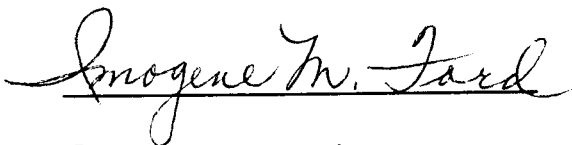


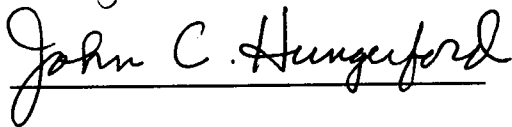
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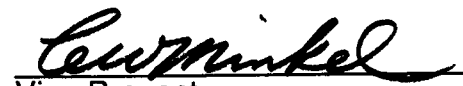

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**THE EFFECT OF SEAMS AND CLOSURES ON PESTICIDE
PENETRATION THROUGH FABRICS**

**A Thesis
Presented for a
Masters of Science Degree
The University of Tennessee, Knoxville**

**Carol A. Dimit
May 1989**

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ABSTRACT

The purpose of this study was to evaluate the effect of seams and closures on pesticide penetration through fabrics. Three studies were conducted. The studies all used a multilayer sample which either had a seam or zipper closure implemented into its top test layer. The multilayer sample was then sprayed in a lab in a spray chamber, extracted, and analyzed by a high performance liquid chromatograph.

A seam study and a zipper closure study were done with the pesticide Dicofo[®]. The seam study analyzed four fabrics and five seams, along with a 'no seam' which represented the base line or control. A Duncan's Multiple Range Test was performed on rankings. The analysis showed no significant differences among the seams due to the limited size of the sample. The zipper study analyzed five different zipper closures with the fabric Tyvek[®]. The study found through an analysis of variance that the lapped traditional zipper allowed the least amount of Dicofo[®] to penetrate. Out of sixteen replications only one sample allowed penetration for the lapped traditional zipper. The seam study for the pesticide Terrazole[®] analyzed the fabrics denim and Tyvek[®] with three seams, and a 'no seam' which represented the base line or control. The study performed an orthogonal contrast analysis. The analysis found the Tyvek[®] fabric provided a better barrier to Terrazole[®] than the denim fabric. The denim fabric with a seam provided a better barrier to Terrazole[®] than the denim samples with no seam. The Tyvek[®] fabric with a seam provided a better barrier to Terrazole[®] than the Tyvek[®] samples with no seam. Finally the seam that provided the best barrier to Terrazole[®] was the plain seam.

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CHAPTER 1

INTRODUCTION

Pesticide Hazards

The National Electronic Injury Surveillance System, NEISS, reported 16,934 pesticide poisonings in 1983, and 15,726 pesticide poisonings in 1985. The number of lethal poisonings as reported by the National Center for Health in 1984 was 148. The preceding estimate included poisonings by "agricultural and horticultural chemicals and pharmaceutical preparations other than plant foods and fertilizers" (National Center for Health Statistics, 1984). It is important to note that the occupational age group 25-64 accounted for 66% of this total of lethal poisonings.

The year 1986 further revealed health problems caused by chronic exposure to pesticides (McDonald, 1987). A study conducted in Kansas by the National Cancer Institute revealed that farmers who were exposed to herbicides more than 20 days each year had six times the risk of developing non-Hodgkins Lymphoma as compared to non- farmers. The study also revealed that farmers who did not use protective equipment had a 40% higher risk of getting this type of cancer than those farmers who practiced protective measures.

Benefits of Pesticides

This growing body of evidence exposes the hazards of pesticides; why then do we use pesticides? It has been through the use of pesticides that man has been able to improve the quality of the environment for himself, for domestic animals, and for plants. In 1850 a United States farmer was able to produce only enough food for himself and three other people (Bohmont, 1981). One hundred years later, due to the advent of pesticides a United States farmer could produce enough food for himself and twenty-four other people. Today a United States farmer can produce enough food for himself and fifty other people (Bohmont, 1981).

Pesticides have also been of great economic benefit to the United States consumer. People in the United States spend 15% of their income on food--this is less than anywhere else in the world (Bohmont, 1981). The United States, and the world, have become dependent on the use of pesticides, and chemicals in general. "If we are to have the benefit of a range of chemicals as a part of integrated pest management programs, regulations must take not only the negative, but also the positive side of the matter into consideration" (Barrons, 1981, p. 237). Our answer is in research, creating ways to protect us from the hazards, and educating the public on these modes of protection. Yet, research goals cannot stop here; they should also educate the public on the hazards, the benefits, and the need for pesticides.

Entry of Pesticides

Pesticide poisonings are capable of affecting all sites of the body, (Figure 1). The symptoms include any of the following: headache, blurred vision, sweating, salivation, miosis, dyspnea, elevated blood pressure, tachycardia, and coma.

Entry of pesticides can occur by three routes, oral, respiratory, and dermal. Dermal exposure is the most prevalent route of the pesticide (Wolfe, Durham, and Armstrong, 1967). The results from the Wolfe et al. (1967) study has spurred much research in the area of agricultural protective clothing.

Agricultural Protective Apparel Research

The purpose of this research was to determine if garment construction affects pesticide penetration. Fabrics, seams and closures were developed and tested for their ability to provide a barrier against pesticides. To meet this functional end, an approach must be developed. The approach is referred to as functional design, and involves a process that takes the designer step by step from the inception of the idea through the evaluation of the final design. DeJonge (1984) adapted a strategy developed by J. Christopher Jones (1970) to clothing design. DeJonge's adaption, the functional design strategy, is shown in Figure 2. In light of the many pesticide poisonings that occur every year (NEISS, 1984), and the fact that dermal exposure accounts for 87% of the total exposure experienced by agricultural workers (Durham & Wolfe, 1962; Maibach, Fieldman, Milby, & Serat, 1971), one can see the need for the development of protective apparel. The ongoing research, of which this

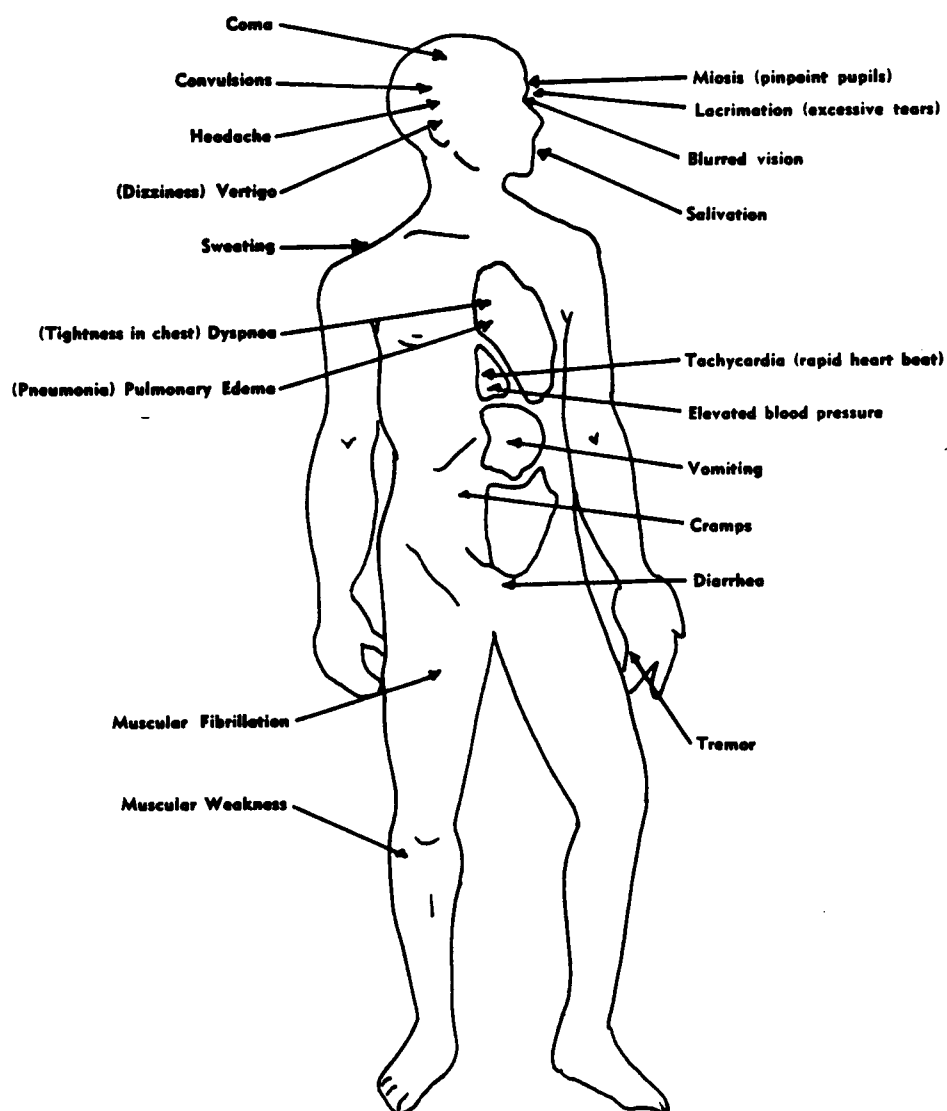


Figure 1. Symptoms of Pesticide Poisoning (Bohmton, 1981)

FUNCTIONAL CLOTHING DESIGN PROCESS AND STRATEGY SELECTION

	2 Design situation explored	3 Problem structure perceived	4 Specifications described	5 Design criteria established	6 Prototype developed	7 Design evaluation
1 Request made	1.2 State general objective Brainstorming User interview and observation Visual inconsistency Literature search					
2 Design situation explored		2.3 Brainstorming Observation analysis Market analysis Literature search Identification of critical factors Definition of problem				
3 Problem structure perceived	3.2 Brainstorming Visual inconsistency Reassess critical factors		3.4 Activity assessment Movement assessment Impact assessment Thermal assessment Social-psychological assessment			
4 Specifications described	4.2 State objectives Check specifications against objectives	4.3 Reassess critical factors		4.5 Charting Ranking and weighing Prioritizing		
5 Design criteria established	5.2 State objectives Check criteria against objective	5.3 Identify critical factors	5.4 Literature review of assessment areas to check specifications		5.6 Materials testing Technique evaluation Brainstorming Creative integration Solutions weighed against criteria	
6 Prototype developed	6.2 Visual inconsistency Identify objective User interview	6.3 Identify critical factors	6.4 Literature review of assessment areas	6.5 Rank order specifications		6.7 Specification testing User satisfaction

Figure 2. Functional Design Process and Strategy Selection (DeJonge, 1984)

study is a part , has been aimed at developing protective agricultural garment. The garment design should have several critical factors: (a) it should provide a barrier to pesticide penetration; (b) it should be thermally comfortable; (c) it should be an acceptable mode of protection to the agricultural worker; and (d) it should be affordable. The researchers were aware of the paradox created by these often conflicting objectives, but their hope was to establish a criteria with tradeoffs that would best fulfill these goals. The first stage of the strategy, developed by DeJonge (1984), identified the general areas the research would explore: (a) to determine agricultural attitudes and preferences for protective clothing (Henry, 1980); (b) to conduct a market analysis on protective clothing and to determine what the farmer would actually wear (King, 1984); and (c) to develop thermal analysis (Branson, 1982) and impact analysis studies in terms of deposition and penetration of the pesticide (Easter, 1982; Leonas, 1986; Orlando, Branson, Ayres, & Leavitt, 1981). The present research is in the technique evaluation stage of the functional design process. Previous research has identified fabrics that provide a pesticide barrier and are thermally comfortable and affordable (Branson, 1982; DeJonge & Easter, 1987). In this technique evaluation process, fabrics that have already been identified as protective barriers are utilized, and an attempt is made to determine how different types of seams and zipper closures will affect pesticide penetration.

Purpose of the Study

Nielson and Moraski discussed protective clothing and the agricultural worker at the 1984 International Symposium on the Performance of Protective

Clothing. The article pointed out issues and problems that needed to be analyzed as established by the 1981 Hazard Evaluation Division group from the Office of Pesticide Programs. One of the research issues that was identified by the group was to "determine the effects of clothing design for example, seam leakage, on protective capability" (Nielson & Moraski, 1984). The findings of the Hazard Evaluation Division helped pinpoint the direction of this study. The goal of this research is to determine if garment construction affects pesticide penetration. The objective of this research was to determine which of the various constructions for seams and zippers provide the least amount of pesticide penetration.

The research first investigated whether the independent variable of type of seam revealed a greater difference in penetration, or if the independent variable of fabrics revealed the greater difference in pesticide penetration. In addition, the research investigated which seams and which zipper closures provided the best barrier to pesticide penetration. The null hypotheses are stated below.

Hypotheses:

- 1) There is no significant difference between the types of seams and fabrics in terms of pesticide penetration.
- 2) There is no significant difference between the types of seams in terms of pesticide penetration.
- 3) There is no significant difference between the types of construction used for the zipper closures in terms of pesticide penetration.

Limitations of the Study

- 1) Only two pesticides were used in the study.
- 2) Only four fabrics were used in the study.

CHAPTER II

REVIEW OF LITERATURE

Dermal exposure accounts for 87% of the total body's pesticide exposure (Wolfe et al., 1967). The deposition of pesticide can occur on the exposed and on the clothed areas of the skin surface. The exposure of pesticide is determined by the overall deposition of pesticide on the workers' body. Clothing can be designed to serve as a barrier to pesticide penetration, and therefore limit the amount of pesticide that is deposited on the workers' body.

The research discussed here is concerned with evaluating the effectiveness of seams and closures as a barrier against pesticides. Deposition, penetration, fabric, and seam or closure location, will be important in determining where and how pesticide exposure occurs on the body.

Deposition

Traditional pesticide exposure studies assumed any clothing worn by the agricultural worker provided complete protection from the pesticides, they looked at the deposition of the pesticide only on the exposed skin surfaces of the face, hands, forearms, and the 'v' of the neck (Batchelor & Walker, 1954; Batchelor, Walker, & Elliot, 1956; Comer, Staiff, Armstrong, & Wolfe, 1975; Lavy, Mattice, Fynn, and Davis, 1982; Wolfe, Armstrong, & Durham 1966; Wolfe, Durham, & Batchelor, 1961). Batchelor and Walker (1954) determined the amount of Parathion® exposure that came in contact with the unprotected

areas of the agricultural workers' skin. The workers applied various concentrates of Parathion® emulsions and suspensions with high pressure hand or air blast spray equipment. Respirator filter pads 2 3/4 inch in diameter were attached to various parts of the body or clothing with masking tape. The locations were the back of the forearms, the front of the thighs, the top of shoulders, the back of the neck, and the front of the neck (jugular notch). The pads were in position for one or two cycles. The high pressure hand sprayers sprayed one entire apple tree which lasted approximately 6 minutes. The air blast sprayer's cycle included the loading operation and the period from loading until the tank was emptied, approximately 5-12 minutes. After the exposure period the pads were placed in individual petri dishes and sent to the lab. A 1.56 inch square was cut from the center of each pad and the parathion was extracted with a Soxhlet® extractor. A total of 119 dermal pads were collected and these were divided among the high pressure and air blast spray operations.

In general, the results for the high pressure spraying had the heaviest deposit on the forearms (20.25 mg/ft²/hr); with slightly less on the shoulders (13.75 mg/ft²/hr), thigh (10.35 mg/ft²/hr), chest (8.2 mg/ft²/hr), and the back of the neck (5.9 mg/ft²/hr). The results for the air blast spraying had the heaviest deposition on the shoulders (26.25 mg/ft²/hr), the forearms (25.95 mg/ft²/hr), and the thighs (23.3 mg/ft²/hr); with somewhat less on the neck (12.2 mg/ft²/hr), and the chest (9.0 mg/ft²/hr). These results were then used to compute the dermal exposure that occurred to the exposed skin surfaces. First the surface area of the unclothed body parts was calculated by Berkow's method (1931). The shoulder values were used for facial exposure, and the forearm values for hands. The air blast sprayers received the highest deposits

on their forearms (33.8 mg/body part/hr) and their hands (22.6 mg/body part/hr); with slightly less on their faces (18.4 mg/body part/hr); and the least amount on the back of their neck (1.5 mg/body part/hr) and the front of the neck (1.4 mg/body part/hr). The high pressure hand sprayers also received the highest deposits on their forearms (26.4 mg/body part/hr) and hands (17.7 mg/body part/hr), with slightly less on the face (9.7 mg/body part/hr); and the least amounts being on the front of the neck (1.3 mg/body part/hr), and the back of the neck (0.7 mg/body part/hr).

A study conducted by Batchelor and Walker (1956) also used the 2 3/4" respirator pads to measure dermal exposure. In this case they were measuring the exposure of agricultural workers to Dinitroorthocresol® from apple thinning sprays. The pad locations, spraying cycles, and extraction procedures replicated the procedures used in the Batchelor and Walker (1954) study. However, this study stated the following assumption: the operator wore a shirt with short sleeves, an open collar, and no hat or gloves; and the clothing gave complete protection to the area it covered. The study gave the amount of pesticide that was deposited on each of the pads and then used this data and Berkow's method to determine the amount of pesticide deposition that could occur on the exposed skin areas of the sprayers body. It is interesting to note that there were pads placed on the thigh area, as in the previous study, but the amount of pesticide deposition was not mentioned in this study.

Once again it was determined that the highest areas of deposition would occur on the forearms (27.2 mg/body part/hr) and the hands (18.2 mg/body part/hr); with slightly less on the face (14.2 mg/body part/hr); and the least

amount being deposited on the back of the neck (2.0 mg/body part/hr), and the v of the chest (1.6 mg/body part/hr).

Culver, Caplan, and Batchelor (1956) conducted a study on the exposure of workers during the application of Malathion® and Chlorthion® as a method for mosquito control. The dermal exposure was conducted using 1.5" by 16" absorbent alpha cellulose headbands and 1.5" by 8" bands around the ankles, under the pants, but over the socks. Cotton knit gloves were worn on the right or the left hand and were alternated for each succeeding exposure. The workers wore long sleeved shirts buttoned at the neck and wrist to protect them from mosquito bites. Square pads 4"x4" were taped at the forearms and the back and front of the neck, on top of the clothing, to determine the exposure this skin area would have received, if the worker had worn short sleeves with an open neck. Once again the results of analysis from pads and bands related to the corresponding skin area, as in the Batchelor and Walker (1954) study. The pads and gloves were analyzed for Malathion® by a modified total phosphorous method, while they were analyzed for the Chlorthion® using a colorimetric method developed by Chemagro Corporation. The application occurred in three man teams. Three men were stationed in the upwind end of the field at 10, 17, and 25 yards. One man drove the jeep that carried the aerosol machine, while another man walked behind and along the upwind side of the machine to check its operations and clock the speed of the jeep.

The highest exposure once again occurred on the forearms and hands for all the workers. The exposure for the jeep driver's forearms was 108-242 mg of Malathion® and 3-5 mg of Chlorthion®, the pesticide that was deposited on his hands was 28-80 mg of Malathion® and 9-14 mg of Chlorthion®. The

man who walked behind the jeep had pesticide deposited on his forearms in the amount of 2-4 mg for both pesticides. The pesticide deposited on his hands was in the amount of 3-10 mg for Malathion® and 1-4 mg for Chlorthion®. The exposure for the field observers averaged about 3-5 mg of Malathion® and 2-4 mg of Chlorthion® for the forearms, and 2-5 mg of Malathion® and 1 mg of Chlorthion® for the hands.

The jeep driver who performed all formulating and transferring of materials received the highest exposure to his exposed skin areas (Malathion® 32-86 mg and for Chlorthion® 9-15 mg). It is interesting to note that he always wore cotton gloves under long heavy rubber gauntlets, yet his hand exposure from the cotton gloves was 27-80 mg. This represented 84% to 93% of his total skin exposure for the Malathion®, and for Chlorthion® it was 93-100% of his total skin exposure. Another interesting point occurred with the field workers, the band that was placed under the pants and around the ankle, had Malathion® on it (1-3 mg, 1-2 mg, and 2-3 mg). The exposure that occurred beneath the rubber gloves and beneath the pants was never acknowledged as penetration, nor was the assumption that clothing provided complete protection questioned in this study.

In 1961 Wolf et al. studied the health hazards of dinitro compounds. Once again they conducted dermal exposure studies using absorbent alpha cellulose pads; in addition, they used items of cotton clothing on various parts of the body, and hand washes with water in a polyethylene bag. They held the assumptions that the operators wore a shirt with short sleeves and an open collar, no hat or gloves, and that the clothing gave complete protection to the area it covered. The pads were placed on the shoulders, the 'v' of the chest, the back of neck, the forearms, the thighs, the legs, and above the

ankles. The amount recovered was recorded in mg/ft²/hr and then converted and calculated in terms of exposure for body parts.

The average dermal exposure for dinitro-*o*-secondary butylphenol (DNOSBP) was 88.7 mg/hr for the upper body exposed skin areas. The hands received the highest share, 87% of the exposed skin total. In the DNOSBP study considerable variation occurred in hand exposure between careful and careless workers, 29.6 mg/hr to 95.5 mg/hr. Also if the worker wore gloves this provided some protection, although penetration still occurred. If the worker wore gloves, the exposure was 22.4 mg/hr; and if gloves were not worn, the exposure was 91.1 mg/hr.

The study also looked at thigh, leg, and upper ankle exposure. The researchers found that the total deposition of spray for DNOSBP on these lower extremities came to 131.0 mg/hr, a higher figure than the 88.7 mg/hr for the unclothed parts of the body. In this case, they were looking at the body's total deposition for both the clothed and unclothed parts, but they were still extrapolating from pads placed on a particular body part. The highest area of deposition on the pads for DNOSBP was found on the thighs (118.9 mg/body part/hr), then the hands (77.3 mg/body part/hr), the legs (12.2 mg/body part/hr), and the forearms (9.7 mg/body part/hr); the least amount occurred on the face (1.1 mg/body part/hr), the 'v' of the chest (0.5 mg/body part/hr), and the back of the neck (0.1 mg/body part/hr), with a negligible amount occurring above the ankles. The highest area of deposition on the pads for dinitroorthocresol (Na-DNOC) was also the thighs (30.4 mg/body part/hr), with the forearms being the next highest area (11.0 mg/body part/hr), then the legs (9.2 mg/body part/hr), and the face (4.9 mg/body part/hr). The lowest deposition occurred on the back of the neck (0.7 mg/body part/hr), and the 'v'

of the chest (0.4 mg/body part/hr), with a negligible amount being deposited above the ankles.

Although this study, by Wolfe et al. (1961), made the traditional assumption that the workers' clothing provided complete protection to the area it covered, they also challenged this premise by questioning whether any DNOSBP reached the skin beneath the clothing. It would seem that researchers were beginning to forgo the assumption that clothing provided complete protection to the area it covered. In the study, several workers wore tee shirts under their clothing for 2.5-8 hours of the spray operations. At the end of each test period, the tee shirt was cut off and analyzed. The amount recovered was 0.004, 0.06, and 0.90 mg/hr. The study also determined the amount of DNOSBP penetration that occurred through shoes. Socks were worn for 2.5-10 hours during spray operations. The amount recovered was 0.004, 0.034, and 0.07 mg/hr. The highest penetration, 0.07 mg/hr, occurred for the operator wearing low cut canvas shoes; all the other operators wore leather shoes.

Durham and Wolfe (1962) described and evaluated methods for evaluating dermal exposure. One of the methods was the traditional procedure of applying absorbent pads at various points on the worker's body, and then allowing him to go about his usual spray operations for a specific amount of time. The pads were then removed and sent to a laboratory where the pesticide was extracted. Durham and Wolfe concluded that the drawback of the pad technique was that it was based on the assumption that the pad area was representative of the entire body part being measured. Another method described by Durham and Wolfe was the use of white cotton knit garments. Gloves were used to measure exposure to hands, while tee shirts

were used for measuring upper body exposure (the amount of toxicant that penetrated the outer clothing); and socks were used to measure the amount that penetrated the shoes.

The past studies made several assumptions: patches could represent the entire body parts that were being measured; the shoulder pads were representative of the face; the clothing worn was a short sleeve shirt with an open collar with no gloves or hats; and finally clothing provided complete protection to the body part it covered. At times the previous studies challenged these assumptions and found that penetration was occurring beneath the outer clothing, that the lower body received a high deposit of pesticides, sometimes higher than the exposed skin surfaces (Wolfe et al., 1961). Yet research conducted by Wolfe et al. (1963, 1966, and 1974), by Comer et al. (1975), and by Lavy et al. (1982), still maintained these assumptions and utilized the traditional dermal patch method as described by Durham and Wolfe (1962).

Penetration

Penetration is defined as the flow of the liquid at a nonmolecular level through closures, porous materials, seams, pinholes, or imperfections in a protective clothing material (Schwope, 1983). The context of this study was to evaluate the penetration of pesticide through various textiles, seams, and closures. Textiles that provide the best barrier to pesticides and the textile/penetration interaction must be considered. The textile/penetration interaction is a process that, "is largely governed by capillary forces owing to the tight packing of the fibers: the yarns act as wicks" (Freed, Davies, Peters,

& Parveen, 1980). A tightly woven fabric with long smooth yarns wicks more quickly and easily than a fabric with randomly arranged fibers in its yarns, or in a fabric structure without yarns (Orlando et al., 1981). Kim and Kim (1987) found that a lighter, higher-count, finer yarn fabric would have smaller interfiber and interyarn capillary radii, which would thus tend to increase the transporting capacity of a pesticide. Raheel (1988) determined that the resistance of a fabric to penetration depended on its chemical nature, geometry, and roughness of fiber surfaces, as well as on the capillary spacings in the yarns and fibers ends. Raheel (1988) also pointed out that textiles do not have ideal surfaces and under dynamic conditions such as encountered by pesticide application conditions, the porosity of a fiber, yarn and fabric is important. To avoid film formation and capillary transport of the pesticide, Raheel found that the fibers should be uniformly separated with discontinuous capillaries and held in the fabric so that the surface tension of the liquid cannot pull them together. This would point to the spunbonded and fusion bonded nonwoven fabrics as the ideal candidates for presenting such a configuration. Yet, Raheel also found that if one were to apply a finish to a textile this finish would mask the effects of fiber chemistry and porosity. One hundred percent cotton and cotton/polyester blends were found to exhibit the same good barrier properties as the spunbonded Tyvek® fabric. These results are attributed to the decrease in surface energy of the fabric, hence an increase in interfacial tension between liquid and fabric.

Freed, Davies, Peters, and Parveen (1980) analyzed the repellency effectiveness of several fluoroaliphatic resins on a 100% cotton fabric and a 65/35% polyester/cotton denim fabric. The study differed from the traditional pesticide exposure study in that it attempted to test fabrics and treatments that

would provide barriers to pesticide penetration. Direct spraying of pesticide emulsions on the treated cloth samples were used with an alpha cellulose pad placed behind the test fabric to provide a collector layer. The samples were sprayed, and then extracted and analyzed by gas chromatography. This is a much more rigorous test of protection because relatively large amounts of the emulsion are directly impacted on the cloth as compared to the drift spray exposure experienced in the field. Another part of the study tested the penetration of the pesticide spray through a series of 50 μ l drops of pesticide emulsion applied at a 30° angle on the two study fabrics treated with Scotchgard®.

The results of the study indicated that textiles treated with fluoroaliphatic resin do have repellency to pesticide sprays. In all cases except with the chlorpropham, the Scotchgard® treatment improved repellency. One important finding of the study was that the type of fabric appeared to have an effect on the penetration of the chemicals. The 100% cotton allowed less pesticide to penetrate when compared with the 65/35% polyester/cotton denim. The reason for this is that the 100% cotton absorbs more liquid than the polyester blend. The fluoroaliphatic resin treatment not only reduced the amount of chemical deposited, but very substantially reduced the penetration of the pesticide through the treated textile. The reduction in penetration ranged from about 35% for chlorpropham to an over 1000-fold reduction in the case of pentachlorophenol. It was apparent, that the type of fabric had a significant effect on the penetration of pesticides for the untreated samples. The 100% untreated cotton samples allowed less penetration of the pesticides tested than the polyester blend untreated samples. However, the treated samples had nearly the same repellent properties for the compounds. The fabric

make-up was not as significant when a Scotchgard® treatment was applied to the textile.

The researchers from this study felt that the cotton fabric, with its high absorbency, provided better protection than the synthetic woven fabrics. They felt cotton garments of sufficiently heavy weave would afford substantial protection to the operator during normal spray applications. The researchers also felt that the Scotchgard® was an effective treatment in imparting repellency to clothing, and that it reduced the penetration of pesticides through cloth.

Orlando et al. (1981) used a laboratory controlled method to compare different fabrics in terms of pesticide penetration. A Beltsville Experimental Sprayer was adapted for the lab to allow uniform deposition of the pesticide Guthion® on the fabric samples. The samples were composed of a nine inch square assembly of a top test fabric, a middle fabric comprised of eleven layers of gauze and a foil bottom layer. There were six fabrics tested that comprised this top layer: a 100% cotton woven chambray; a Scotch-guard® treated sample of the same chambray; a Tyvek® 100% olefin spun bonded nonwoven; a Crowntex® single ply fibretex polypropylene web laminated with two plies of facial grade tissue with an adhesive binder; and two variations of Gore-Tex®. After spraying the samples, a three inch square was cut from the test layer, extracted and analyzed. Then a three inch square was cut from the gauze and foil layers and also extracted and analyzed by gas chromatography.

It was found that the Gore-Tex®, the Tyvek® and the Crowntex® gave 25 times more protection than the treated chambray. The treated chambray gave only 1.2 times more protection than the untreated chambray. The Tyvek® provided the best barrier to the pesticide with its mean penetration of

the test layer (amount found on the guaze layer) being 0.014 ug/cm², while the Crowntex® allowed 0.023 ug/cm² of penetration. The fabrics providing the least barrier properties were the two cotton chambray fabrics. As the chambray is a tightly woven fabric of smooth yarns, it has tendency to wick more quickly and easily than with a random arrangement of fibers in its yarns, or a fabric structure without yarns.

Davies et al. (1982) varied from the traditional dermal studies in that the research attempted to evaluate the efficacy of protective clothing rather than to quantify the total work exposure. The researchers did not hold the assumption that clothing provided complete protection, instead they looked at the amount of pesticide, ethion, penetration that occurred beneath the outer clothing. Another interesting aspect of the study is that the researchers did not have the traditional assumptions about the workers' attire. The research documented what each worker wore for one phase of the study, and for another phase of the study issued each worker a 100% cotton denim coverall of uniform design and weight, with or without a Scotchgard® treatment.

The patch was placed in only one location in this study, above the pocket on the inside and the outside of the garment. The percentage of the amount of pesticide that penetrated was determined by dividing the amount of pesticide residue found on the interior patch by the amount of pesticide found on the exterior patch and then multiplying this by a 100. The ethion penetration percentage means for workers who wore their own clothing was 27.6 for mixers and 16.5 for applicators; for workers who wore the untreated uniforms it was 4.0 for the mixers and 0.7 for the applicators; and for the workers who wore the treated uniforms it was 3.6 for the mixers and 0.6 for the applicators. In all phases, the mixers had a higher penetration of ethion. The

cotton coveralls appeared to provide the best barrier to pesticide, while the treated cotton coveralls slightly enhanced the barrier properties.

The study pointed out that clothing design and the fabric make-up were an important aspect in developing a garment which provided an optimum barrier to pesticide penetration. The fabric chosen in this study was a 100% cotton denim. It was chosen because of its high comfort value. Since spraying occurs during the hot summer months a breathable fabric was preferred by the workers. Thus the researchers in this study felt reassured when the denim demonstrated good barrier properties, and when the workers themselves indicated they found the garment comfortable.

Nigg, Stamper, and Queen (1986) conducted a study in which their primary purpose was to determine the degree of protection provided by Tyvek® coveralls. Subjects wore Tyvek® coveralls with alpha-cellulose pads placed at various body locations on and underneath the coverall and performed spraying and mixing-loading operations with the pesticide Dicofof®. The pads were extracted and analyzed by gas chromatography.

The highest deposition of pesticide occurred on the thighs-buttocks area of the applicators, 44%, and on the shins-feet area of the mixer-loader, 48%. The next highest areas of deposition for the applicators occurred on the shins-feet 28%; followed by 7% on the chest, upperarms, and forearms, and 5% on the back; with the least, 3%, occurring on the head-neck area. The next highest areas of deposition for the mixer-loaders occurred on the thighs-buttocks 39%; followed by 4% on the chest and forearms, and 3% on the back; and finally 1% on the head-neck and upperarms. In this study it was found that the applicators received 64% of their exposure to clothing below the waist, while mixer loaders received 87% of their exposure below the waist.

The study also determined that an applicator could reduce his total dermal exposure 38% by wearing a Tyvek® coverall, while a mixer loader could reduce his exposure by 40%.

Franklin et al. (1981) used a variation of the patch method along with the addition of a fluorescent tracer to the pesticide. The pesticide used was Guthion® 50, a wettable powder. Fourteen participants were issued a standard set of clothing consisting of cotton pants, a thin short sleeved cotton shirt, and a thick long sleeved coverall. The patch technique was used. The patches were surgical gauze pads mounted in cardboard lantern slide mounts and backed with impermeable plastic. These patches were pinned to the underside of the clothing on the chest back, the upper and lower arm, and the upper and lower leg. The patches were extracted twice with 50 ml of acetonitrile and then analyzed with gas chromatograph.

The fluorescent tracer was detected on the subjects' body through the use of long wave ultraviolet photography. Out of sixteen sets of patches nine had detectable levels of the pesticide Guthion®. The means (ng/cm² x kg) for the amount of Guthion® that penetrated the clothing of the workers were the front, 0.8, the back and upper arm, 0.6, the lower arm, 3.2, and the upper and lower arm, 0.4. The finding of Guthion® on the patches was consistent with the finding of tracer in these same areas.

Fenske, Leffingwell, and Spear (1985) also used a fluorescent tracer mixed with an organophosphate pesticide in air blast sprayers. The subjects conducted four complete spray cycles, with the exceptions of workers #5 and #6 spraying for a shorter time due to weather constraints, and worker #1 spraying only three loadings since he used higher concentrations. The clothing and equipment worn by the workers consisted of the following:

respirators, long sleeve cotton coveralls, and short sleeve cotton tee shirts. In addition, some workers wore extra shirts and work pants beneath this clothing.

This study modified the traditional dermal monitor as developed by Durham and Wolfe (1962). The monitor consisted of a solvent-extracted 12-ply surgical gauze pad (3x3 inch), backed by polyethylene, and placed in a paper envelope. Four dermal monitors were placed on each worker, two on the inside (on the right breast and the left shoulder blade), and two on the outside (on the left breast and right shoulder blade). These were then extracted and analyzed with gas chromatography.

Long wave ultraviolet light illumination revealed fluorescent tracer on the skin surface, and the pattern of exposure was digitized with a video imaging system. Quantifiable levels of tracer were found on all body parts of Worker #1. Worker #2 exhibited the highest exposure to his face, which was uncovered. High levels were also found on his hands even though gloves were worn. The most surprising finding was the elevated levels of tracer found on the worker's chest. This particular worker had worn a flannel shirt and tee shirt in addition to the tee shirt and coveralls issued. Protected areas accounted for 42% (worker #2) and 71% (worker #1) of the total exposure, for the two workers who had exposure to nearly all body regions. The study pointed out that the traditional assumption that clothing provided complete protection appeared to be in error. Based on the results of the fluorescent tracer data, the researchers felt it reasonable to argue that this assumption might be inappropriate.

Freeborg, Daniel and Konopinski (1985) analyzed the dermal exposure of lawn care specialists. They used the traditional pads, but differed from the procedure by only placing pads under the clothing of workers; in this sense

they were measuring pesticide penetration. The association of Agricultural Chemists analytical method 6.431-6.435 was used for the extraction of the dermal pads, and then they were analyzed by gas chromatography. Four exposure studies were done under actual conditions normal for the application procedure. The front and back body pads, as well as ankle pads, generally showed only traces or low levels of Diazinon®. The body pads with the greatest amount of contamination were found on the wrist and on the inner thigh just below the scrotal area. The mean dermal exposure for the right inner thigh was 315.5 ug/200 cm², and for the left inner thigh was 268 ug/200 cm². The study did not specify the type of clothing or fabric that was worn by the operators.

DeJonge, Ayers, and Branson (1985) varied from the traditional patch method, they used visual ultraviolet and colormetric analytical techniques to evaluate the spray deposited on human subjects' clothing during air blast spraying. In this study the total garment was analyzed for pesticide deposition; the researcher was no longer assuming that a single patch could represent an entire body part. The study also only looked at the deposition that occurred on the clothing and made no assumptions about the exposed skin surfaces.

The subjects, tractor operators, wore control garments, hooded jumpsuits, made of white Gore-Tex®. The spray solution contained a fluorescein dye that was added at rates that simulated pesticide use. Following the exposure of the garments during air blast spraying, the garments were taken and cut into back and front sections, and mounted on a styrofoam board. The sections were sprayed with 2.5% starch solution to activate the dye and then they were photographed with ultraviolet light.

The visual inspection of the slides demonstrated a higher dye deposition for high volume spraying than for the low volume spraying. The specific body parts that repeatedly received greater deposits were the head and shoulder area in both the front and back and the front torso and upper leg areas.

As the visual analysis was a subjective procedure, colormetric analysis provided the necessary backup documentation. The colormetric analysis began with the garment being cut into 14 body part sections. These sections were then individually placed in a bag of distilled water and agitated by hand and then the liquid was removed and saved in a vial. The fabric section was repeatedly rinsed until the solution no longer emitted any color. The volume within each vial was recorded, and then a liquid sample was examined with a spectrophotometer. The concentrations were plotted as absorbance in units of $\mu\text{g}/\text{ml}$. Each of the specimens was then dried, weighed, and its area determined. From the colormetric analysis and the sample areas, the amount of dye in units of $\mu\text{g dye}/\text{cm}^2$ was obtained. The mean values for pesticide deposition for the high volume ranged from 1.67 to 25.79 $\mu\text{g}/\text{cm}^2$. The values for the low volume ranged from .87 to 5.15 $\mu\text{g}/\text{cm}^2$. Both the ultraviolet and colormetric analysis confirmed the results for highest areas of deposition to be: the head (24.3mm $\mu\text{g}/\text{cm}$), front upper arm and back upper torso (over 20 $\mu\text{g}/\text{cm}$), and the front upper legs (11.86 $\mu\text{g}/\text{cm RV}$).

Slocum and Shern (1988) also used visual ultraviolet and colormetric analytical techniques to evaluate the pesticide spray deposited on clothing. In this case, the researchers were evaluating the pesticide exposure of lawn care specialists. The clothing worn by the participants were long sleeved white nylon coveralls and gloves. After the applicators had completed their walk the suits were dried, photographed and cut into 23 pieces corresponding

to the areas of the body. The pieces were then weighed and the area was calculated for the weight of a 2 x 2 cm square. A standard spectrophotometric analysis was done after four rinses in distilled water. The most significant amounts of dye were found on the lower portion of the body, both front and back. The greatest amount of dye was below the knee. The second largest amount of dye was on the hands.

The Abbott , Bonsall, Chester, Hart, and Turnbull (1985) study also used a control garment as the collection medium for the pesticide, 2,4-dichlorophenoxy acetic acid. The traditional patch studies would collect only a representative sample of the total pesticide exposure and then interpret it with surface area extrapolation. In this study, the exposure would be determined from the total garment. The control garment used was a disposable Strentex Corovin® coverall, with Strentex Tyvek® gauntlets, hoods, and white nylon socks. The gauntlet, socks, and hood were extracted whole, while the coverall was sectioned into the following portions: arms, body front and back, and both legs above and below the knee. The analysis was done using a high pressure liquid chromatography.

The dermal exposure from mixing and loading was predominately to the hands, accounting for 76% of the exposure when the worker loaded the tractor drawn hydraulic sprayer and 94% of the exposure when the worker loaded the tractor mounted controlled droplet applicator (CDA) sprayer. Exposure for the spraying was also predominately to the hands accounting for 58% when the worker operated the tractor drawn hydraulic sprayer; 66% when the worker operated the tractor mounted hydraulic sprayer; and 86% when the worker operated the tractor mounted CDA. Knapsack spraying resulted in a higher percentage of exposure to the legs, left lower leg, 39.1% and 24.3%,

and right lower leg, 42.4% and 27.3%. The lower legs were also the next highest area of exposure in the tractor drawn and mounted machinery.

A study by Fenske (1988) found one of the highest areas of deposition for pesticide spray applicators to be on the torso/arms, 4.86 mg, or 63.8% of the total body exposure. The head/neck area exposure was found to be 1.81 mg, or 23.8% of the total body exposure; while the hands accounted for 0.95 mg, or 12.4% of the total body exposure. The mixers highest deposition area was on the hands (1.84 mg, or 43.3% of the total body exposure); followed by the torso/arms area (1.54 mg, or 36.2% of the total body exposure); with the least amount being deposited on the head/neck area (0.87 mg, or 20.5% of the total body exposure).

The study's primary purpose was to determine whether the fluorescent tracer technique could provide a valid relative measure of dermal exposure. The correlation between dermal exposure and the urine analysis was very high ($r=0.89$) which suggests that the fluorescent tracer deposition is a valid method for determining dermal exposure during pesticide application. In this study, nineteen workers conducted mixing and high-volume airblast spraying. Throughout the study, the workers were monitored simultaneously by urine analysis and fluorescent tracer evaluation for dermal exposure. The study was held in the citrus groves of the Central Valley of California. The sample consisted of seven mixers and 14 applicators, one mixer worked with two applicators each day. All workers wore baseball caps, half-mask respirators equipped with pesticide cartridges, neoprene gloves, work boots, 100% cotton tee shirts, 65/35 cotton/polyester work pants, and either 65/35 cotton/polyester coveralls or 50/50 cotton/polyester work shirts.

The instrument employed to quantify dermal fluorescence was a

computer-based image processing system interfaced with a television camera. The camera makes a single scan and the image is captured by the computer and written onto a disk as a digitized video image. The workers were examined in a darkened room under long-wave ultraviolet light (320-400 nm) before they began working and immediately after the exposure period. The video images that were recorded were for the following body parts: head, hands, left and right forearms, left and right upper arms, and torso. There was no exposure detected on the legs. The traditional gauze patches were employed in order to determine the relative deposition of Malathion® and tracer. These patches were attached on the outside of each workers' clothing at the following locations: head, shoulders, back, chest, forearms, thighs, and lower legs. The urine was collected initially as a preexposure sample, and then additional samples were collected every 8 hours for 3 days. The Malathion® and tracer were extracted in acetonitrile and analyzed by gas chromatography and spectrofluorometry.

Summary

The studies reviewed here have identified the parts of the body that receive the most pesticide penetration; either through the traditional patch method or an adaption of the patch method or through the addition of fluorescent tracers to the pesticide. They all seem to be in agreement that the forearm, the thigh and the chest receive the highest deposits of pesticide. In comparing these findings with the results from a study done by Maibach et al. (1971), it becomes clear that there is a need for protective clothing. The Maibach et al. (1971) study applied pesticides labeled with radioactive carbon

directly onto the skin of volunteers; the purpose was to study the effect of anatomic site on pesticide penetration. The results for Parathion® found that the under arm absorbed 64% of the pesticide applied, the upper forearm 29%, the scrotum 100%, and the abdomen 19%. These results demonstrate the need for providing a barrier between the skin and the pesticide with clothing; furthermore, this clothing must be specially designed to provide the extra protection needed for these high pesticide deposition areas, and high absorption areas of the skin.

Wolfe et al. (1961) identified the thigh as being one of the highest areas of deposition with 118 mg/body part/hr; Nigg et al. (1986) identified it as a high deposition area receiving 44% of the total pesticide body exposure; while DeJonge et al. (1985) stated it as a high area with 11.86 mg/cm. The necessity of clothing providing a barrier to the pesticide becomes crucial; even more so when you relate it back to the Maibach et al. (1971) study. Skin in the area of the scrotum, absorbs 100% of the pesticide that is deposited on it.

The upper torso/arms was identified as a high deposition area by Batchelor et al. (1954) with 26.25 mg/ft²/hr for the shoulder and 25.95 mg/ft²/hr for the forearms; by Franklin et al. (1981) with 0.8 ng/cm x kg; by DeJonge et al. (1985) with 20 ug/cm for the front upper arm and back upper torso; and by Fenske (1988) with 4.86 mg on the upper torso/arms which was 63.8% of the total body exposure. Once again, the need for clothing to provide a barrier to pesticides becomes a necessity, especially when compared with the results of Maibach et al. (1971) study. The skin on the upper forearm absorbs 29% of the pesticide, the under arm 64%, and the abdomen 19% of the pesticide.

Now that it has been established that pesticide is deposited on the skin beneath protective clothing, it becomes apparent that further research needs

to be done in the area of protective apparel. One aspect of protective apparel for pesticides that has not been developed is the seams and closures which are used in the protective garment.

A study conducted by Staiff, Davies, and Stevens (1982) distributed several dozen of the various types of semi-disposable jackets, or jacket and trouser sets, to orchardists to use during spraying in very high temperatures. Nearly all the applicators felt the garment provided adequate protection. However, some of the garments leaked around the seams. As the shoulder seams (the shoulder being an area of high pesticide deposition) became stretched, they allowed leakage either through the seam or through the elongated stitch holes. Staiff et al. (1982) felt additional research needed to be conducted in developing better seam designs. This study's purpose is to evaluate seam and closure designs and determine those which best provide a barrier to pesticides.

Seams and closures, as stated by Berardinelli and Cottingham (1986), are the 'limiting' factor in protective apparel. This study will focus on the testing of seams and closures and evaluating them for their barrier properties in terms of pesticide exposure. It will take into consideration the areas in which these seams and closures will be located; whether they are in an area of high deposition, and or high skin absorption.

CHAPTER III

METHODOLOGY

Previous research had identified fabrics that provided adequate protection from pesticide penetration (DeJonge, Easter, 1987), yet they were breathable, and the research had identified the areas of the body receiving the highest amount of pesticide deposition (DeJonge, Ayers, Branson, 1985). The direction of this study, in terms of the functional design process, was in technique testing. Seams and closures were to be tested for their barrier properties in terms of pesticide penetration. The following chapter includes the initial market analysis, the experimental design, the fabrics, the sample preparation, and information on the pesticide. The chapter also includes lab procedures for the contamination, the cutting, the extraction, and the analysis of the samples.

Market Analysis

A market analysis was undertaken to determine what types of protective apparel were available in today's market. A letter was sent to 80 companies requesting information on protective apparel. Thirty companies sent pamphlets in response to the letter. The pamphlets were reviewed and outfits were selected and either purchased from the company, or donated by the company. The garments were then analyzed to determine the different types of seams, zippers, and zipper closures utilized in the industry. All of the garments reviewed and the protective garments available to the farmer in the

farm stores were made of a Tyvek® fabric. Both metal and nylon zippers were utilized. The seams were an overlock stitch 504 and the plain stitch 301 as determined by Federal Standard 751a (Hudson, 1988) . The thread was synthetic, 100% polyester, and the amount of stitches averaged 4 stitches per centimeter (10 stitches per inch). Some of these designs were then replicated in this study along with several experimental designs.

Experimental Design

The seams (six variations), design of closures (five variations), and the fabric (four variations) were the independent variables. The dependent variable was the pesticide penetration, the pesticide Dicofol® was used in the first seam experiment and the closure experiment, and the pesticide Terrazole® was used in the second seam experiment. The seam experiments were conducted with five replications for each sample in the study. The closure experiment was conducted with sixteen replications for each sample in the study. The sampling diagrams which illustrate the randomization for the samples in each study are shown in Appendix A.

The first seam experiment used a two way analysis of variance to test the effect of fabrics and seams (independent variables) on pesticide penetration (dependent variable) with the pesticide was Dicofol®. Thus a 4 x 6 factorial analysis was developed for the first experiment with five replications.

I. Fabrics:

- a) 100% Cotton Denim
- b) 100% Polyolefin Tyvek®
- c) 100% Polypropylene SMS®
- d) Polyester/Wood Pulp Sontara®

II. Seams:

- a) Plain
- b) Flatfell
- c) Bound
- d) Overlock Inside Seam
- e) Overlock Outside Seam
- f) No Seam

The second seam experiment conducted a two way analysis of variance on four seam types (independent variable), and two fabric types (independent variable), on pesticide penetration (dependent variable) with the pesticide Terrazole®. Five replications were conducted on each of the seam types. The experiment was a 4 x 2 factorial analysis of variance.

I. Fabrics:

- a) 100% Polyolefin Tyvek®
- b) 100% Cotton Denim

II. Seams:

- a) Plain
- b) Overlock Inside Seam
- c) Overlock Outside Seam
- d) No Seam

The closure experiment tested the effect of closures (independent variable) on pesticide penetration (dependent variable) with the pesticide Dicofof®. The experimental design was an incomplete block design with five treatments (zipper closures) arranged in block sizes of four. The incomplete block design is shown in Appendix A. Tyvek® was the control fabric used in this second experiment. Sixteen replications were conducted on each of the five closure types.

I. Fabrics:

- a) 100% Polyolefin Tyvek®

II. Closures:

- a) Centered
- b) Lapped Traditional
- c) Lapped Experimental
- d) Open Face Nylon Zipper
- e) Open Face Metal Zipper

The dependent variable, the amount of contaminant or pesticide, was evaluated by analyzing the extracts from the samples on a high performance liquid chromatograph (HPLC). The extracts were measured in ng/μl and converted to μg/cm². The detection limit of the analysis was .0258 μg/m².

Fabrics

Fabrics were chosen because they provided adequate protection from pesticide penetration as evaluated from a recent study by DeJonge and Easter (1987). Each of the fabrics used in the present study gave nondetectable measurements for the three pesticides used in the DeJonge

and Easter (1987) study. In addition, the denim fabric was chosen because it provided a barrier to the pesticides and because it is the most prevalent fabric worn by agricultural workers. Tables 1 and 2 give the descriptions and characteristics of the fabrics used in this study.

Sample Preparation

The denim was stripped of sizing by washing it one complete cycle with a one-half cup of Liquid ALL[®], and one complete cycle without detergent. This was an adaptation of the AATCC 135-1978. A Sears Kenmore[®] washer and dryer were used. A tee shirt knit (50/50 cotton/polyester), served as the pesticide collection layer and was also washed according to an adaptation of the AATCC 135-1978. The nonwoven fabrics were not washed.

The overlock seams were sewn with a mercerized cotton covered polyester thread, with a thread count of 10. The overlock seams were sewn on a Singer[®] Overlock, Professional #10 UJ 13. The needle used was a #2053. All the other seams were sewn on a Singer[®] Sewing Machine Model #28/08 with 100% polyester thread, with a thread count of 30. The needle used was a #80/11. The plain, flatfell, and bound seams were sewn with a 301 stitch (Hudson, 1988). The overlock seams were sewn with a 504 stitch (Hudson, 1988). For all the seams, four stitches per centimeter (10 stitches per inch) were used as that was the average number of stitches per centimeter found in the protective garments available on the market. The Sewing Procedures and figures of the seams and closures are shown in Appendix B.

A permanent marker traced a 6 x 6 inch template onto the face of the fabric. The template had a 7.62 x 2.54 cm (3 x 1 inch) rectangle in its

Table 1. Fabric Descriptions

Code	Common Name	Fiber Content	Construction	Finish
W25	Denim	100% cotton	Woven--twill	None
N1	Tyvek	100% polyethylene	Nonwoven--PB	None
N4	Sontara	polyester/wood pulp	Nonwoven	FL
N8	SMS	100% polypropylene	Nonwoven--SB/MB/SB	FL
PB--Point bonded SB--Spunbonded MB--Melt blown		FL--Fluorocarbon water repellent		

Table 2. Fabric Characteristics

Fabric	Thickness (mm)	Weight (gm/m ²)	Air Permeability (m ³ /sec/m ²)	Spray Rating	Yarn Count warp	Yarn Count fill
Denim	0.66	276.3	0.13	0	71	49
Tyvek	0.10	45.6	0.009	90	NA	NA
Sontara	0.32	72.7	0.298	90	NA	NA
SMS	0.29	62.4	0.056	70	NA	NA
The following methods were used: Thickness - ASTM D177-64 Weight - ASTM D3776-79 Air Permeability - ASTM D3737-75				Spray Rating - AATCC 22-1980 Yarn Count - ASTM D3775-79		

center--this was centered and traced over the seam or zipper closure. The fabric samples were composed of four layers, two layers of aluminum foil--one to catch backsplash, and one to simulate the skin. A layer of double knit 50/50 cotton/polyester, was the collector layer. The final layer was the test layer--the three fabrics used in this study along with their seam or zipper closure. Figure 3 illustrates the multilayer sample. First, the aluminum layers were placed in position. The aluminum's dull side was marked and faced downward. The next aluminum foil layer was placed on top of the other, its dull side facing downward and its 7.62 x 2.54 cm (3 x 1 inch) rectangle centered over the other aluminum rectangle. The next layer was the tee shirt knit and its 7.62 x 2.54 cm (3 x 1 inch) rectangle also faced downward and was centered over the aluminum's rectangle. The top layer was the test fabric and its 7.62 x 2.54 cm (3 x 1 inch) layer faced upward and was centered over the previous layer's rectangle. The layers were held together with 2.54 cm (one inch) pieces of double stick tape placed at the top and bottom of the sample. The samples edges were sealed with a 2.54 cm (1 inch) masking tape, folding 1.27 cm (1/2 inch) on the top and the other 1.27 cm (1/2 inch) on the bottom.

The four layer samples were placed in a conditioning room at least 24 hours prior to spraying. The samples were then brought into the lab just before spraying them. The conditions in the room were held constant at 70°F and 65% humidity. The decision for using these standard conditions was based upon the results of a previous study (Anastasakis & DeJonge, 1987).

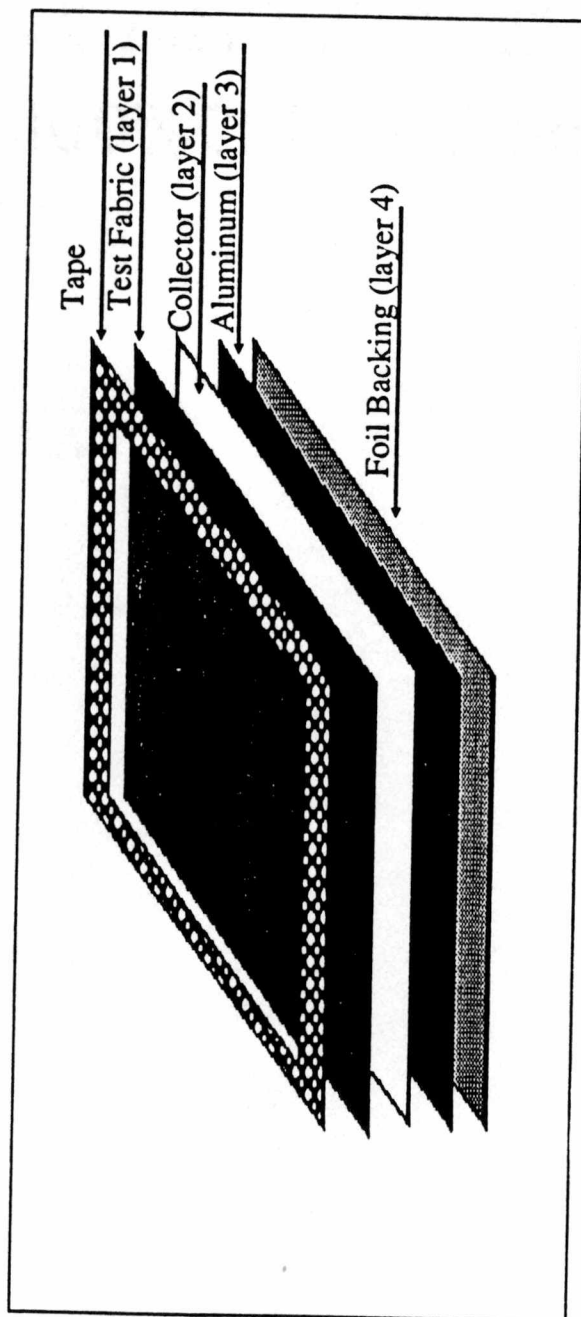


Figure 3. Multilayer Sample (DeJonge & Easter 1989)

Pesticide

The pesticides, Dicofol® (4,4-alpha-trichloro-methylbenzhydrol), a chlorinated hydrocarbon, and Terrazole® (5-ethoxy-3-(trichloromethyl)-1,2,4-thiadiazole), a thiadiazole, were used in this study. They are both moderately toxic. Dicofol® contains an active ingredient of 42%, while Terrazole® contains an active ingredient of 25%. An emulsifiable concentrate formulation was diluted in water to make a 12% solution of the pesticide. In order to obtain this 12% concentrate Matthews' (1979) equation was used. The equation had 'Q' as the diluent and 'A' as the active ingredient.

$$Q \times \frac{\text{percent concentrate required}}{\text{percent concentration of active ingredient}} = A$$

Dicofol®:

$$1000 \text{ ml} \times \frac{12\% \text{ concentration}}{42\% \text{ active ingredient}} = 2.8571 \text{ gm/liter}$$

Terrazole®:

$$1000 \text{ ml} \times \frac{12\% \text{ concentration}}{25\% \text{ active ingredient}} = 4.8 \text{ gm/liter}$$

Spraying of the Fabric

The fabric samples were contaminated in a spray chamber designed to simulate a field spray application (Leonas, DeJonge, Duckett, 1987). The chamber (Figure 4) provides a flexible nozzle size; in this study a TeeJet® #730023 nozzle was used. The spray chamber operated at a pressure of 40 psi, which produced a 52° angle fan spray and a good dispersion of the spray pattern (Leonas et al., 1987). A plastic bottle contained the pesticide solution and a magnetic mixer maintained the pesticide formulation in suspension. The height of the nozzle was 30.48 cm (12 inches) above the samples. The fabric

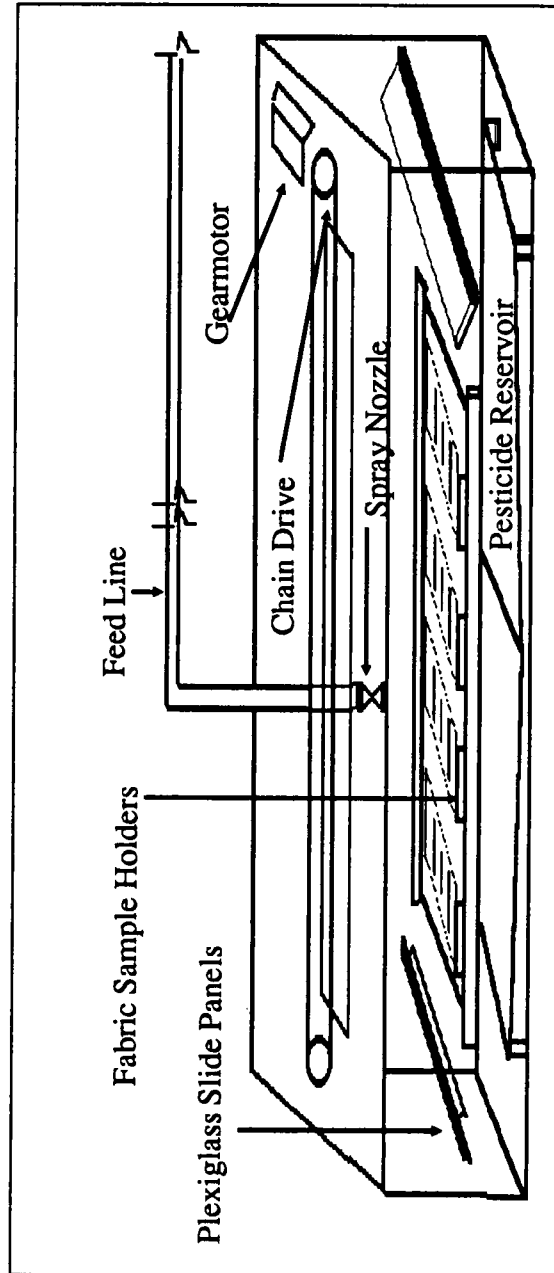


Figure 4. Spray Chamber (DeJonge & Easter, 1989)

samples were placed on a frame and held on with metal clips. The spray chamber housed four of these frames, labeled A-D, which were placed at an angle of 90° from the spray nozzle.

The fabric samples with their replications were randomized and labeled according to the block (spray run) and slot (frame A, B, C, or D). The sampling diagrams which illustrate the randomization for the samples in each study are shown in Appendix A. The samples were then sprayed, removed from the frames, and allowed to dry for one hour under a hood. The third experiment with the pesticide Terrazole® had the spray nozzle pass by the fabric samples twice. In order to provide a more aggressive spraying.

Cutting of the Fabrics

The next step was the cutting of the samples. The bottom foil, which was used to prevent backsplash, was discarded. The second foil layer was separated from the next layer. Its 7.62 cm (3 x 1 inch) rectangle was cut with scissors rinsed in methanol. The rectangle was placed in a labeled test tube. This procedure was followed for rest of the layers, with the scissors being rinsed with methanol between each layer.

Extraction

Test tubes were filled with 25 ml of methanol. Next the tubes were agitated on a Burrell® Wrist Action Shaker for 30 minutes. The solution was then transferred, without the 7.62 cm (3 x 1 inch) fabric sample, to 1ml vials and stored in a freezer.

Analysis

The analysis was performed by a HPLC machine. The detection limits of the analysis were $.0258 \mu\text{g}/\text{m}^2$. The machine operated at ambient temperature. The detector was a Waters® 490 programmable multiwavelength. The column was a 4 micron Nova pack, 8 mm by 100 mm. The carrier liquid was Acetonitrile and water. The sample 150 microliters was injected through an autosampler. There was a 10% reinjection of all the samples. The software was a Maxima® 820. Appendix C has the conditions listed for the HPLC analysis.

CHAPTER IV

FINDINGS AND DISCUSSION

The purpose of this study was to evaluate seam and closure designs and determine those which best provide a barrier to pesticides. There were three different evaluations conducted. The first study analyzed fabrics and seams sprayed with the pesticide Dicofo[®], the second analyzed fabrics and seams sprayed with the pesticide Terrazole[®], and the third analyzed the fabric Tyvek[®] and zipper closures which were sprayed with the pesticide Dicofo[®].

A multilayer sample was exposed to a pesticide spray system in all three studies. The first layer was the test fabric which contained the seam or zipper closure and was representative of the clothing worn by the agricultural worker. The second layer, 50/50 cotton polyester knit, was the collector layer. The collector layer was sandwiched between the top fabric and the foil. If pesticides were to penetrate the top layer then the collector layer would absorb the residue.

Seam Study for the Pesticide, Dicofo[®]

The four fabrics that were used in this study were examined without seams to provide a base line for evaluating the effect of seams on Dicofo[®] penetration. The four fabrics used were one woven fabric Denim, and three nonwoven fabrics Tyvek[®], SMS[®], and Sontara[®]. Only one fabric, SMS[®], allowed penetration.

Five different seams were evaluated for each of the four fabrics, yielding 20 fabric/seam combinations. In addition, each of these different seam/fabric combinations were replicated five times. Of the seams evaluated, 14 allowed penetration. Table 3 shows the results of the amount of pesticide that penetrated for each of these 14 seams. The percentage of seam samples allowing pesticide penetration are shown in Table 4. For example, 40%, two out of the five Sontara® overlock inside seam samples, allowed penetration of the pesticide. A Duncan's Multiple Range Test was performed on rankings. The analysis showed no significant differences among the seams (Table 5). Therefore, the results of this statistical analysis lead to the acceptance of the null hypotheses; which stated that there was no significant difference between types of seams and fabrics, and that there was no significant difference between types of seams in terms of pesticide penetration.

The one interpretation that can be made is that seams will allow penetration of the pesticide, Dicofol®. This becomes crucial when it is realized that the amount of pesticide that is reported in these studies is only a fraction of the amount the agricultural worker will receive when he is out in the field spraying and brushing against sprayed plants; or when he is mixing the pesticides; and when he is involved in a spill of the pesticide; or when in the normal course of his work, he bends and puts pressure on his clothing and its seams. It becomes apparent that seams as described by Berardinelli and Cottingham (1986) are the 'limiting' factor in the agricultural workers protective clothing.

Although Dicofol® is a widely used pesticide, it also does not allow the penetration that has been shown to occur with other pesticides (Freed et al. 1980; Orlando et al., 1981; Davies et al., 1982; DeJonge & Easter, 1987).

Table 3. Amount of Dicofo[®] Penetration for Seam Study

Fabric/Seam Description	Amt Penetrate ($\mu\text{g}/\text{cm}^2$)*	Standard Deviation
Tyvek ovr/in	0.109 (3)**	0.153
Tyvek ovr/out	0.059 (1)	0.000
SMS flatfell	0.037 (2)	0.027
Sontara flatfell	0.026 (1)	0.000
Tyvek plain	0.026 (1)	0.000
Tyvek flatfell	0.025 (1)	0.000
Denim bound	0.023 (2)	0.005
SMS bound	0.016 (1)	0.000
Denim ovr/out	0.013 (1)	0.000
Sontara ovr/in	0.013 (1)	0.000
Tyvek bound	0.013 (1)	0.000
Sontara ovr/out	0.013 (1)	0.000
SMS plain	0.010 (3)	0.004
Sontara plain	0.001 (1)	0.000

* The detection limit was $.0258 \mu\text{g}/\text{cm}^2$

** Indicates the number of replications that allowed penetration out of total of 5 replications

Table 4. Mean Percentage of Seams that
Allowed Dicofo[®] Penetration

Fabric/Seam Description	Percentage Penetrate (%)*
Denim Bound	40
Denim ovr/out	25
Tyvek plain	20
Tyvek flatfell	17
Tyvek bound	20
Tyvek ovr/out	20
Tyvek ovr/in	60
SMS plain	60
SMS flatfell	40
SMS bound	20
SMS no seam	20
Sontara plain	20
Sontara flatfell	20
Sontara ovr/out	20
Sontara ovr/in	40

* Percentages are based upon 5 replications

Table 5. Analysis of Variance for Dicofol[®] Seam Study

SOURCE	df	SS	MS	F	LEVEL OF SIGNIFICANCE
SEAM	14	2471.179	176.513	0.520	0.909

Therefore, a second pesticide Terrazole® was selected for additional seam testing.

Seam Study for the Pesticide Terrazole®

The Terrazole® study evaluated two fabrics: denim commonly used by the agricultural workers and the nonwoven textile Tyvek®. Three seam constructions were used along with a 'no seam' sample, yielding eight fabric/seam combinations. In addition, each of these different seam/fabric combinations were replicated five times. The seam constructions were an overlock outside stitch, an overlock inside stitch, and a plain stitch. The samples were sprayed twice in the spray chamber to provide a more aggressive spray method. The analysis of variance and the mean penetration for the samples are shown in Tables 6 and 7. The pesticide Terrazole® penetrated both the denim and Tyvek® samples, with or without a seam construction; furthermore the pesticide penetrated all five of the replications of each sample type.

The differences among the means were partitioned through a set of orthogonal contrast analyses. The orthogonal design allows for the collection of observations that permit the estimation and testing of the various treatment effects and interaction effects separately (Hays, 1973). The two requirements that are necessary for an experiment to be regarded as an orthogonal design are as follows: (1) the observations within a treatment combination are sampled at random; (2) the number of observations in each possible combination of treatments are the same (Hays, 1973). The usual procedure is to set up an experiment to be analyzed by two-way analysis, or higher as in

Table 6. Analysis of Variance for Terrazole[®] Seam Study

SOURCE	df	MS	F	SIGNIFICANCE LEVEL
TOTAL	42			
SEAM	7	0.471	7.160	0.0001
ERROR	35	0.067		

Table 7. Amount of Terrazole[®] Penetration for Seam Study

Fabric/Seam Description	Amt Penetrate ($\mu\text{g}/\text{cm}^2$)*	Standard Deviation
Denim plain	0.485 **	0.196
Denim ovr/out	0.938	0.262
Denim ovr/in	1.044	0.224
Denim no seam	1.253	0.358
Tyvek plain	0.388	0.208
Tyvek ovr/in	0.709	0.319
Tyvek ovr/out	0.797	0.135
Tyvek no seam	0.732	0.267

* The detection limit was $.0258 \mu\text{g}/\text{cm}^2$

** All five replications for each seam type allowed penetration of the pesticide

this experiment and to assign subjects at random and independently so as to have an equal number in each combination. This experiment followed the same procedure. Tables 6-8 illustrate these means, level of significance, and orthogonal contrast analysis. As in the previous study, the first step was to examine the difference between the 'no seam' samples and the seams. The denim 'no seam' had more penetration of the pesticide than the seams. This was verified with a 0.001 level of significance (Table 8). However Tyvek® did not have a significant level of difference. The estimated difference for the Tyvek® 'no seam' was -0.100, which indicated the 'no seam' had the higher level of penetration. The reason for the nonsignificant level is witnessed in the overlock outside seam which was the only seam construction which had a higher level of penetration than the 'no seam' for the Tyvek® samples.

The conclusion drawn from these contrasts is that the denim fabric with a seam construction provided a better barrier to the pesticide Terrazole® than the denim 'no seam' samples. The extra layers of fabric within the seam construction provide a barrier to the pesticide both physically and chemically.

Denim's 100% cotton content gives it the physical property of being very hygroscopic, thus it would readily absorb the water than the Tyvek® samples, this is illustrated in Table 8. The estimated difference was 0.273 and the level of significance was 0.001. This leads to the rejection of the null hypothesis which states that there is no significant difference between types of seams and fabrics in terms of pesticide penetration. The textile/penetration interaction is a process that, "is largely governed by capillary forces owing to the tight packing of the fibers: the yarns act as wicks" (Freed, et al.,1980). It would appear that as the denim is a tightly woven fabric it has a tendency to

Table 8. Orthogonal Contrast Analysis
Terrazole® Seam Study

FABRIC		DENIM				TYVEK®				EST. DIFF.	LEVEL SIGN.
SEAMS		PLAIN	IN	OUT	NO	PLAIN	IN	OUT	NO		
MEANS*		0.485	0.938	1.044	1.253	0.388	0.709	0.797	0.732		
NO.	CONTRAST										
1	Denim vs Tyvek®	1/4	1/4	1/4	1/4	-1/4	-1/4	-1/4	-1/4	0.273	0.001
2	No Seam vs Seam (Denim)	1/3	1/3	1/3	-1	0	0	0	0	-0.431	0.001
3	No Seam vs Seam (Tyvek®)	0	0	0	0	1/3	1/3	1/3	-1	-0.100	0.452
4	Plain vs Overlock (Denim)	1	-1/2	-1/2	0	0	0	0	0	-0.505	0.001
5	Plain vs Overlock (Tyvek®)	0	0	0	0	1	-1/2	-1/2	0	-0.365	0.009
6	In vs Out (Denim)	0	1	-1	0	0	0	0	0	0.106	0.516
7	In vs Out (Tyvek®)	0	0	0	0	0	1	-1	0	-0.088	0.592

* The units for the means are in $\mu\text{g}/\text{cm}^2$ with the detection limit being $.0258\mu\text{g}/\text{cm}^2$

wick more quickly and easily than with the random arrangement of fibers encountered with the Tyvek® nonwoven. Tyvek® was found to provide 25 times more protection than a treated chambray, 100% cotton tightly woven structure (Orlando et al., 1981). Film formation and capillary transport of the pesticide can be avoided if a fabric's fibers are uniformly separated with discontinuous capillaries (Raheel 1988). This would point to spunbonded and fusionbonded nonwoven fabrics, such as Tyvek®.

A comparison was also made between the plain seam and the average of the overlock stitched seams inside and outside. In both the denim and the Tyvek® analyses the overlock seams allowed more penetration of the pesticide. The estimated difference for the denim was -0.505, and the level of significance was 0.001. The estimated difference for the Tyvek® was -0.365, and the level of significance was 0.009 (Table 8). This leads to the rejection of the second null hypothesis which states that there is no significant difference between seams in terms of pesticide penetration. It would seem that the plain seam provided a better physical barrier than the overlock seams. The plain seam is sewn and then laid flat open, this provides extra fabric protection on each side of the seam. Although the seam is directly in the middle, the actual needle punctures are on the inside of the garment. Also the overlock stitch might stress and stretch the fabric more due to the fact that it has more sewing lines and needle punctures. The overlock stitch would have more possibilities for hole punctures than the plain seams. It has a plain stitch sewn into the fabric, and then next to that an overcast stitch which encases the ends of the fabric. In addition, the overlock stitch has the two sides of the seam sewn together and placed to one side of the fabric sample, this gives only one side of the seam more physical protection. The outside overlock

stitch construction leaves an exposed seam, and thus the exposed needle punctures created while making the seam .

The final comparison conducted in the analysis was between the inside overlock stitch and the outside overlock stitch. Although the estimated differences for both the denim and Tyvek® pointed to the overlock outside stitch as allowing the most penetration, this result was not significant, as depicted in Table 8. Overall one would expect these two seams to provide about the same protection. Possibly the outside overlock stitch allowed more penetration, since its seam is on the outside of the fabric. The exposed needle punctures that were created while making the seam, might allow more penetration of the pesticide.

Zipper Study for Pesticide. Dicofof®

The Zipper study used only the fabric Tyvek® in all zipper constructions to eliminate fabric effect. The pesticide used was Dicofof®. Five different zipper constructions-- a centered, a lapped traditional, a lapped experimental, an open face nylon, and an open face metal-- were evaluated. Sixteen replications of all zipper constructions were evaluated. The analysis was performed on ranks instead of the amount of pesticide that penetrated due to the heterogeneity of residual variances. The study had been designed with an incomplete blocking design--to check the effect of blocking. The blocking effect was found to be insignificant-- the position of the sample within the spray chamber (slot A-B) was found to be insignificant in terms of the amount of pesticide that penetrated.

A comparison of the zippers with the 'no seam' Tyvek® sample

revealed that the 'no seam' did not allow any penetration of the pesticide, Dicofol®. Twenty-two percent of the zipper samples allowed penetration.

Table 9 gives the mean amount of pesticide that penetrated for each zipper type, this mean was determined only from the replications that allowed penetration. Table 10 gives the percentage of the zipper samples for each zipper type which had penetration. The centered zipper which is most often used in agricultural protective garments allowed the most penetration at 41%. That is, seven out of the sixteen centered zipper replications allowed penetration of the pesticide. The lapped traditional zipper allowed the least percentage of penetration at 8%; only one of its sixteen replications allowed penetration of the pesticide. The analysis concluded that the lapped traditional zipper provided the best barrier to the pesticide Dicofol® and that it was significantly different from the centered zipper, with a level of significance of 0.031 (Table 11). It is thus possible to reject the hypothesis, which states that there is no difference between the types of construction used for the zipper closures in terms of pesticide penetration.

The lapped traditional zipper provided the best barrier, and this is understandable as it had the most layers of fabric over the zipper and least needle punctures exposed to the outside of the garment. The lapped experimental did not do as well, possibly this was due to the fact that it had one less layer of fabric in its lapped construction.

Table 9. Amount of Dicofo[®] Penetration for Zipper Study

Zipper Description	Amt Penetrate ($\mu\text{g}/\text{cm}$)*	Standard Deviation
Centered	0.072 (7)**	0.089
Lapped Traditional	0.067 (1)	0.000
Lapped Experimental	0.030 (3)	0.032
Open Nylon	0.341 (5)	0.443
Open Metal	0.029 (3)	0.031

* The detection limit was $.0258 \mu\text{g}/\text{cm}^2$

** Indicates the number of replications that allowed penetration out of a total of 16 replications.

Table 10. Mean Percentage of Zippers
That Allowed Penetration

ZIPPER DESCRIPTION	PERCENTAGE PENETRATED (%)*
CENTERED	41
LAPPED TRADITIONAL	8
LAP EXPERIMENTAL	18
OPEN NYLON	24
OPEN METAL	16

* Percentages are based upon 16 replications

Table 11. Significant Level of Probability Between Zippers

	Centered	Lapped Traditional	Lapped Experimental	Open Nylon	Open Metal
Centered		0.031*	0.132	0.249	0.088
Lapped Traditional	0.031*		0.488	0.293	0.621
Lapped Experimental	0.132	0.488		0.711	0.841
Open Nylon	0.249	0.293	0.711		0.567
Open Metal	0.088	0.621	0.567	0.567	

*Level of Significance <.05

Summary

The purpose of this study was to determine if seam and zipper constructions affected pesticide penetration. The results show that seams and zippers may alter the penetration of pesticides through fabrics. In the Dicofo[®] studies, the seams and the zippers allowed penetration while the 'no seam' constructions did not allow penetration. However, a 'best' seam construction could not be isolated. The zipper study found the lapped traditional zipper performed significantly better than the other zipper constructions. Both the seams and 'no seam' constructions in the Terrazole[®] study allowed penetration, with the seams providing a better barrier to the pesticide. The plain seam provided the optimum barrier to the pesticide for both the denim fabric and the Tyvek[®] textile.

In the seam studies the denim allowed more Terrazole[®] to penetrate than Dicofo[®]. This result could be attributed to the chemical differences of the pesticides and their interaction with the denim fiber content. Terrazole[®], itself, does not hydrogen bond with the hydroxyl groups of the 100% cotton denim, whereas the Dicofo[®] has an OH group which is available for bonding with the hydroxyl groups of the cotton. Given this argument, Terrazole[®] should penetrate, since the denim would be unable to absorb the Terrazole[®] component of the pesticide emulsion.

Another conclusion that can be drawn from the Terrazole[®] seam study concerns the difference between the Tyvek[®] and denim fabrics. The Tyvek[®] seam constructions allowed less penetration of the pesticide than the denim seam constructions as shown in Table 8. The level of significance was 0.001. The reason for this difference is due to the fabric constructions. Denim is a

tightly woven fabric which causes its yarns to act as wicks (Freed et al., 1980). Tyvek® is composed of fibers uniformly separated with discontinuous capillaries and held in the fabric so that the surface tension of the liquid cannot pull them together, thus capillary transport of the pesticide is avoided (Raheel, 1988).

Seams and zipper constructions have been shown to alter the performance of pesticide penetration through fabrics. It is therefore recommended that seams, zipper closures and their placement be taken into consideration when developing protective clothing.

CHAPTER V

SUMMARY AND RECOMMENDATIONS

In light of the many pesticide poisonings that occur every year (NEISS, 1983), and the fact that dermal exposure accounts for 87% of the total exposure experienced by agricultural workers (Durham & Wolfe, 1962; Maibach et al., 1971), one can see the need for the development of protective apparel. The purpose of this research was to determine if garment construction effects pesticide penetration, namely if seams and closures effect the penetration of pesticide through fabrics. In this technique evaluation process, fabrics that have already been identified as protective barriers were utilized (DeJonge & Easter, 1987), and an attempt was made to determine how different types of seams and zipper closures effected pesticide penetration.

The seams and zipper closures were chosen after a market analysis was undertaken to determine the types of protective apparel available in today's market. All of the samples reviewed and the protective garments available to the farmer in the farm stores were made of a Tyvek® fabric. Both metal and nylon zippers were utilized. The seams were an overlock stitch 504 and the plain stitch 301 as determined by Federal Standard 751a (Hudson, 1988). The thread when tested was synthetic, 100% polyester, and the amount of stitches averaged 4 stitches per centimeter (10 stitches per inch). Both the plain and overlock stitches were evaluated and the Tyvek® textile was used. In addition denim was used, as it is a fabric which is preferred by

the agricultural workers. Both metal and nylon zipper closures were tested .

Two seam studies were conducted. The first seam study used the pesticide Dicofo[®] as it is widely used by farmers. Four fabrics were chosen, denim, since it is preferred by the farmers; Tyvek[®], since it is used for agricultural protective garments; the nonwoven Sontara[®], since preliminary field studies have shown it to be thermally comfortable; and the nonwoven SMS[®], since it has performed well as a barrier to pesticides. All these fabrics performed well as barriers to pesticide (DeJonge & Easter, 1987; Nigg, 1986). The analysis showed no significant differences among seams. However, 14 of the 20 seams did allow penetration of the pesticide through the top test layer to the knit layer. This lead to the conclusion that seams do allow penetration of pesticide, and that they need to be taken into consideration when designing protective apparel.

The second seam study used a more assertive spray method with the pesticide Terrazole[®]. The Terrazole[®] study only evaluated two fabrics, denim and the nonwoven textile Tyvek[®]. Three different seam constructions were used along with a 'no seam' sample, yielding eight fabric/seam combinations. In addition, each of these different seam/fabric combinations was replicated five times. The seam constructions were an overlock outside stitch and overlock inside stitch and a plain stitch, all found in the protective apparel available to agricultural workers in today's market. The samples were sprayed twice with the spray chamber to allow a more aggressive procedure. The pesticide Terrazole[®] penetrated both the denim and Tyvek[®] samples, with or without a seam construction; furthermore the pesticide penetrated all five of the replications of each sample type.

One of the conclusions drawn from this study was that the denim fabric

with a seam construction provided a better barrier to the pesticide Terrazole® than the denim 'no seam' samples. Overall the denim samples allowed more penetration of the pesticide Terrazole® than the Tyvek® samples. The Tyvek® textile was isolated as the textile that provided the best barrier to the pesticide, Terrazole®. This leads to the rejection of the null hypothesis which states that there is no significant difference between types of seams and fabrics in terms of pesticide penetration.

A comparison was also made between the plain seam and the average of the overlock stitched seams inside and outside. In both the denim and the Tyvek® analysis the overlock seams allowed more penetration of the pesticide. The plain seam was the seam that provided the best barrier to pesticide penetration. This leads to the rejection of the null hypothesis which states that there is no significant difference between types of seams in terms of pesticide penetration.

The Zipper study used the nonwoven Tyvek® with the pesticide Dicofof®. Five different zipper constructions-- a centered, a lapped traditional, a lapped experimental, an open face nylon, and an open face metal were evaluated. The different zipper constructions were made into samples with each type being replicated 16 times.

A comparison of the zippers with the 'no seam' Tyvek® sample of the first seam study, revealed the following: the 'no seam' did not allow any penetration of the pesticide, while the zippers did allow penetration of the pesticide. Twenty-two percent of the zipper samples allowed penetration. It becomes important, then, to provide a zipper which will provide the best barrier to the pesticide, and optimum protection to the wearer.

The centered zipper which is most often used in agricultural protective

garments allowed the most penetration at 41%. In other words, seven out of the sixteen centered zipper replications allowed penetration of the pesticide. The lapped traditional zipper allowed the least percentage of penetration at 8%, only one out of sixteen replications allowed penetration of the pesticide. The analysis of variance concluded that the lapped traditional zipper provided the best barrier to the pesticide Dicofol® and it was significantly different from the centered zipper. It is thus possible to reject the hypothesis, which states that there is no difference between the types of construction used for the zipper closures in terms of pesticide penetration.

The results of this research show that seams and zippers allowed penetration of pesticides. In the case of the pesticide Dicofol®, the seams and the zippers allowed penetration while the 'no seam' constructions did not allow penetration. These findings illustrated the need for selecting a seam or zipper which provides a barrier to pesticides. However, in the seam study a 'best' seam construction could not be isolated. Whereas with the zipper study, the lapped traditional zipper was found to be significantly better than the other zipper constructions. In the Terrazole® study both the seams and 'no seam' constructions allowed penetration, with the seams providing a better barrier to the pesticide. It was possible to isolate a 'best' seam. The plain seam provided the optimum barrier to the pesticide for both the denim fabric and the Tyvek® textile.

In the seam studies the denim allowed more Terrazole® to penetrate than the Dicofol®. This result could be attributed to the chemical differences of the pesticides and their interaction with the denim fiber content. Terrazole® is not able to hydrogen bond with the hydroxyl groups of the 100% cotton denim, whereas the Dicofol® has an OH group which is available for bonding

with the hydroxyl groups of the cotton. Therefore more Terrazole® will penetrate, since the denim will be unable to absorb the Terrazole® component of the pesticide emulsion.

Another conclusion that can be drawn from the Terrazole® seam study concerns the difference between the Tyvek® and denim fabrics. The Tyvek® seam constructions allowed less penetration of the pesticide than the denim seam constructions. The reason for this difference is due to the fabric constructions. Denim is a tightly woven fabric which causes its yarns to act as wicks (Freed et al., 1980). Tyvek® is composed of fibers uniformly separated with discontinuous capillaries and held in the fabric so that the surface tension of the liquid cannot pull them together, thus capillary transport of the pesticide is avoided (Raheel, 1988).

Seams and closures, as stated by Berardinelli and Cottingham (1986), are the 'limiting' factor in protective apparel. This study focused on the testing of seams and closures and evaluating them for their barrier properties in terms of pesticide exposure. It took into consideration the areas in which these seams and closures would be located; whether they were in an area of high deposition, and or high skin absorption.

The studies reviewed for this research have identified the parts of the body that receive the most pesticide deposition; either through the traditional patch method or an adaption of the patch method or through the addition of fluorescent tracers to the pesticide. They all seem to be in agreement that the forearm, the thigh and the chest receive the highest deposits of pesticide. In comparing these findings with the results from the Maibach et al. (1971) it becomes clear that there is a need for protective clothing. The Maibach et al. (1971) study applied pesticides labeled with radioactive carbon directly onto

the skin of volunteers. The results for Parathion® found that the under arm absorbed 64% of the pesticide applied, the upper forearm 29%, the scrotum 100%, and the abdomen 19%. These results demonstrate the need for providing a barrier between the skin and the pesticide with clothing; furthermore, this clothing must be specially designed to provide the extra protection needed for these high pesticide deposition areas, and high absorption areas of the skin.

The thigh was identified as being one of the highest areas of deposition (DeJonge et al., 1985; Nigg et al., 1986; & Wolfe et al., 1961). The necessity of clothing providing a barrier to the pesticide becomes crucial; even more so when you consider that skin in the scrotum area absorbs 100% of the pesticide that is deposited on it (Maibach et al., 1971). The scrotum area of the protective garment usually has a zipper closure, one can see the need for a zipper closure that will provide the best barrier possible to the pesticide. This study identified the traditional lapped zipper as providing the 'best' barrier to the pesticide Dicofol®. In sixteen replications of the traditional lapped zipper only 8% had pesticide penetration occur; in other words, only one replication of this zipper allowed penetration of the pesticide.

The upper torso/arms was also identified as a high deposition area (Batchelor et al., 1954; DeJonge et al., 1985; Fenske, 1988; & Franklin et al., 1981). Once again the need for clothing to provide a barrier to pesticides becomes a necessity, especially when results show that the skin on the upper forearm absorbs 29% of the pesticide, the under arm 64%, and the abdomen 19% of the pesticide (Maibach et al., 1971). Seams might be located in the garment at the forearm, at the under arm, or at the shoulder. The 'best' seam, the seam that provided the optimum barrier to the pesticide Terrazole® was

the plain seam. Furthermore, the plain seam was found to provide the 'best' barrier to Terrazole® in both the denim and Tyvek® textiles.

Recommendations

This study examined only one aspect of protective apparel for pesticides, the seams and closures which are used in the protective garment. The study was also limited in that only two pesticides were utilized. In addition, the Dicofol® seam study was unable to find any significant differences due to the limited sample size. It might be beneficial to repeat this study with a larger sample size.

Recommendations Based Upon Conclusions of this Study

The following constructions can be recommended for use in protective apparel:

1. A lapped traditional zipper
2. A plain seam

Recommendations for Future Studies

1. Further studies could be done on seams with larger sample sizes, and more pesticides.
2. A field study utilizing the seam and zipper that performed the best in this study could be conducted on garments made of denim and Tyvek® textiles.
3. The addition of the application of stress before penetration testing could be applied to seams and zipper closures.

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APPENDIXES

APPENDIX A

SAMPLING DIAGRAMS

Table 63. SAMPLING DIAGRAM EFFECT OF SEAMS - DICOFOL												
Fabric ID	1	2	3	4	5	6	7	8	9	10	11	12
Block												
1	1		2				4					3
2					4		1					
3								4				1
4	2							3				1
5		2							4		3	
6					3				1			
7						3					1	
8										2		
9			1	4						2		
10	3						2					
11		1			4			2				
12			1		4						2	
13				2					1			
14	2	1										3
15									4		2	
16		1									3	
17			2					3	3			
18												
19			2		4	3						
20		1										

Fabric ID	13	14	15	16	17	18	19	20	21	22	23	24
Block												
1												
2	3								2			
3	3								2			
4										4		
5								1				
6				4				2				
7		2						4				
8		3							4	1		
9					3							
10	1									4		
11						3						
12												3
13				3							4	
14		4										
15	3							1				
16		2				4						
17	4			1								
18				1		4		2				
19											1	
20		2	3					4				
21			3		2							

Figure 5. Sampling Diagram Seams /Dicofol® (DeJonge & Easter, 1989)

Table 65. SAMPLING DIAGRAM EFFECT OF SEAMS -TERRAZOLE®											
Fabric ID	1	4	5	6	7	10	11	12			
Block											
1	3			4	1	2					
2	2	3		1			4				
3	2	4				3					
4	2		4		3		1				
5	3					1	4				
6		1	2	3		4					
7			1		4	3		2			
8		3	4				1	2			
9		4		1	2			3			
10				1	3		4	2			

Figure 6. Sampling Diagram Seams /Terrazole® (DeJonge & Easter, 1989)

Table 66. SAMPLING DIAGRAM EFFECT OF ZIPPERS - DICOFOL					
Fabric ID Block	1z	2z	3z	4z	5z
1	1	2	4		3
2	1	2		3	4
3	1		4	3	2
4		1	2	3	4
5	1	3	4	2	
6	4	2		3	1
7	1	2	4		3
8	2		4	3	1
9		3	1	4	2
10	4	1	2	3	
11	3	4		2	1
12	4		3	2	1
13	2	4	3		1
14	4	2	3	1	
15		4	2	3	1
16	1		3	2	4
17	3	4		2	1
18	1	4	3		2
19	2	1	4	3	
20		2	3	1	4

Figure 7. Sampling Diagram Closures/Dicofol® (DeJonge & Easter, 1989)

APPENDIX B

SEWING PROCEDURES AND SEAM AND ZIPPER DRAWINGS

SEWING PROCEDURES FOR SEAMS AND ZIPPERS

I SEAMS

A. MATERIALS FOR OVERLOCK SEAMS

THREAD: Mercerized cotton covered polyester
MACHINE: Singer® Overlock Professional #10 UJ 13
NEEDLE: 2053
SEAM: 504 stitch (Hudson, 1988)
STITCH: 4 stitches/centimeter (10 stitches/inch)

PROCEDURES FOR SEWING

OVERLOCK INSIDE SEAM

With right sides of fabric together sew a 504 stitch.

OVERLOCK OUTSIDE SEAM

With wrong sides of fabric together sew a 504 stitch.

B. MATERIALS FOR PLAIN, FLATFELL, BOUND, SEAMS

THREAD: 100% polyester
MACHINE: Singer® Model #28/108
NEEDLE: #80/11
SEAM: 301 stitch (Hudson, 1988)
STITCH: 4 stitches/centimeter (10 stitches/inch)

PROCEDURES FOR SEWING

PLAIN

With right sides together sew a 301 stitch with a 1.58 centimeters (5/8 inch) seam allowance.

FLATFELL

- 1) With wrong sides together sew a 301 stitch with 1.58 centimeters (5/8 inch) seam allowance.
- 2) Press seam open then to one side.
- 3) Trim inner seam allowance to 0.317 centimeters (1/8 inch).

- 4) Press under 0.635 centimeters (1/4 inch) on outer seam allowance.
- 5) Stitch this folded edge to garment.

BOUND

- 1) With wrong sides together sew a 301 stitch with 1.5 centimeter (5/8 inch) seam allowance.
- 2) Trim seam allowance to 0.635 centimeters (1/4 inch).
- 3) Bind seam allowance with self fabric; for denim use Wrights® extra wide 100% cotton double fold bias tape.
- 4) Self fabric binding--made of 2.54 centimeters (1 inch) strip of self fabric which has each end pressed 0.635 centimeters (1/4 inch).

II ZIPPERS

A. MATERIALS FOR ALL ZIPPERS

THREAD: 100% polyester
 MACHINE: Singer® Model #28/108
 NEEDLE: #80/11
 SEAM: 301 stitch (Hudson, 1988)
 STITCH: 4 stitches/centimeter (10 stitches/inch)

B. PROCEDURE FOR SEWING ZIPPERS

OPEN METAL AND NYLON ZIPPERS

- 1) Place zipper directly on top of right side of fabric. With zipper foot stitch a 301 stitch down one edge of zipper tape across bottom and up the other edge of the tape.
- 2) Slit the fabric directly behind the zipper--make the slit in the lengthwise direction of the zipper coils and center the slit between the two stitching lines.

CENTERED ZIPPER

- 1) Place right sides of fabric together sew a 301 stitch with machine basting allowing for 1.58 centimeter (5/8 inch) seam allowance.
- 2) Press seam open, center zipper on seam side facing seam.
- 3) Stitch down one edge zipper tape across bottom and up other edge of tape.
- 4) Pull out basting stitch on right side of fabric.

EXPERIMENTAL LAPPED ZIPPER

- 1) Press under 1.58 centimeters (5/8 inch) on one side fabric.
- 2) Stitch this pressed edge with a 301 stitch to right side of zipper tape with zipper foot on right side of zipper.
- 3) Place a 7.62 centimeter (3 inch) wide and 5.08 centimeter (2 inch) wide piece fabric with right sides together. The 7.62 centimeter (3 inch) wide piece on top and left edges together.
- 4) Place the edges of fabric over unsewn left side of zipper tape. The bulk of fabric pieces will overlap right side of zipper.
- 5) Sew along unsewn left edge of zipper tape through both fabric and tape with a 301 stitch and zipper foot.
- 6) Fold back the top 7.62 centimeter (3 inch) wide piece fabric.
- 7) Place a double stick tape along inner or under edge of overlapping 5.08

centimeter (2 inch) wide fabric to seal zipper closure.

TRADITIONAL LAPPED ZIPPER

- 1) With right sides together of two 7.62 centimeter (3 inch) pieces of fabric sew a 301 stitch.
- 2) Press open seam and position zipper face down on right side of right 7.62 centimeter (3 inch) piece, the facing.
- 3) Align zipper along seam and sew a 301 stitch with zipper foot on left side of zipper tape.
- 4) Turn facing inside along seam line.
- 5) Fold a 1.9 centimeter (3/4 inch) fold in a piece of fabric. Make it have a 3.8 centimeter (1.5 inch) fabric width with a 1.9 centimeter (3/4 inch) width fold and then a 7.62 centimeter (3 inch) width of fabric coming out of tip fold.
- 6) Fit other edge, right side of zipper, so fold line meets right side of zipper coils; and the 3.8 centimeter (1.5 inch) fabric (under the fold) is under the zipper and the 7.62 centimeter (3 inch) fabric (top side fold) is to the right of the zipper.
- 7) Sew a 301 seam with zipper foot along right edge of front of zipper through fabric fold and zipper tape.

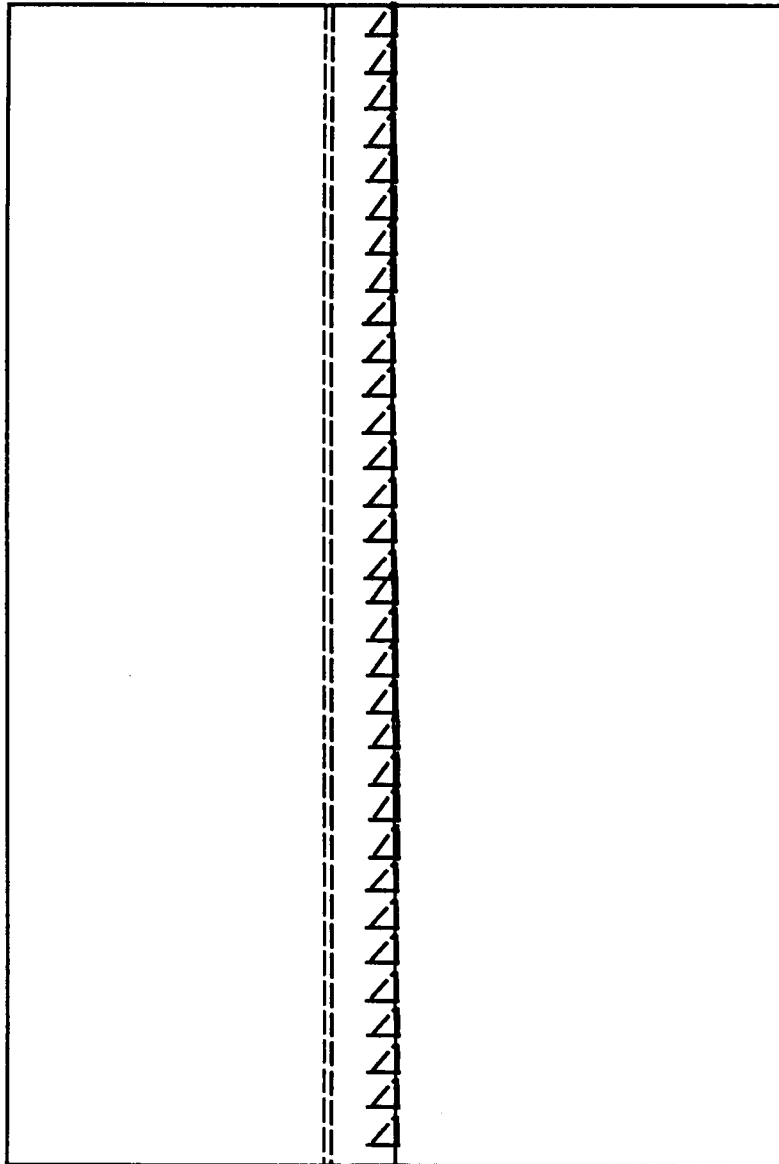


Figure 8. Overlock Outside Seam

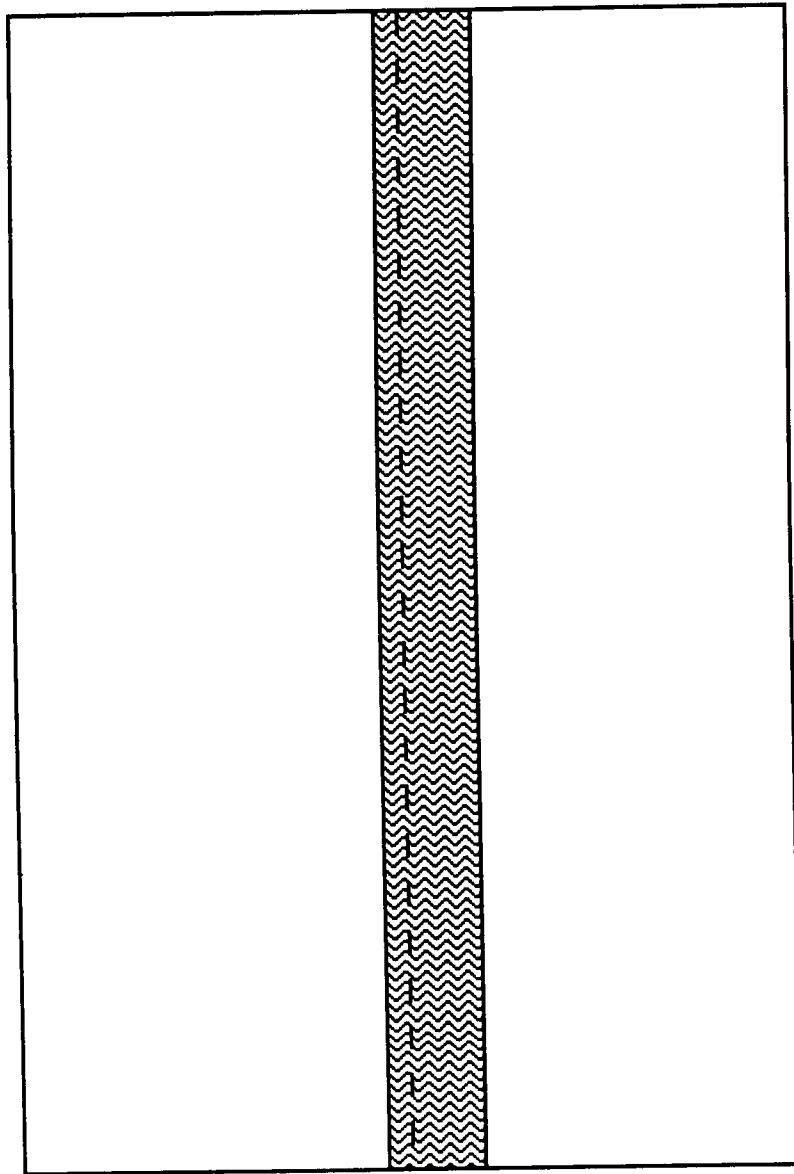


Figure 9. Bound Seam

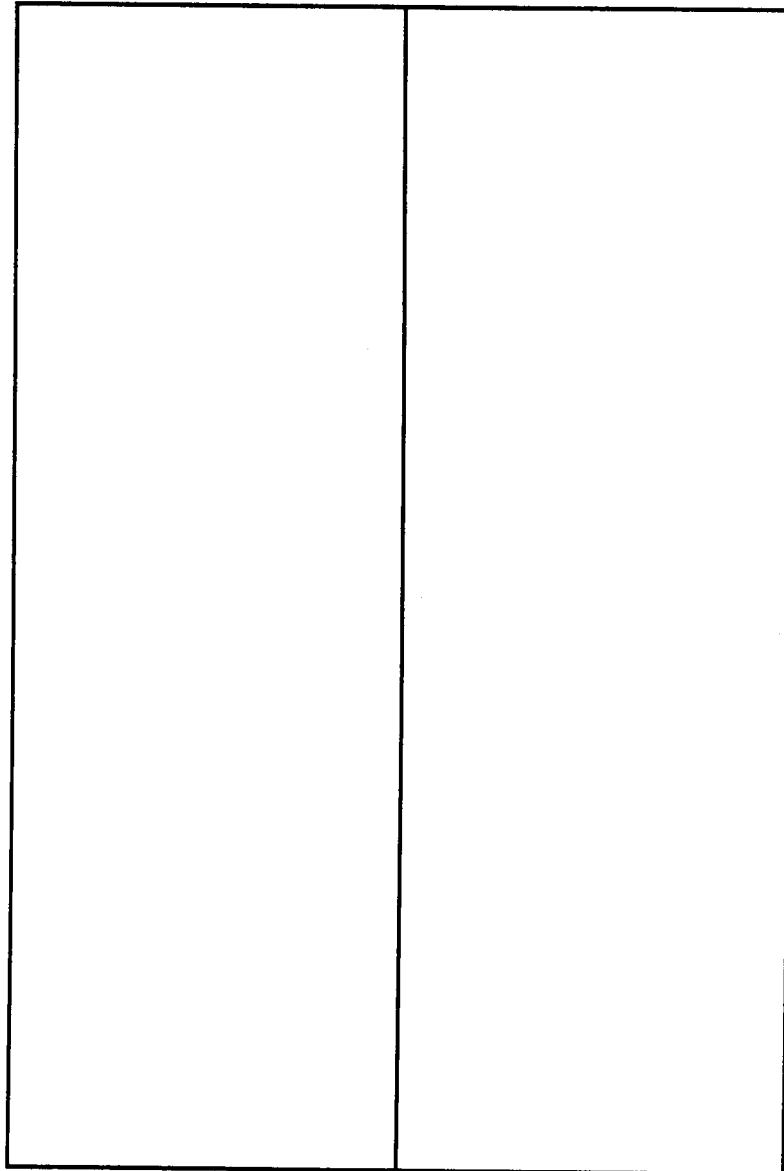


Figure 10. Plain Seam

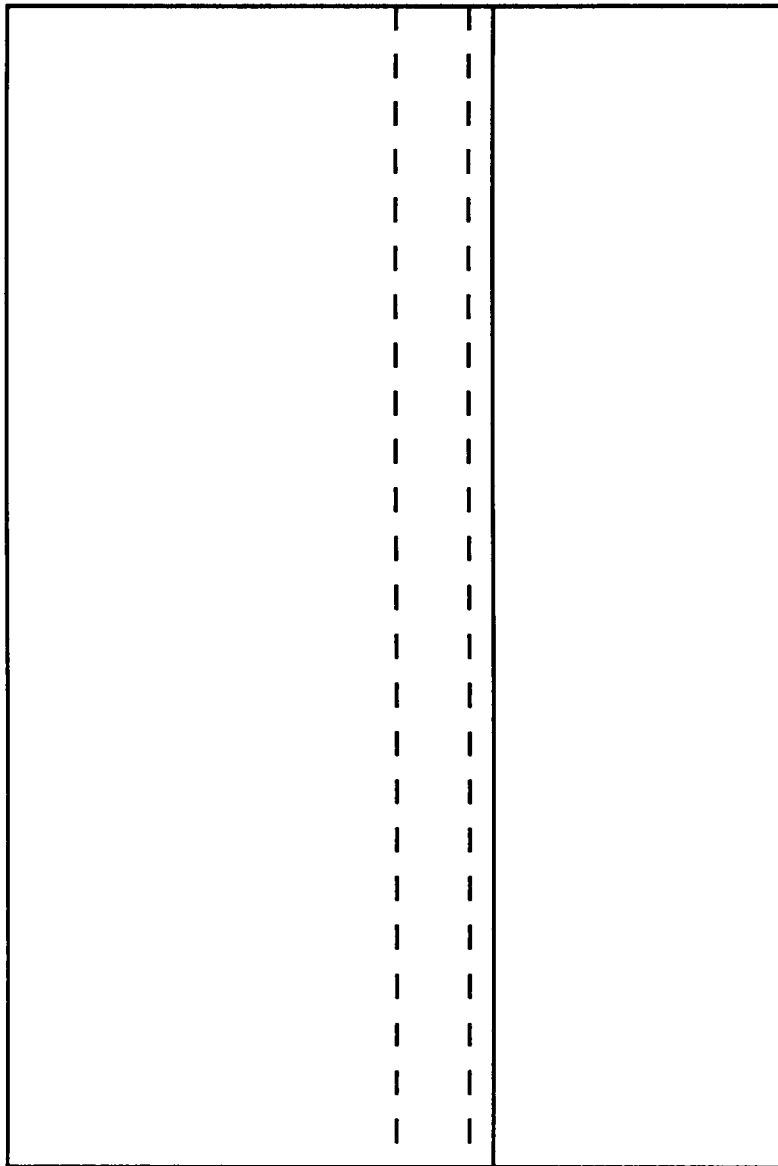


Figure 11. Flatfell Seam

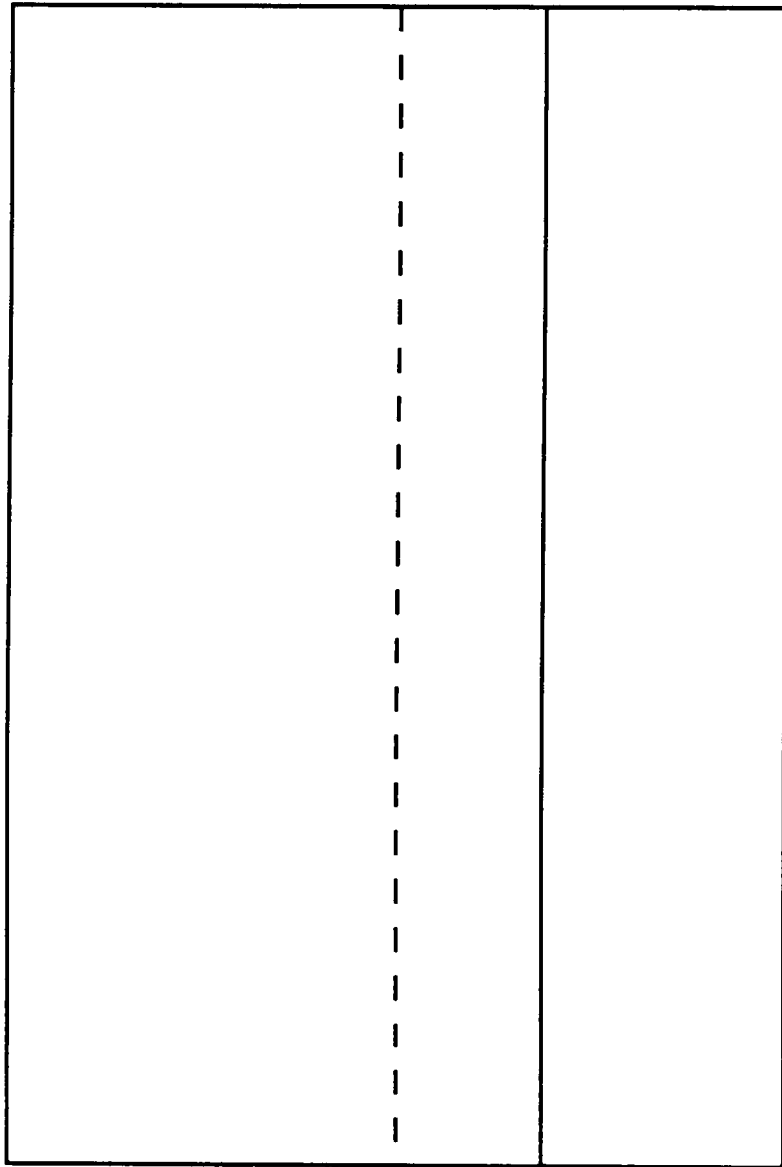


Figure 12. Traditional or Experimental Lapped Zipper

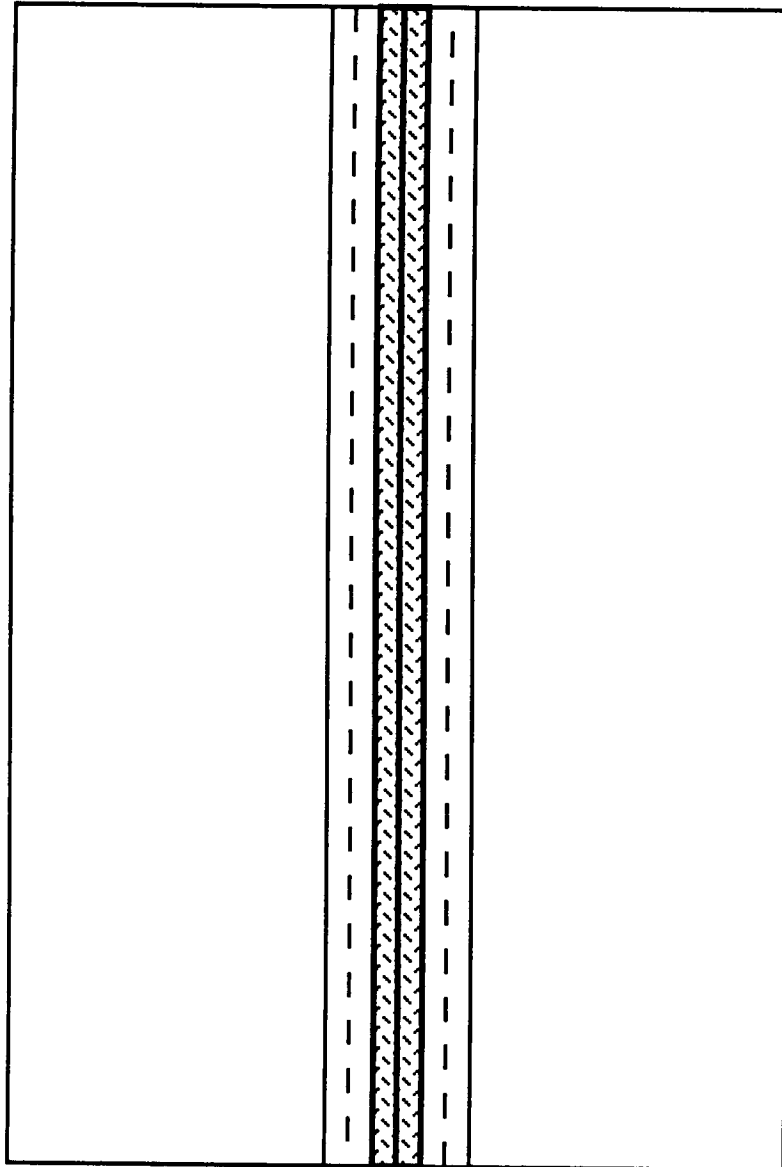


Figure 13. Open Face Zipper

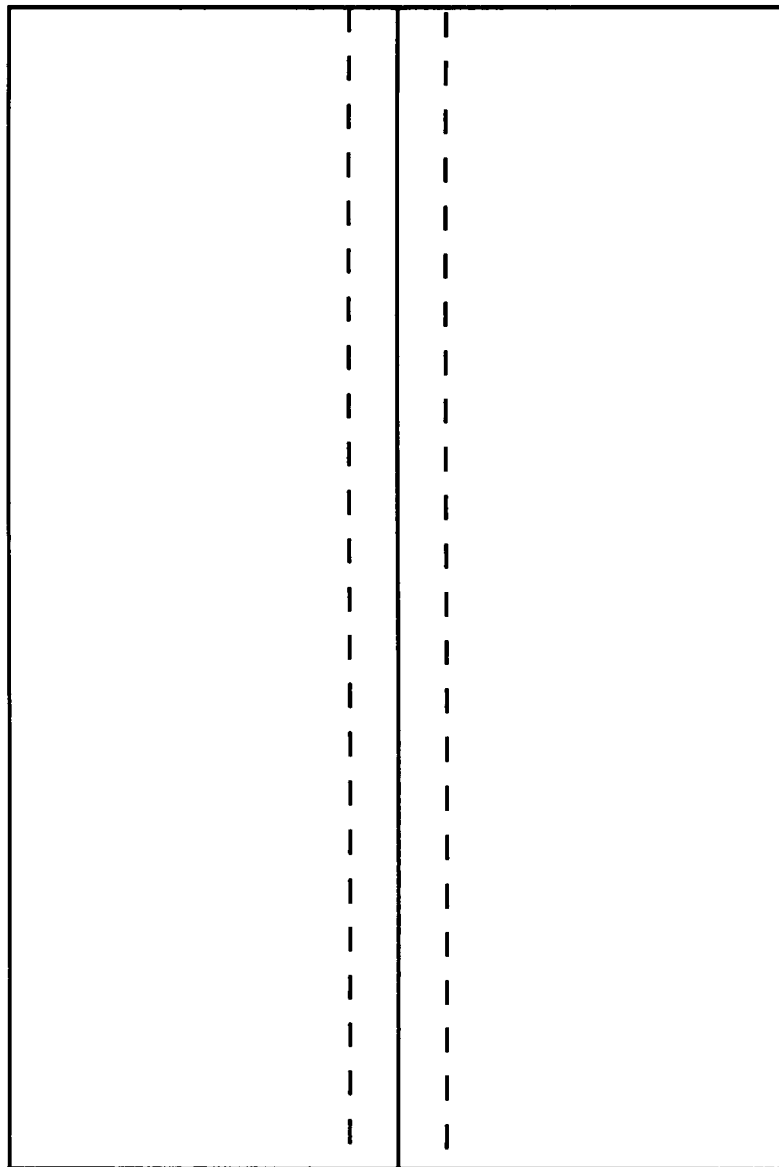


Figure 14. Centered Zipper

APPENDIX C

HPLC CONDITIONS

HIGH PERFORMANCE LIQUID CHROMATOGRAPH CONDITIONS

Dicofol®

- Column: Waters RCM 100 equipped with 8 mm diameter, 100 mm long Nova-pak C-18 radial compression column.
- Packing: Nova-pak C-18. End capped, C₁₈ alkyl, bonded silica, four micrometer diameter spherical particles.
- Mobile Phase: 75% acetonitrile/25% water; HPLC grade (Burdick & Jackson)
- Detector: Waters 490 UV detector at 230 nm

Terrazole®

- Column: Waters RCM 100 equipped with 8 mm diameter, 100 mm long Nova-pak C-18 radial compression column.
- Packing: Nova-pak C-18. End Capped, C₁₈ alkyl, bonded silica, four micrometer diameter spherical particles.
- Mobile Phase: 70% acetonitrile/30% water; HPLC grade (Burdick & Jackson)
- Detector: Waters 490 UV detector at 230 nm

VITA

Carol A. Dimit was born in Chicago, Illinois on June 18, 1959. She graduated from St. Francis De Sales High School in May of 1977. She received her Respiratory Technician Degree from Parkland College, Champaign, Illinois, in December of 1982. She worked as a Respiratory Technician in Bedford Indiana. She entered the University of Indiana, Bloomington, in the Fall of 1983. She completed these studies in the Spring of 1987 when she received her Bachelor of Science degree in Textile Science from the University of Tennessee, Knoxville. As an undergraduate she worked on an EPA sponsored project on pesticides. In conjunction with this project she co-authored a paper on the effect of humidity and temperature on pesticide penetration.

Her work also lead to her position as a graduate research assistant on this same EPA project. She began work on her masters in the summer of 1987. She was awarded her Masters in Science from the School of Human Ecology in the Spring of 1989.

Carol Dimit is currently employed by DeRoyale Industries as a Quality Control Supervisor.