in exacerbating heat stress, and was confirmed by our observations. Use of such garments during high temperature, high humidity conditions places an excessive and potentially dangerous burden on workers. Label requirements for CPC must be qualified by limits on environmental parameters related to heat stress in order to strike a proper balance between protection and comfort.

SECTION 7.

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