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PESTICIDE PENETRATION AND COMFORT PROPERTIES OF PROTECTIVE CLOTHING FABRICS

by

Nancy Elizabeth Hobbs

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Approved by

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APPROVAL PAGE

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This study tested woven and nonwoven fabrics, with and without finishes, as protective barriers to aerosol spray for protective clothing. The research was divided into three parts: 1) the determination of the physical properties; density, air permeability, and water vapor permeability with their relevance to human comfort; 2) the determination of aerosol dye penetration; and 3) the verification of the dye penetration test as a predictor of pesticide penetration.

Seven nonwoven and four woven fabrics were examined for resistance to aerosol spray penetration. Of particular interest were the nonwoven substrates which resist penetration by oils and liquids but allow water vapor transmission. Significant differences in density, air permeability, and water vapor permeability were noted among and between the woven and nonwoven groups of fabrics.

The aerosol spray penetration test developed for this research used methylene blue dye as a tracer to indicate penetration. Three spray emulsions commonly used for pesticide application were tested with the dye tracer: 1) water, 2) water/surfactant 48:1, and 3) cottonseed oil/surfactant 4:1.

The results of the dye penetration test correlated with the Malathion® penetration test indicating that the dye penetration test can be used to estimate pesticide penetration. The results of the aerosol spray test indicated that fluorocarbon barrier finishes prevented aerosol spray penetration. The woven fabrics tested failed to meet the criterion of being resistant to oil-based spray penetration. The finished spun-lace nonwoven fabrics ranked highest in terms of air and water vapor permeability and air permeability and were resistant to aerosol penetration by both water-base and oil-base spray emulsions.

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CHAPTER I

INTRODUCTION

Modern farming techniques rely on the use of pesticide through the growth and harvesting of crops. Therefore, the agricultural worker is exposed to a wide variety of agrichemicals. Pesticides, which include herbicides, insecticides, and fungicides, are composed of a wide variety of chemical compounds of varying degrees of toxicity to humans. This study will examine aerosol dye penetration as a predictor of spray penetration by the organophosphate pesticide Malathion® on selected fabrics.

Clothing for agricultural workers involved in the mixing, loading, and application of pesticides is a barrier between the worker and the environment. The degree of protection offered by the clothing worn depends on 1) the type and amount clothing worn, 2) the ability of the textile substrates to prevent pesticide transfer to the skin, 3) the interaction on environmental and climatological factors, and 4) the type of work performed. Fabrics designed to prevent moisture absorbtion and penetration also tend to block evaporative cooling from the skin making garments made from these fabrics uncomfortable

(Goldman, 1971). The clothing recommended for use by pesticide applicators is often hot, bulky, and uncomfortable. Rubberized jackets and pants, neoprene gloves, and rubber or neoprene boots are often too hot to be worn safely during the hot summer months when most of the pesticide applications take place.

This research focused on nonwoven substrates which offered comfort and protection at a sufficiently low cost per garment as to be potentially disposable after one wearing. Of particular interest to this study were the nonwoven substrates developed for medical use which are designed to resist penetration of lipids and aqueous formulations but allow air and water vapor transmission. These properties are important factors in the body's evaporative cooling process. Woven fabrics similar to those commonly found in apparel worn by farm workers were also examined as controls.

Justification

During the mixing, loading, or application of pesticides most persons risk poisoning due to dermal exposure, inhalation, or ingestion. Most cases of pesticide-related illness are due to carelessness, accidents, and failure to follow recommended safety procedures, including the failure to wear protective apparel and devices.

In 1983, the State of California's Department of Food and Agriculture reported 128 cases of skin-related illnesses and 220 cases of systemic illnesses among pesticide applicators and mixer/loaders. Each case reported was judged to have adequate information on which to base an exposure/illness relationship. The North Carolina Department of Human Resources, Environmental Epidemiology Branch, reported 39 cases of agricultural pesticide-related illnesses in 1982.

Exposure to pesticides occurs during four operations. The first occasion for exposure is during the mixing and loading operations. The second exposure period is during the application of the pesticide. The third possibility for exposure-related injuries occurs during the unloading, cleaning, and disposal operations. The fourth contact with the chemicals occurs when field workers are exposed to treated foliage and/or produce prior to the chemical reduction or breakdown of the pesticide.

The United States Department of Agriculture (USDA), the Environmental Protection Agency (EPA), and the National Institute of Occupational Safety and Health (NIOSH) recommend the wearing of protective clothing for all people involved in the handling and application of most pesticides. The recommended clothing articles for general use include long-sleeved shirts and long-legged trousers or coverall-type garments. When handling toxic and concentrated pesticides, the use of a liquid-proof raincoat or apron is also recommended. The garments recommended for general use do not provide adequate protection when liquid or aerosol application methods are used. Garments become wet and wick the pesticide formulation, resulting in dermal exposure. Liquid-proof garments, recommended by EPA for handling toxic or concentrated pesticides, are generally impermeable to dust, oil, water, and water vapor. A major impediment in the use of this type of protective apparel is a lack of comfort in wearing due to low air and water vapor permeability and, at times, excessive weight.

Exposure to pesticides may not result in outward symptoms or signs of poisoning. Toxicant absorption is measured by sampling the urine for toxicant metabolites and/or sampling the cholinesterase level in the blood. Production of cholinesterase, an enzyme involved in the nerve transmission process, is inhibited by organophosphates (EPA, 1976). There are four levels or classifications of toxicant absorption: detectable, incipient toxicity, poisoning dose, and lethal dose. At the detectable level of toxicant absorption, toxicant metabolites are present but no enzymological effects are yet produced. Incipient toxicity is the result of the absorption of enough pesticide to produce subtle enzymological effects which are short of amounts sufficient to cause symptoms and signs of poisoning. Although laundering procedures have been developed for contaminant removal (Finley & Rogillo, 1969), protective clothing decontamination and reuse are controversial and unresolved issues. (Laughlin & Easter, 1984; Finley et al., 1974; Easley, Laughlin, Gold, & Hill, 1982). In cases where garments have been wetted with highly toxic or concentrated pesticide formulations, the USDA recommends disposal of the contaminated garments rather than laundering. Therefore, the focus of this research was on nonwoven substrates which offer comfort and protection at a low enough cost to be disposable after one wearing.

The effects of hydrophobic and oleophobic finishes were examined as barriers because the degree of soiling and/or wetting of a textile can be modified through application of a finish. Ellzey, Conwick, Drake, and Reeves, (1969) noted that fluorocarbon-based finishes limited wetting by any solvent.

A sense of comfort or discomfort is dependent upon both psychological and physiological stimuli and is identified by conscious and unconscious stored modifiers. The body loses heat through convection, conduction, and evaporation. These avenues of heat loss are important in maintaining a comfort ratio of heat generated to heat lost by the body. This ratio or heat balance is defined as zero when the heat generated by the system through work or absorbed from the environment is equal to the heat lost by the system. The more heat generated by the system through work or absorbed fron the environment, the greater the heat loss necessary to maintain a zero balance.

Under conditions designed to protect the body from exposure to liquids, aerosols, and dust, garments designed to promote heat loss through conduction and convection become impractical. Physiological comfort may be impossible considering the environmental conditions in most agricultural regions during the summer months. However, it is possible to decrease the degree of discomfort. Textile substrates which are both air and water-vapor permeable would provide a greater degree of physical comfort than substrates which are impermeable in that they aid in the evaporative cooling process necessary for the maintenance of the body's heat balance.

Purpose of the Study

The purpose of this study was to evaluate fabrics used or proposed for use in disposable or semi-disposable clothing designed to limit or prevent dermal exposure to the organophosphate class of pesticides. The two objectives were 1) to design a test method to assess the aerosol permeability of various fabrics, and 2) to evaluate the physical properties associated with garment comfort. Direct test methods used to assess fabric permeability to aerosol pesticide sprays require care during the handling, storage, and disposal of the pesticide, the contamined equipment, and the test samples. Analytical methods used (gas chromatography or bioassay) are time consuming and costly. Therefore, a dye spray test that was more cost effective, less dangerous, and more immediate was developed. The second objective of this study, to examine factors related to the fabric construction that are associated with the physical comfort of the wearer, was selected because workers often choose comfort over protection particularly when the results of exposure may not be immediately noticeable.

Hypotheses

Based on these facts, the following hypotheses were formulated:

I. No difference exists in the densities of the test fabrics.

A. There is no difference in density among the woven test fabrics.

B. There is no difference in density among the nonwoven test fabrics.

C. There is no difference in density between the woven and nonwiven test fabrics.

II. No difference exists between the textile substrates tested as measured by air permeability.

A. There is no difference in air permeability among woven test fabrics.

B. There is no difference in air permeability among nonwoven test fabrics.

C. There is no difference in air permeability between woven and nonwoven textile substrates.

III. No difference in water vapor permeability exists in water vapor permeability between the textile substrates tested.

A. There is no difference in water vapor permeability among the woven test fabrics.

B. There is no difference in water vapor permeability among the nonwoven test fabrics.

C. There is no difference in water vapor permeability between the woven and nonwoven test fabrics.

IV. No difference exists between the protective value of functionally finished textile substrates and those without finishes as indicated by aerosol dye permeability using methylene blue dye as an indicator in water-(with and without surfactant) and oil-based emulsions.

A. There are no differences in the protective values of the test fabrics as indicated by dye penetration among finished and unfinished woven test fabrics.

B. There are no differences in the protective values of the test fabrics as indicated by dye penetration among finished and unfinished nonwoven test fabrics.

C. There is no difference in the protective value as indicated by dye penetration between finished and unfinished woven and nonwoven test fabrics.

V. No difference exists between the protective value of the functionally finished woven and nonwoven test fabrics as indicated by aerosol dye penetration using methylene blue dye as an indicator in water-(with and with out surfactant) and oil-based emulsions.

A. No difference in the protective value as indicated by dye penetration exists among finished woven test fabrics.

B. No difference in the protective value as indicated by dye penetration exists among finished nonwoven test fabrics.

C. No difference in the protective value as indicated by dye penetration exists between finished woven and nonwoven test fabrics.

VI. Protective value as measured by the aerosol spray penetration test using methylene blue dye as an indicator in water-(with and without surfactant) and oil-based spray emulsions is not predictive of aerosol penetration by the pesticide Malathion as measured by GLC.

Definition of Terms

Acetylcholinesterase (AChE). AChE or cholinesterase is a chemical catalyst (enzyme) that helps regulate the activity of nerve impulses.

Aerosol. An extremely fine mist or fog consisting of solid or liquid particles suspended in air.

<u>Barrier finish</u>. A surface treatment applied to textiles to prevent penetration by liquids or soils.

<u>Dermal Toxicity</u>. Ability of a chemical to cause injury when absorbed through the skin.

<u>Emulsifier</u>. A chemical which aids in suspending one liquid in another.

<u>Impermeable</u>. Cannot be penetrated.

<u>Organophosphate</u>. A synthetic organic pesticide containing carbon, hydrogen, and phosphorous.

<u>OSHA</u>. Occupational Safety and Health Administration

<u>Penetration</u>. The act of entering or the ability to enter.

<u>Spun-bonded</u>. A nonwoven fabric composed of a calendared bat of extruded fibers.

<u>Spun-bonded with melt-blown fibers</u> (spun-bonded/MB). A calendarded bat of interlaced melt-blown fibers.

<u>Spun lace</u>. A nonwoven fabric made by entangling fiber filaments using jets of water.

<u>Surfactant</u>. A chemical which increases the emulsifying, dispersing, spreading, and wetting properties of a liquid.

Limitations of Study

1. The sample size was limited to four woven fabrics and seven nonwoven fabrics.

2. The results of the study are limited to laboratory results; no field testing was included in the study.

3. Malathion was the only pesticide of the organophosphorous class of pesticides to be tested.

4. One set of spray conditions (droplet size, spray time, distance from sprayer, and pressure) was used throughout the aerosol spray testing.

CHAPTER II

REVIEW OF LITERATURE

Historical Overview

Documentation of organophosphate poisoning began after World War II. Few scientists and health officials believed or recognized that a hazard existed and the matter was a topic of open debate at the 1952 American Chemical Society meeting (Experts agree, 1952). Quimby and Lemmon (1958) reported scattered poisonings among fieldworkers (pickers) 8 to 34 days following pesticide application. They attributed the poisonings to residual dust on the foliage. Milby, Ottoboni, and Mitchel (1964), reporting on a field investigation of California peach harvesters, linked poisoning symptoms with organophosphate exposure. The relationship of contaminated clothing to dermal exposure and subsequent organophosphate poisoning was discussed by Southwick, Mecham, Cannon & Gortatowski (1974) in a report of the death of an elderly man due to pesticide intoxication. In the results of a field investigation of an organophosphate intoxication incident, Maddy (1975) noted that intoxication was directly related to field exposure. Wolfe, Armstrong and Durham (1966) found an apparently significant variation in hazard for each pesticide type examined in the study depending upon the type of activity performed by the worker. Loaders and flaggers for air applications received highest levels of dermal exposure.

Dermal Exposure

Dermal exposure is the primary cause of pesticide intoxication. Ninty-seven percent of the pesticide to which a body is exposed during most situations is absorbed dermally (Wolfe, 1973). Applicators of liquid pesticide formulations are more susceptible to poisoning due to the wetting, absorption, and wicking of the pesticide by the garments worn during exposure situations. Ordinary clothing materials are poor barriers against toxic materials. Liquid pesticides wick into and are confined to the capillaries which exist between the fibers of the yarns in the outer fabric layer.

Clinical Response Studies. Clinical response studies of organophosphate exposure began in the middle to late 1970's. Spear et al. (1977) monitored organophosphate intoxication and measured the clinical responses of inexperienced orange grove pickers. Clinical results were used to estimate dermal dosage/exposure to foliar pesticide residue. Morgan (1980), discussing the differences and similarities between the clinical manifestations of chronic and acute organophosphate poisoning, concluded that the worker must be protected from both acute and chronic poisoning through minimizing contacts with pesticides, monitoring the work environment, and through the provision of practical garments. Hussain, Blatherwick, Gaunce, & MacKenzie (1981) advocated the routine monitoring of agricultural workers exposed to anticholinesterase insecticides in order to detect incipient effects well before overt abnormalities occur.

Dose-Response Relationships. Dose-response relationships for various organophosphate pesticides were discussed by Popendorf and Leffingwell (1982). Based on assumed exposure models, decay processes, and decay conditions, they found that exposure dosage decreases as post spray time increases. Due to this finding, Popendorf and Leffingwell favored using delayed reentry intervals as safety procedures over the use of personal protection such as impervious clothing. Impervious clothing, they felt, was "impractical to use, expensive, and would impose additional health risks due to heat stress." Furthermore, they stated that protective clothing and other technological controls are "largely nonexistent for many harvest and other field practices." (Popendorf & Leffingwell, 1982).

Dubois, Doull, Salern and Coon (1949) and Grob, Garlick, and Harvey (1950) identified the neurologic mechanism of the enzyme acetylcholinesterase (AChE) and its inhibition by parathion and other organophosphate pesticides. Spector (1959) and Heath (1961) expanded earlier toxiological research and documented the pathological symptoms of AChE inhibition. Evaluation technology improved during the mid-1960's. Gas-liquid chromatography replaced colorimetric residue analysis. This change in methodology made it possible to separate and quantify parathion from its oxygen analog, paraoxon, which has been found to be more toxic. Gage (1967) published results of a clinical evaluation of intoxication and its effects. Wills and Dubois (1972) discussed effects of field exposure to organophosphates.

Risk Assessment. Risk of exposure to pesticides is classified into three levels of severity: acute, chronic, and incidental. Chronic exposure is further divided into two subcategories: high occupational and low incidental. Of concern are populations of special risk for acute and chronic high occupational exposure, which includes agricultural workers, expecially applicators, mixers, and pickers. Exposure is measured in terms of toxicant absorption. Both acute and chronic exposure and the resulting toxicant absorption can result in physiological and/or psychological manifestations. Of the two, chronic exposure is of greater concern and the long-term effects are not fully known (Davies & Freed, 1980).

Exposure to pesticides may not result in outward symptoms or signs of poisoning. Although no overt signs of pesticide poisoning were reported, agricultural workers examined monthly during one growing season were found to have lower AChE levels than persons not exposed to pesticides (Hussain et al., 1981). Toxicant absorption is measured by examining urine samples for toxicant metabolites and/or sampling the blood cholinesterase level. Production of cholinesterase, an enzyme involved in the nerve transmission process, is inhibited by organophosphates (Hussain et al., 1981). There are four levels or classifications of toxicant absorption: detectable, incipient toxicity, poisoning dose, and lethal dose. At the detectable level of toxicant absorption, toxicant metabolites are present but no enzymological effects are produced (Morgan, 1980).

A major discussion of the effects of long-term, recurring exposure was published by Davis et al. (1975).

The documented persistent or protracted responses discussed included behavioral or central nervous system effects, renal disfunction, effects on ocular motor responses, and other chronic health effects. Morgan (1977) noted the following signs of symptoms of organophosphate (OP) poisoning: headache, dizziness, extreme weakness, ataxia, tiny pupils, dark or blurred vision, muscle twitching and/or tremor, nausea, and a slow heartbeat. Other symptoms included respiratory depression, pulmonary edema, extreme bradycardia, and heart block. Chronic effects, Morgan noted, often result in a influenza-like illness characterized by weakness, anorexia, and malaise. Exposure to OP pesticides can be measured through blood analysis to measure red cell AChE depression and through urinalysis for OP metabolites. However, the effects of anticholinesterase agents on health are caused primarily by inhibition of AChE in cholinergic synapses, not by any coincident inhibition of blood cholinesterases (Hussain et al., 1981).

Measurement of Dermal Exposure. There are three routes by which pesticides may enter the body; dermal, respiratory, and oral. Wolfe's reports of exposure studies indicate that of the pesticide to which a body is exposed during most situations, especially during liquid spray applications, 97 percent is deposited on the skin (Wolfe, 1973). Therefore, it is important to provide adequate protection of the skin during periods of exposure risk. Spear et al. (1977), using gauze pads placed next to the fieldworkers' (pickers') skin, monitored amounts of pesticide residue penetrating the workers' clothing and the resulting estimated mean dermal dose for each body area was computed. The hands and forearms received approximately equal doses; when combined they contributed 45 to 50 percent of the entire dermal dose. The shoulders and upper arms added 10 to 15 percent, the torso 10 percent, and the legs 15 to 20 percent of the total dose. Spear noted that the figures would probably vary slightly with liquids and aerosol sprays with the shoulders and upper arms increasing in percent exposure.

Insecticides are usually sufficiently lipid soluble to diffuse through the skin, which consists of layers of lipids. Pesticides may diffuse directly through the skin layers or through hair shafts, ducts, or pores (Wester & Maibach, 1983). Rate of toxicant absorption is affected by a number of factors including environmental conditions (temperature, relative humidity), location and surface area of applied dose, concentration and type of toxicant, and possible interaction of toxicants, and age of the person exposed to the toxicant.

In a discussion of pesticide application safety, Baker and Bradshaw (1979) noted the differences in rates of absorption of different areas of the body. Using the rate the forearm absorbed pesticide as a base line of 1.0, absorption rates of other areas of the body were compared. The reported absorption rates were the palm of the hand, 1.3; the ball of the foot, 1.6; the abdomen, 2.1; the scalp, 3.7; the forehead, 4.2; the ear canal, 5.4; and the scrotal area 11.8. Baker and Bradshaw also noted that cuts and scrapes and also the eyes required special attention and protection.

Risk Reduction. Reduction of risk is two-fold. It includes measures designed to reduce the transfer of toxic residues to the workers and measures designed to reduce the residues available for exposure of the workers. Federal reentry standards (1974) were designed with the latter measure in mind. With the use of nonpersistent compounds, standards for safe reentry could be established based on the detection of vaporous and dislodgeable residues. Federal reentry standards as published by the EPA in 1974 included field reentry standards and a description of the protective requirements for workers who must enter treated fields prior to expiration of the required time lapse.

These apparel standards included long-sleeved shirts, slacks, gloves, respirators or dust masks, and hats.

<u>Protective Clothing.</u> Measures designed to reduce contamination of the skin by toxic substances include protective clothing. In various publications the USDA and EPA recommend the use of cloth coveralls or trousers and long-sleeved shirts for protection. When there is a chance of wetting the fabric through use or contact with sprays then waterproof garments are recommended. Unlined neoprene boots, neoprene gloves, and a waterproof, wide-brimmed hat are also recommended. Ainsworth (1971) recommended three lines of approach to selection or design of protective clothing depending on the type and specificity of the hazard: impregnating normal working clothing with a chemical which would react with and destroy the toxic chemical on contact; using a chemically resistant, specially designed outer garment, usually impermeable; and using a disposable garment which, once removed, would take the liquid contamination away with it.

<u>Decontamination of Protective Clothing.</u> Because pesticide residues can build up on the fabric surface and migrate through to the skin, daily laundering of reusable work clothing, including the hat, is important. Boots and

gloves should be washed, inside and out, and thoroughly dried. Laundering of pesticide-contaminated clothing does present certain risks, particularly if recommended laundering procedures are not followed. Southwick et al. (1974) reported that laundering of parathion-contaminated clothing in either ionic or catatonic detergents removed less that 50 percent of the available parathion. The addition of hypochlorite bleach increased the percentage of contaminant removed to 81 percent. They also noted that a noncontaminated piece of fabric laundered simultaneously with the contaminated fabrics contained 633 ppm of parathion following the laundering process.

Finley et al. (1979) monitored the efficiency of the laundering process in removing field residues from 100 percent cotton and 50/50 cotton/polyester fabrics. A procedure utilizing one wash and two rinse cycles followed by air drying was found to remove 75 to 95 percent of the contaminant (significant at $p<.05$). A second wash cycle did not remove an additional significant amount on a percentage basis. An alkaline wash medium was recommended based on a previous study in which Finley noted that methyl parathion was hydrolyzed to p-nitrophenol and other materials in an alkaline medium (Finley et al., 1974). Finley also noted that laundering contaminated garments through three complete cycles did not remove all residues.

Lillie, Livingston, and Hamilton (1981) noted that the removal of insecticides and herbicides from contaminated clothing was unaffected by water temperature. However, the authors recommended a laundering temperature of 140 F because, although not significant at the .05 level, a larger quantity of toxicant was removed at that wash temperature.

The pH of the wash water has been noted as a factor in the removal of pesticides from clothing. Easley et al. (1982) noted that an ammonia presoak combined with laundering removed 80 to 96 percent of the methyl parathion. It was their conclusion that a basic wash medium aided in the reduction of the amount of methyl parathion present following laundering. However, a minimum of three launderings was required before biological activity reached a harmless level. In a study on the removal of Captan and Guthion from 100 percent cotton and Goretex fabrics, Easter (1983) used a wash medium pH of 9.20 ± 0.2. Easter reported that the percentage of pesticide removed ranged from 72.7 percent to 99.8 percent and amount removed increased as temperature increased.

<u>Disposable Garments.</u> The use of nonwoven disposable garments has several advantages. Nonwoven fabrics are inexpensive and fast to produce. They function more

efficiently than woven fabrics in preventing chemical vapor transfer in that the pore size is small and the pathways through the fabric are tortuous (Ainsworth, 1971). Nonwoven fabric construction offers increased control over the thickness and the fiber to air volume ratio. The weight and thickness of most nonwoven fabrics used in protective clothing impose very little heat stress when worn as an overgarment or alone. Another advantage of the use of nonwoven fabrics for disposable garments is that the randomly laid fiber arrangement and small pore size allow for a more even and complete coating by barrier finishes. Nonwoven fabrics are generally stiffer than woven fabrics of similar weight. This poor drape, if exploited properly in the garment design, could aid in releasing water vapor through the air flow generated by normal body movement in a work situation (Ainsworth, 1971).

Pesticides are applied in both water-based and oil-based media. Oil-based media are particularly difficult to remove from synthetics such as nylon or polyester during standard or recommended laundering procedures. Easter (1983) noted that oil-based toxicant was more difficult to remove from Goretex® (nylon) and from cotton. Concentration was also a factor. Easley et al. (1982) noted that highly concentrated pesticides were difficult to remove to any safe level. In cases where garments have been wetted with highly toxic or concentrated pesticide formulations, the USDA recommends disposal of the contaminated garments rather than laundering. In circumstances where garment disposal is recommended, nonwoven limited-use garments are economically advantagous.

<u>Functional Finishes.</u> Hydrophobic and oleophobic fabric finishes yield increased soil release and repellency properties. Pesticide sprays are applied in either a water-based or an oil-based emulsion of the pesticide dissolved in an organic solvent. Pesticide-wetted clothing is a source of vapor which diffuses inward, through the clothing to the skin as well as outward into the surrounding air. To minimize pesticide aerosol penetration the application of a fabric finish that imparts hydrophobicity and oleophobicity becomes necessary.

Both fabric structure and surface free energy affect the extent of fabric penetration by impinging aerosol particles. Phobicity between a liquid and a solid film is dependent on contact angles of 90° or more (Pittman et al.,1971). The critical surface energy for wetting of a solid is the amount of surface energy required by a liquid to ensure perfect wetting. A liquid of equal or lower surface energy of a given solid would exhibit a contact angle of zero. A liquid of higher surface energy would yield a finite contact angle on that solid (Zisman, 1964).

Barrier finishes such as fluorocarbon-based finishes impart oleophobic and hydrophobic properties by lowering fabric free surface energy, thus limiting wetting by any solvent (Ellzey et al., 1969). Silicon-based finishes are unable to lower the fabric free surface energy to a value low enough that would render fabrics oil repellent (Berch, Peper, & Drake, 1965). Finishes such as poly 1, 1-dihydroperfluoroctyl methacrylate have very low surface energy values (10.6γ_c) and impart both oil and water repellency (Zisman, 1964).

The composite structure of the fabric structure, Zisman (1964) noted, is such that the surface energy provided by a finish of polytetrafluoroethylene (18.5 /cm) is too high to yield oil repellency. Zisman (1964) has also shown that solids containing long chain perfluoroalkyl groups have the lowest possible surface energy. This he attributed to a lack of polarity and polarizability in the perfluoroalkyl groups. Fluorocarbon-based finishes used as soil-repellent and soil-release finishes are composed primarily of fluorocarbon acrylates or copolymers with olefins (Pittman et al., 1971).

The application of a barrier finish coats the fabric surface, filling in crevices and surface rugosities on fibers. Finishes also fill in the interstial spaces between fibers in nonwoven fabrics and between fibers in yarn bundles in woven fabrics. This polymeric coating limits entrapment of soils and liquids on the fabric surface (Warburton & Parkhill, 1973).

Factors Affecting Garment Comfort

Comfort is best described by the person experiencing it. It is a sensation that is easily recognized and is often defined in terms of not being uncomfortable, or as the absense of unpleasantness (Slater, 1977). It is much easier to verbalize discomfort than it is to define comfort. Rodwell, Renbourn, Greenland, and Ketchington (1957) state that comfort is influenced by the physiological reactions of the wearer. Pontrelli (1977) noted that the aspect of comfort is a subjective response resulting from many other stimuli and is not a cause but a conclusion.

Physical comfort is determined by how well the body can maintain a zero heat balance. The body generates heat metabolically which increases during work. The body's heat balence or ratio is defined as zero when the heat generated and absorbed by the body is equal to the heat lost by the body. Heat is lost through convection, conduction, radiation, and evaporation. Clothing acts as an insulator and impedes heat transfer to and from the body. Garments designed to promote heat loss through conduction and convection are impractical under conditions designed to protect the body from exposure to liquids, aerosols, and dusts. In such cases, evaporative heat loss becomes extremely important in maintaning safe body temperatures. Under stress conditions, garments of fabrics that are air and water vapor permeable which allow evaporative cooling are necessary to prevent illness or injury due to heat stress.

Water Vapor Permeability. When man is at rest, approximately 25 percent of his heat loss is through evaporation. One-half of this evaporative heat loss takes place on the skin surface (Goldman, 1971). Any clothing item which inhibits the passage of water vapor blocks evaporative cooling. The rate of evaporative cooling is dependent on the dispersal of the vapor, produced by the evaporation of perspiration at the skin surface, through the clothing layers to the outside environment. Moisture vapor transmission disperses outward from the body only if the vapor pressure of the surrounding atmosphere is less than that in the air at the body surface. Moisture vapor transmission then is a critical performance property of weather conditions (Weiner, 1971). If water vapor cannot escape through the clothing at a sufficient rate, the relative humidity at the skin level will increase, yielding an uncomfortable sensation of clamminess. The degree of discomfort increases as the relative humidity in the air next to the skin increases.

Mecheels (1971) listed three conditions to be considered for determination of water vapor permeability of clothing systems.

1. Ventilation openings of the clothing system.
2. The point at which the microclimate between the skin and clothing reaches or passes 75% R.H. at which point the subjective comfort rating reduces substantially.
3. How the clothing functions during water condensation under conditions of rising ambient relative humidity.

Rees (1971) reported that water vapor resistance values of a fabric are more useful than air permeability values in the analysis of clothing items. Water vapor can diffuse through materials that are considered impermeable. The total resistance of a clothing system to the passage of water vapor is controlled by the layer of most resistance (Rees, 1971). Fourt and Hollies (1970) noted that the resistance of a woven fabric to vapor transfer depends on the thickness of the fabric and the tightness of the weave. Whelan, MacHattie, Goodings, and Hurt (1955) expressed resistance in terms of thickness and fiber volume. Excluding fabrics of very high or low air permeability, they stated, air permeability had no effect on water vapor resistance.

Woodcock (1962) developed a "moisture permeability" index based on the evaporative cooling produced by the moisture evaporated from the skin and its passage through the clothing system. The dimension of the index was dependent upon the ratio of the resistance of a clothing assembly to heat and water vapor transfer. Spencer-Smith (1977) stated that the study of water vapor transfer in the absence of temperature gradients was unrealistic due to environmental interaction that occurs with heat transfer.

According to Rees (1971), for a resting subject in a state of comfort, the relative humidity at the skin level is lower than that of the ambient air. Heat and moisture in the form of water vapor flow continuously from the skin through the clothing to the environment. "Consequently a gradient of temperature and of degree of dampness (relative humidity and water vapor pressure) exist from the skin to the ambient air." However, Rees (1971) concluded, the rate of evaporation is dependent on the difference in water vapor pressure between a surface and the ambient air rather than differences in relative humidity. Slater (1977) stated that the movement of water vapor through a fabric depends considerably "on the microporous nature of the material, and this movement can therefore be modified by any operation that brings about a change in this structure."

Air Permeability. Air permeability refers to the rate of air flow through a material under differential pressure between two fabric surfaces. The air permeability of a fabric can be affected by yarn and fabric type and altered by fabric finishing. Yarn twist and crimp and the weave influence the shape and area of the interstices between yarns. Fabric construction which permits yarns to extend easily would open up the fabric increasing the free flow of air. Air permeability is affected by various finishing techniques such as hot calendaring or coating which flatten yarns and close up the open areas resulting in decreased air permeability. The range of air permeabilities of most fabrics used for clothing is below 500 $ft.^3/ft.^2$ min. when measured at a pressure difference equal to 0.5" water.

Evaporative resistance is independent of weaving texture and air permeability under diffusion conditions. Natural movements of the body produce fluctuating air flows through permeable clothing. Air flow through the fabric results in higher water vapor transmission (Ainsworth, 1971). Fabrics with higher air permeabilities have increased moisture vapor transmission at low windages (Spencer-Smith, 1971). In hot climates, however, it was found that for fabrics in the lower ranges of porosity, thinness of fabric is more important than porosity in reducing heat burden. Also, the diffusion layer of relatively still air between the clothing surface and the general atmosphere reduces the effect of porosity, so that at low rates of air movement, there is no difference between extremely tightly woven and moderately tightly woven hygroscopic fibers (Newburgh, 1949).

CHAPTER III

METHODOLOGY

This research focused on nonwoven substrates which offered protection at a sufficiently low cost as to be disposed of after one wearing. Particle penetration of pesticide sprays is dependent on the characteristics of fabric design, the fiber/yarn interstices, and the nature of the pesticide particles rather than a specific pesticide or fiber (Serat, Van Loon, & Serat 1978). The presence of a surfactant and the nature of the spray medium also affect particle penetration. Therefore the substitution of a dye as an indicator for the pesticide in the aerosol spray test was examined as a rapid and safe method of determining aerosol pesticide penetration.

Assuming that fabrics would offer greater comfort than plastic films or rubberized fabrics as garment substrates, a range of finished and unfinished, woven and nonwoven fabrics were examined. Of particular interest were the nonwoven substrates developed for medical use which are designed to resist penetration of lipids and water but allow water vapor transmission. Scotchgard®, a fluorocarbon finish manufactured by the 3M Corporation, was applied to fabrics not commercially finished with a soil repellant. The physical properties relating to the potential comfort of the test fabrics that were examined were weight, thickness, density, air permeability, and water vapor permeability.

Materials

Three categories of nonwoven fabrics were examined for aerosol penetration, density, water vapor permeability, and air permeability:

1. Spun-lace, 100% polyester and a polyester/rayon blend
2. Spun-bonded, 100% olefin, nonperforated, and polypropylene coated styles
3. Spun-bonded polypropylene with melt blown fibers (spun-bonded/MB).

Four woven fabrics were selected:

1. Twill weave, denim, 100% cotton
2. Muslin, 100% cotton commercially finished with Scotchgard® (fluorocarbon)
3. Muslin, 100% cotton with a Quarpel© (fluorocarbon) finish.
4. Muslin, 35% cotton/65%polyester with a Quarpel® finish.

The selection of fabrics was based on the types of fabrics recommended for "general use", fabrics currently in use, and fabrics proposed for use in protective clothing. Filter paper was used as the backing substrate and was placed behind the test fabrics to absorb any aerosol spray penetrating the test fabric. A containment box of Tuffak®, a polycarbonate, was designed to contain the mounted samples during spraying to prevent contamination of the work area and to recover excess spray (Appendix A.). Frames of Tuffak® were designed to hold the fabric in place and to prevent back or side contamination of the test fabric (Appendix B.). The aerosol spraying device used was a Sears Craftsman airless paint sprayer model number 165. The spray rate was adjusted to a volume of 120 ml of water per minute.

To reduce the risk of pesticide exposure and the time required for extraction and analysis, methylene blue dye was substituted for the pesticide. Aerosol solutions representative of pesticide spraying media were used to test aerosol spray penetration. The first spray medium tested consisted of distilled water. The second consisted of a surfactant formulation (an emulsifier concentrate of the type commercially used) mixed with distilled water. The third spray emulsion was a cottonseed oil blended with the surfactant formulation. The dye solution was mixed with each of the spray formulations allowing a visual estimate of penetration. Methylene blue was the dye chosen because its molecular weight (319.86) is similar to that of two of the most commonly used organophosphate pesticides, Malathion® (330.36) and parathion (291.27); also the dye is very intense and relatively nontoxic to humans.

An emulsifiable concentrate of Malathion® (O,O-dimethyl dithiophosphate of diethyl mercaptosuccinate) containing 50% active ingredient was used in a fourth aerosol spray solution. The amount of Malathion® penetrating the test fabric was analyzed using gas/liquid chromatography (GLC). The results of the GLC used to determined the amount of pesticide penetrating to the backing substrate was compared to the visual results of the penetration.

Procedure

Physical Test Data. The physical data for each fabric were compiled as follows: weight, thickness, density, air permeability, and water vapor permeability. Fabrics were conditioned in accordance with ASTM standards (21°±1°C and 65 ± 2% relative humidity) for 24 hours prior to testing. Three test replications were made for each fabric under test. Fabric samples were obtained from yardage or test garments. All results were reported in standard SI units.

Fabric density was computed by dividing the sample mass by the sample volume to obtain kg/m^3.

The ASTM D 737-75 "Standard Test Method for Air Permeability of Textile Materials, 1983" was the testing procedure followed to measure the air permeability of the test fabrics. A Fraiser air permeabilicy test apparatus was used to determine the volume of air (m^3) per second that flowed through a square meter of fabric at a pressure drop of 124 pascals. The prescribed pressure differential used was 0.5" (12.7 cm) of water.

The "Standard Test for Water Vapor Transmission of Materials in Sheet Form, Procedure B" (ASTM 396-66, 1972) was the method selected to measure water vapor transmission. Procedure B is the evaporative dish method of determining water vapor transmission described by Fourt and Hollies (1970) and Weiner (1971) in which the test fabric is placed over a dish of water and weight loss over time is computed. The weight lost by the assembly represents the amount of water vapor produced over the water surface that diffused through the test fabric.

Each test fabric was placed across the top of a dish containing 25 ml of distilled water. The distance from the surface of the water to the fabric was 2.5cm. The fabric was sealed to the rim of the dish and the assembly was weighed. Each assembly was reweighed every eight hours over a five-day period and the percentage of weight loss was computed.

Finish Application. The nonwoven test fabrics were tested in both unfinished and finished states. The finish (Scotchgard® aerosol spray) was applied following the manufacturer's instructions. The spray container was held five inches above the fabric and moved over the fabric while spraying to achieve even coating. Spray was applied for approximately 10 seconds per test sample (18.5cm x 18.5cm), thoroughly wetting the fabric surface. Finished samples were allowed to dry and condition for 24 hours prior to test.

Spray Formulation. The spray formulation for the three aerosol dye spray tests were mixed as follows: 1. water; 2. water/surfactant (48:1); and 3. unrefined cottonseed oil/surfactant (4:1). All formulations contained 0.1 percent methylene blue dye as an indicator. The proprietary surfactant was obtained from a pesticide manufacturer and is used in commercial pesticide formulations.

A commercial emulsifiable pesticide concentrate containing 50 percent of the active ingredient Malathion®, 33 percent aromatic solvent, and 17 percent inert ingredients was used for the pesticide aerosol spray test.

The recommended amount of concentrate per gallon of water ranged from one and one half teaspoons for use on vegetables to ten tablespoons for use in animal kennels against fleas. The formulation chosen for use in the spray test contained ten tablespoons of the emulsifiable concentrate per gallon of water (4 percent solution). This particular formulation was chosen because it was the highest percentage dosage recommended by the manufacturer. Manufacturer's mixing intructions were followed. Distilled water was used for test purposes.

Aerosol Spray Penetration using Methylene Blue. The design of the aerosol spray test was based on the ASTM method B 117-73, Standard Method of Salt Spray (Fog) Testing, developed primarily for testing metallic and metal coated specimens. The spray test procedure was designed to assess the resistance of fabrics to penetration of aerosol sprays. The testing procedure consisted of mounting a fabric sample (18.5cm x 18.5cm) in the Tuffak® frame (Appendix B) over an absorbent backing (18.5cm diameter filter paper) and placing the framed sample upright in the containment box at a distance of 30.5 cm in front of the airless sprayer so that the exposed test fabric was facing toward the nozzle of the sprayer. A circular area (12.5 cm diameter) was exposed to the aerosol spray. Three test replications were completed for each fabric tested with each aerosol spray formulation. The spray time for the water-base solutions was 60 seconds. The spray time for the oil-base solution was 30 seconds. The increased concentration of surfactant in the oil-base formulation resulted in a superior wetting system which reduced the spray time required for sample differentiation to 30 seconds. The average amount of spray applied to the surface of the test fabric was .25g per cm^2 of the exposed area for both the water-base and oil-base solutions.

<u>Pesticide Aerosol Spray Penetration.</u> The aerosol pesticide spray test followed the same spray procedure used for testing the water based dye spray solutions. However, to prevent the contamination of the backing material, aluminum foil was placed under the filter paper. The test fabric was placed on top of the filter paper and the aluminum foil was folded over the edges and creased to seal the filter paper between the foil and the test fabric. Following the spray test the filter paper was removed, sealed in a self-sealable freezer bag, and placed in a container in the freezer until extraction procedures could be followed.

The filter papers containing Malathion© were extracted using a Soxtec® extraction system. Methanol was the solute used for the extraction. Beakers containing methanol were mounted and sealed in place. The extractor thimbles containing the comtaminated filter paper were lowered into corresponding beakers containing 50ml of heated (65 C) methanol. The time for the reflux cycle was 45 minutes. The thimble was then raised out of the solvent and rinsed using a soxhlet extraction procedure. The time allotted for the rinse cycle was 15 minutes. The solvent containing the extracted Malathion© was placed in glass bottles with screw cap closures and kept in a freezer until the analyses could be performed. Prior to analysis, each sample was allowed to warm to room temperature and approximate sample volume was determined.

Analyses were performed using a Tracor© 560 gas chromatograph equipped with a flame photometric detector operating in the phosphorous specific mode (526nm filter). Separations were achieved at an isothermal oven temperature of 210°C using a 6' x 2mm glass column packed with 10 percent DC-200 on 80/100 GCQ (Applied Science Laboratories, Inc.). A dectector operating temperature of 200°C and an injection port temperature of 225° C were used.

The stock solution used for a standard was a one to twenty dilution of the stock spray solution and contained 700 ug/ml as malathion. All analyses were based upon standards generated from this stock solution. When necessary, a small portion of a test sample solution was diluted with methanol to achieve an appropriate concentration for gas chromatographic (GC) analysis.

Statistical Analysis

Physical Test Data. Three test replications were made for each of the eleven test fabrics for all physical tests performed. Fabric mean and standard deviation were computed for each set of test results. One-way analysis of variance (ANOVA) was used to compare fabric testing results for each physical property tested. Statisical results were considered significant at or above the 95 percent confidence level. Duncan's Multiple Range test ($p<.05$) was used as a post hoc test following ANOVA to examine the between-group variation. Paired *t*-tests were used in some cases to examine differences between fabrics.

Aerosol Spray Test Data. The results of the aerosol dye spray test were evaluated visually and recorded as pass or fail. Failure was determined by noting the presense of methylene blue dye on the backing substrate. A frequency count was also made based on an individual performance on the three spray tests.

Following extraction and analysis, the mean penetration of pesticide per cm^2 was computed for each fabric in test runs with Malathion®. The fabrics were grouped according to performance (pass/fail) on the three aerosol dye penetration tests. The four groupings which resulted with the three spray tests were pass-pass-pass, pass-pass-fail, pass-fail-fail, and fail-fail-fail. A one way ANOVA was performed to examine between-group variability. Duncan's Multiple Range test ($p<.05$) was performed as a post hoc test.

CHAPTER IV

RESULTS

Physical Properties

The physical properties of density, air permeability, and water vapor permeability were determined using standard testing methodology. Following statistical analyses, the between-group variability, by fabric type, was found to be significant for all of the physical properties tested. The results of the physical tests are shown in Table 1.

Density. Fabric density was computed by dividing sample mass by sample volume. Test fabric weights ranged from 283 g/m^2 for denim to 40 g/m^2 for spun-bonded olefin. The woven test fabric weights ranged from 283 g/m^2 to 113 g/m^2. Nonwoven fabrics weighed significantly (.05) less than the woven fabrics. The spun-bonded olefin was the thinnest test fabric and measured .010 cm. The denim (.057 cm) was the thickest. The thickness of the spun-bonded olefin fabrics were significantly lower than the other fabrics tested.

Fabric densities ranged from 162 kg/m^3 (50g/m^2 spun-bonded/MB) to 514 kg/m^3 (Scotchgard© finished 100 percent cotton shirting). The ANOVA of fabric densities

Table 1

A Comparison of Physical Properties of Woven and Nonwoven Fabrics for Protective Clothing for Pesticide Workers

Fabrics Tested	Weight g/m^2	Thickness cm	Density kg/m^3		Air Permeability $(m^3$ of air/s$)/m^2$		Water Vapor Permeability total Δg	
	$\bar{x}$	$\bar{x}$	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
<u>Woven Test Fabrics</u>								
Denim	283	.057	381	2.3	.05	.001	10.8	.3
Commercially finished cotton (Scotchgard©)	157	.029	541	6.4	.34	.01	11.7	.1
Quarpel© finished cotton	113	.025	440	8.9	.57	.05	11.5	.2
Quarpel© finished 35/65 cotton/polyester	117	.024	490	2.6	.34	.03	11.8	.4
<u>Nonwoven Test Fabrics</u>								
Spun-lace polyester	90	.026	354	0.01	.28	.01	12.0	.1
Commercially finished polyester/rayon spun-lace	70	.027	229	0.01	.36	.01	12.0	.1
Spun-bonded olefin	40	.010	384	2.3	.0044	.0001	8.0	.2
Polyethylene coated spun-bonded olefin	70	.013	534	0.01	.0044	.0001	7.5	.1
Spun-bonded/MB ($90g/m^2$)	90	.051	175	1.5	.04	.001	11.7	.3
Spun-bonded/MB ($50g/m^2$)	50	.031	162	1.5	.0044	.0001	9.6	.1
Commercially finished spun-bonded/MB ($50g/m^2$)	50	.028	179	1.0	.0044	.0001	9.7	.1

indicated a significant difference between woven and nonwoven fabrics at the .05 level of significance. Duncan's Multiple Range test ($p<.05$) was used to determine the location of the between fabric variation. Fabric densities were highest for the woven fabrics, which ranged from 440 kg/m^3 (Quarpel® finished cotton to 541 kg/m^3 (Scotchgard® finished cotton) (Figure 1).

Figure 1: Duncan's Multiple Range Comparison of Woven Fabric Density ($p<.05$), (m^3 of air/s)/m^2

	Quarpel® cotton	Quarpel® cotton/ polyester	Denim	Scotchgard® cotton
$\bar{x}$	453	490	496	541

There were significant differences between each of the nonwoven test fabrics (Figure 2). The spun-bonded/MB fabrics were the least dense (161 kg/m^3 to 179 kg/m^3). The density of the spun-bonded olefin fabrics and the spun lace fabrics were similar ranging from 229 kg/m^3 (commercially finished spun-lace polyester/rayon) to 384 kg/m^3 (spun-bonded olefin). The polyethylene coated spun-bonded ofefin was an exception with a density of 526 kg/m^3. The high density of this fabric can be attributed to the presense of the polyethylene film coating.

Figure 2: Duncan's Multiple Range Comparison of the Density of the Nonwoven Test Fabrics ($p < .05$)

	Spun-bonded/ MB 50g	Spun-bonded/ MB 90g	Finished spun-bonded/ MB 50g	Finished spun-lace poly./ray.	Spun-lace polyester	Spun-bonded olefin	Polyeth. coated spun-bonded
$\bar{x}$	162	175	179	233	354	384	526

<u>Air Permeability.</u> The one-way ANOVA indicated that there was no significant variation in air permeability between the woven and nonwoven groups of test fabrics. Air permeability readings (Table 1) indicated that the polyester spun-lace fabrics were closest to those of the shirting weight woven fabrics and would probably have a comfort rating similar to finished woven fabrics of similar density. *T* tests indicated that the air permeability readings for denim and spun-bonded/MB ($90g/m^2$) were significantly lower than the other woven and spun-lace fabrics. The readings for the spun-bonded olefin and $50g/m^2$ spun-bonded/MB fabrics were significantly lower than the denim or the $90g/m^2$ spun-bonded/MB fabrics. There were significant (.05) differences between the woven test

fabrics. The Quarpel© finished cotton was significantly greater ($p<.05$) than the other woven test fabrics (Figure 3).

Figure 3: Duncan's Multiple Range Comparison of the Air Permeability of the Woven test Fabrics ($p<.05$)

	Denim	Scotchgard© cotton	Quarpel© cotton/ polyester	Quarpel© cotton
$\bar{x}$	.054	.338	.342	.576

The differences in air permeability between the nonwoven test fabrics was significant at the .01 level. Although the differences in air permeability between the spun-lace fabrics were significant they were significantly more air permeable than the other nonwoven test fabrics. The spun-bonded and spun-bonded/MB fabrics exhibited low or no air permeability (<0.0044 (m^3 of air/s)/m^2) with the exception of the the 90g/m^2 spun-bonded/MB which had a slightly higher air permeability of .04 (m^3 of air/s)/m^2. This low air permeability indicates that garments of these fabrics would have low comfort in a work situation since air permeability readings of .0044 (m^3 of air/s)/m^2 are defined as being impermeable to air flow (Figure 4).

Figure 4: Duncan's Multiple Range Comparison of the Air Permeability of the Nonwoven Test Fabrics (p<.05)

	Spun-bonded olefin	Polyeth. coated spun-bonded	Spun-bonded/ MB 50g	Finished spun-bonded/ MB 50g	Spun-bonded/ MB 50g	Spun-lace polyester	Finished spun-lace poly./ray.
$\bar{x}$	.004	.004	.004	.004	.037	.323	.417

Water Vapor Permeability. Water vapor permeability as defined by the total mass of water evaporated (measured by sample weight loss test) indicated that the nonwoven spun-lace fabrics and the spun-bonded/MB (90g) were similar to the woven fabrics. The results of the ANOVA comparing woven and nonwoven test fabrics was not significant. There were no significant differences in permeability between the woven test fabrics (Figure 5). Total sample weight loss for the woven fabrics ranged from 10.8g (denim) to 11.8g (Quarpel® finished cotton/polyester).

Figure 5: Duncan's Multiple Range Comparison of the Water Vapor Permeability of the Woven Test Fabrics (p<.05)

	Denim	Quarpel© cotton	Scotchgard© cotton	Quarpel© cotton/ polyester
x	10.8	11.5	11.7	11.8

The water vapor permeability for the nonwoven test fabrics ranged from 7.5 (polypropylene coated spun-bonded) to 11.7g (polyester/rayon spun-lace). A one-way ANOVA of the results of the water vapor test on the nonwoven test fabrics indicated that the between fabric variation was significant at the .01 level. The water vapor permeability results of spun-bonded fabrics were significantly lower (.05 level) than the other nonwoven test fabrics. The water vapor permeabilities of the spun-lace fabrics were similar to the $90g/m^2$ spun-bonded/MB but not to the $50g/m^2$ spun-bonded/MB test fabrics (Figure 6).

Figure 6: Duncan's Multiple Range Comparison of the Water Vapor Permeability of the Nonwoven Test Fabrics ($p<.05$)

Polyeth. coated spun-bonded	Spun-bonded olefin	Spun-bonded/ MB 50g	Finished spun-bonded/ MB 50g	Spun-lace polyester	Spun-bonded/ MB 90g	Finished spun-lace poly./ray.
$\bar{x}$ 7.53	7.74	9.64	9.67	11.65	11.73	11.74

Aerosol Dye Test Penetration

The results of the aerosol dye penetration tests are shown in Table 2. Failure was determined by noting the presence of methylene blue dye on the backing substrate.

Table 2

Pass - Fail Results of Aerosol Dye Penetration by Fabrics Tested

Fabrics Tested	Solution 1*	Solution 2**	Solution 3***
Woven Test Fabrics			
Denim - unwashed	Fail[1]	Fail[2]	Fail
Denim - 3 washes	Fail	Fail	Fail
Commercially finished cotton (Scotchgard®)	Pass	Pass	Pass
Quarpel® finished cotton	Pass	Pass	Fail
Quarpel® finished 35/65 cotton/polyester	Pass	Pass	Fail
Nonwoven Test Fabrics			
Spun-lace polyester	Fail	Fail	Fail
Scotchgard® finished polyester spun-lace	Pass	Pass	Pass
Commercially finished polyester/rayon spun-lace	Pass	Pass	Pass
Spun-bonded olefin	Pass	Fail	Fail
Scotchgard® finished Spun-bonded olefin	Pass	Pass	Pass
Polyethylene coated Spun-bonded olefin	Pass	Pass	Pass
Spun-bonded/MB ($90 g/m^2$)	Pass	Fail	Fail
Scotchgard® finished spun-bonded/MB ($90 g/m^2$)	Pass	Pass	Pass
Spun-bonded/MB ($50 g/m^2$)	Pass	Fail	Fail
Scotchgard® finished Spun-bonded/MB ($50 g/m^2$)	Pass	Pass	Pass
Commercially finished spun-bonded/MB ($50 g/m^2$)	Pass	Fail	Fail

*Water base aerosol spray
**Water/surfactant aerosol spray
***Cottonseed oil/surfactant aerosol spray
[1]Results for Solution 1, unwashed denim, represent six test replications rather than the standard three.
[2]Pass or Fail, unless otherwise noted, indicates that all three replications failed or passed (dye penetration did or did not occur).

If there was no visual evidence of methylene blue on the backing substrate, the fabric was said to have passed.

Solution 1 (water). The unwashed denim, tested with Solution 1 failed one of the three test replications; therefore, three additional test replications were made using Solution I and the test results combined. Three of the six test replications failed the aerosol spray test using Solution I and the fabric was said to have failed. After laundering three times following the laundering procedure described in the AATCC Test Method 124-1978 "Appearance of Durable Press Fabrics after Repeated Home Launderings," the denim failed all Solution I spray test replications. This indicated that the removal of resins and sizes applied during manufacturing decreased fabric resistance to aerosol spray penetration and wicking. All other fabrics tested either passed or failed all test replications.

Solution 2 (water and surfactant). The finished fabrics with the exception of the commercially finished spun-bonded/MB passed the spray test with Solution 2. The presence of the surfactant altered the surface tension between the solution and the unfinished fabrics resulting in increased pesticide penetration and wicking. The failure of the commercially finished spun-bonded/MB is probably due to the chemical composition of the finish. The identity of the finish is not known, however since the fluorocarbon finished spun-bonded/MB fabrics did pass, the finish is possibly a silicon-based finish.

Solution 3 (cottonseed oil and surfactant). None of the woven fabrics passed the spray test using Solution 3. The inter-yarn spaces were too large to provide adequate protection even when finished with fluorocarbon based finishes. This factor did not apply to the fluorocarbon finished nonwoven fabrics tested which were successful in preventing penetration and wicking through the test fabric by the oil-based spray. The polyethylene coated spun-bonded test fabric was also oleophobic and passed the oil-based spray test.

Fabric Performance Of the 16 fabrics tested, six passed all three spray tests. All were nonwoven and all were finished with a fluorocarbon based finish with the exception of the polyethylene coated spun-bonded polyester. The three fabrics that passed the water-based test solutions but not the oil-based solution were the commercially finished (Scotchgard©) cotton, the Quarpel® finished cotton, and the Quarpel® finished polyester/cotton blend. Four test fabrics failed to pass the spray tests which contained surfactant in the test spray solution. These fabrics were the unfinished spun-bonded fabric, both unfinished spun-bonded/MB fabrics, and the commercially finished spun-bonded/MB test fabric. The denim fabrics, both the unwashed and the washed, and the unfinished spun-lace polyester fabric failed to pass the spray tests using any of the three test solutions.

Pesticide Penetration.

Pesticide penetration varied over an extremely wide range (Table 3). The lowest amount of penetration was 3.7 ug/cm^2 (the commercially finished spun-lace polyester/rayon). There was no significant difference between the fabrics with penetration readings of 6. ug/cm^2. The low level of penetration found can be considered to be zero. The low amounts of Malathion© present could be attributed to contamination due to the volatility of the Malathion©. The fabric with the highest amount of pesticide penetration was the unwashed denim (259.9 ug/cm^2). There is a significant difference in penetration between fluorocarbon finished and unfinished fabrics. The commercially finished spun-bonded/MB fabric was a very poor barrier, ranking second in amount of pesticide penetration (218.3 ug/cm^2).

Table 3

Results of GLC Analysis of Malathion© Penetration by Fabrics Tested

Fabrics Tested	Total ug of Malathion© Penetration in sample	Malathion© Penetration ug/cm^2*
Woven Test Fabrics		
Denim - unwashed	32,930.0	259.1
Denim - 3 washed	19,775.0	156.1
Commercially finished cotton (Scotchgard©)	710.0	5.6
Quarpel© finished cotton	2,124.5	16.8
Quarpel© finished cotton/polyester	2,083.3	16.4
Nonwoven Test Fabrics		
Spun-lace polyester	22,530.0	177.8
Scotchgard© finished spun-lace polyester	750.0	5.9
Commercially finished polyester/ rayon spun-lace	470.6	3.7
Spun-bonded olefin	2,253.0	17.8
Scotchgard© finished spun-bonded olefin	646.6	5.1
Spun-bonded/MB (90g/m^2)	19,910.0	157.1
Scotchgard©finished spun-bonded/MB (90g/m^2)	7,885.0	62.2
Spun-bonded/MB (50g/m^2)	18,375.0	145.1
Scotchgard© finished spun-bonded/MB (50g/m^2)	2,088	16.5
Commercially finished spun-bonded/MB (50g/m^2)	27,650.0	218.3

*Based on an exposed circular area of 126.7 cm^2.

Comparison of Dye Penetration and Pesticide Penetration. The results of the pesticide penetration tests were arranged based on performance in the dye penetration studies for Solution 1, Solution 2, and Solution 3. The four categories formed were 1) pass-pass-pass, 2) pass-pass-fail, 3) pass-fail-fail, and 4) fail-fail-fail (Table 4).

The results of the one-way ANOVA indicated a significant between-group difference in Malathion© penetration when the four categories were compared. The spray medium used for the Malathion© emulsion was distilled water. Therefore, it was expected that fabrics passing the dye spray test using solution 2 (water and surfactant) would act as more efficient barriers than those fabrics that failed the solution 2 dye spray test. Results of the Duncan's Multiple Range test did indicate that the fabrics in categories 1 and 2 were significantly more efficient barriers to pesticide penetration than were the fabrics in categories 3 and 4. Fabrics in Category I are also expected to limit pesticide penetration by pesticides in oil carriers as well as water carriers.

The fabrics that comprised Category I were fluorocarbon finished nonwoven fabrics. The only fabric in that category with an estimated penetration of over

Table 4

Malathion© Penetration by Test Fabric Aerosol
Dye Spray Test Performance

Dye Test Performance Category by Fabrics Tested	Malathion© Penetration ug/cm²*
Category I. Pass - Pass - Pass	
Scotchgard© finished spun-lace polyester	5.9
Commercially finished spun-lace polyester	3.7
Scotchgard© finished spun-bonded olefin	5.1
Scotchgard© finished spun-bonded/MB (90g/m²)	62.2
Scotchgard© finihsed spun-bonded/MB (50g/m²)	16.5
Polyethylene coated spun-bonded	4.7
Category II. Pass - Pass - Fail	
Commercially finished (Scotchgard©) cotton	5.6
Quarpel© finished cotton	16.8
Quarpel© finished 35/65 cotton/polyester	16.4
Category III. Pass - Fail - Fail	
Spun-bonded olefin	17.8
Spun-bonded/MB (90g/m²)	157.2
Spun-bonded/MB (50g/m²)	145.1
Commercially finishsed spun-bonded/MB (50g/m²)	218.3
Category IV. Fail - Fail - Fail	
Denim - unwashed	259.9
Denim - 3 washes	156.1
Spun-lace polyester	177.9

*Based on an exposed circular area of 126.7 cm².

20 ug/cm^2 was the Scotchgard finished spun-bonded/MB which had an estimated penetration of 62.2 ug/cm^2. This gross variation could be attributed to the following possibilities: 1) the finish was not applied evenly, 2) the backing substrate was contaminated during the test procedure, and/or 3) the backing substrate was contaminated during storage or handling prior to or during the extraction procedure. The mean penetration for the fabrics in category 1 was 16.4 ug/cm. When the result for the Scotchgard© finished spun-bonded/MB (90g/m^2) was removed the mean was 7.2 ug/cm^2.

There was no significant difference ($p<.05$) between the degree of Malathion© penetration of the fabrics in category 1 and category 2, based on Duncan's Multiple Range tests results (Figure 7). The fabrics in category 2 were woven fluorocarbon finished fabrics, all of which failed to pass the oil-based spray test and it is assumed that they would show a much higher degree of Malathion© penetration if an oil-base spray emulsion was used. The mean estimated penetration for the fabrics in category 2 was 12.9 ug/cm^2.

Category 3 represents the group of fabrics that failed the spray tests which contained surfactant. The fabrics in this category were the unfinished nonwoven fabrics and the commercially finished spun-bonded/MB fabic. The unfinished spun-bonded olefin which failed the water/surfactant spray test due to wicking had an estimated penetration of 17.8 ug/cm². This amount was far lower than the other fabrics in this category which ranged from 145.1 ug/cm² to 218.3 ug/cm². The mean penetration of Malathion® was 134.6 ug/cm². The results of Duncan's Multiple Range test indicate that there was a significant difference ($p<.05$) between the degree of penetration in category 2 and category 3 (Figure 7).

The fabrics in category 4 were the unfinished spun-lace polyester and the washed and unwashed denim samples. There was no significant difference between the GLC results of category 4 and category 3 (Figure 7). The range of estimated penetration was from 156.1 ug/cm² to 259.9 ug/cm². The mean estimated penetration for category 4 was 198.0 ug/cm².

Figure 7: Duncan's Multiple Range Comparison of Malathion® Penetration by Aerosol Dye Test Performance. ($p<.05$)

	Category I pass-pass-fail	Category II pass-pass-pass	Category III pass-fail-fail	Category IV fail-fail-fail
$\bar{x}$	12.9	16.4	134.6	198.0

CHAPTER V

CONCLUSIONS

The testing of the fabrics resulted in the acceptance or lack of acceptance of the following hypotheses.

Hypothesis I. There is no difference in the densities of the test fabrics.

A. There is no difference in density among woven test fabrics. The ANOVA indicated that there were significant (.01) differences in density between the woven test fabrics. Specifically there were significant ($p<.05$) differences in density between the Quarpel finished cotton and the Quarpel® finished cotton/polyester fabrics and between the denim and the Scotchgard® finished cotton fabrics. On this basis Hypothesis I: A was not accepted.

B. There is no difference in density among nonwoven test fabrics. The ANOVA results indicated that there were significant (.01) differences in density between the nonwoven test fabrics. The differences between each of the fabrics was significant ($p<.05$). Therefore, Hypothesis I: B was not accepted.

C. There is no difference in density between woven and nonwoven test fabrics. The difference in density between the woven and nonwoven groups of fabrics was significant at the .05 level. Therefore, Hypothesis I: C was not accepted.

Significant (.01) differences in fabric density exist between the nonwoven and woven test fabrics as well as between ($p<.05$) individual fabrics. Therefore, Hypothesis I and subhypotheses A, B, and C were not accepted.

Hypothesis II. No difference exists between the textile substrates tested as measured by air permeability.

A. There is no difference in air permeability among woven test fabrics. The air permeability of the Quarpel finished cotton was significantly greater ($p<.05$) than the other woven fabrics tested. The air permeability of the denim was significantly lower ($p<.05$) than that of the other woven fabric tested. Hypothesis II: A was not accepted.

B. There is no difference in air permeability among nonwoven test fabrics. The air permeability of the commercially finished polyester/rayon spun-lace was significantly greater ($p<.05$) than the polyester spun-lace fabric. The spun-bonded and the spun-bonded/MB fabrics were by definition impermeable to air and were significantly lower ($p<.01$) in air permeability than the spun-lace fabrics. Therefore, Hypothesis II: B was not accepted.

C. There is no difference in air permeability between nonwoven and woven fabrics. The Quarpel® finished cotton shirting had a significantly higher ($p<.05$) air permeability than the other woven fabrics. The air permeability of the spun-bonded and spun-bonded/MB fabrics was significantly lower (.01 ls) and were considered to be impermeable. The air permeability of the denim was significantly higher (.01 ls) than the spun-bonded fabrics but significantly lower (.01) than the woven shirting and the spun-lace fabrics. Hypothesis II: C was not accepted.

There were significant differences in air permeability between fabrics; therefore, subhypotheses A, B, and C were not accepted.

Hypothesis III. No difference in water vapor permeability exists between the textile substrates tested.

A. There is no difference in water vapor permeability among the woven test fabrics. No differences in water vapor permeability were found between the plain weave shirting fabrics tested. The water vapor permeability of the denim twill weave was significantly ($p<.05$) lower than the othe woven test fabrics. On this basis, Hypothesis III: A. was not accepted.

B. There is no difference in water vapor permeability among the nonwoven test fabrics. Significantly lower ($p<.05$) differences in water vapor permeability were noted between the three previously mentioned fabrics and the spun-bonded and the $50g/m^2$ spun-bonded/MB fabrics. Hypothesis III: B. was not accepted.

C. No difference in water vapor permeability exists between woven and nonwoven test fabrics. As a group there were no significant differences between the woven fabrics and the nonwoven fabrics. Therefore, Hypothesis III: C was not accepted.

Between selected fabrics the following was found. No significant differences in water vapor permeability exist between the following woven and nonwoven fabrics: Scotchgard® finished cotton, Quarpel® finished cotton/polyester, Quarpel® finished cotton, spun-lace polyester, commercially finished spun-lace polyester/rayon, and the $90g/m^2$ spun-bonded/MB fabrics. The water vapor permeability of denim was significantly lower (.05 ls) than that of the fabrics mentioned above. The water vapor permeability of the spun-bonded fabrics and the $50g/m^2$ spun-bonded/MB fabrics were significantly lower (.05 ls) than the water vapor permeability of the denim.

There were significant differences within and between the woven and nonwoven groups of fabrics tested; therefore, Hypothesis III and the subhypotheses A, B, and C were not accepted.

<u>Hypothesis IV.</u> No difference exists between the protective value of functionally finished textile substrates and those without finishes as indicated by aerosol dye penetration using methylene blue dye as an indicator in water (with and without surfactant) and oil-based emulsions.

<u>A. There are no differences in the protective value of the test fabrics as indicated by dye penetration among finished and unfinished woven fabrics.</u>

Unfinished woven fabrics did not provide protection from penetration by any of the aerosol spray emulsions tested. The fluorocarbon based finished woven fabrics did provide adequate barriers as measured by dye penetration to water based aerosol sprays (with and without surfactant) but not to oil based sprays. Based on these differences Hypothesis IV: A. was not accepted.

B. There are no differences in the protective value of the test fabrics as indicated by dye penetration among finished and unfinished nonwoven fabrics. None of the unfinished nonwoven textile substrates provided protection against penetration by the water-based (with and without surfactant) or the oil-based spray emulsions. The finished nonwovens with the exception of the commercially finished spun-bonded/MB test fabric provided protection from penetration by all water-based and oil-based sprays tested. The commercially finished spun-bonded/MB test fabric did not provide protection from penetration by the oil test solution or the water test solution which contained the surfactant. The surfactant present in solution 2 decreased the protective quality of the commercially finished spun-bonded/MB allowing penetration. Hypothesis IV: B was not accepted.

C. There is no difference in the protective value as indicated by dye penetration between the finished and unfinished woven and nonwoven test fabrics. The unfinished woven and nonwoven test fabrics did not provide protection from aerosol penetration by any of the water or oil based spray emulsions as indicated by the presense of methylene blue dye on the backing substrate. The finished woven test fabrics provided adequate protection from the water-based sprays (with and without surfactant) but not from the oil-based spray. The finished nonwoven test fabrics, with the exception of the commercially finished spun-bonded/MB test fabric, provided adequate protection from all spray emulsions tested. Hypothesis IV: C was not accepted.

Fabrics without barrier finishes did not offer protection against aerosol penetration; therefore, Hypothesis IV and the subhypotheses A, B, and C were not accepted.

Hypothesis V. No difference exists between the protective value of the functionally finished woven and functionally finished nonwoven test fabrics as indicated by aerosol dye penetration using methylene blue dye as an indicator in water (with and without) oil based spray emulsions.

A. No difference in the protective value as indicated by dye penetration exists among finished woven test fabrics. There was no difference in the protective value as measured by dye penetration among the finished woven test fabrics. All of the finished woven fabrics provide adquate protection against the water-based sprays (with and without surfactant). None provided adequate protection from penetration by the oil-based spray emulsion. Therefore, Hypothesis V: A was accepted.

B. No difference in the protective value as indicated by dye penetration among finished nonwoven test fabrics. The commercially finished spun-bonded/MB test fabric did not provide protection against dye penetration and wicking by either the water/surfactant or the oil-based aerosol sprays. Hypothesis V: B was not accepted.

C. No difference in protective value as indicated by dye penetration exists between the finished woven and nonwoven test fabrics. The finished nonwoven test fabrics, with the exception of the commercially finished spun-bonded/MB test fabric provided adequate protection against aerosol penetration by all test solutions as measured by dye penetration. The finished woven test fabrics and the commercially finished spun-bonded/MB test fabric did not provide protection from penetration by either the water-based spray containing surfactant or the oil-based spray.

Differences in protective value as measured by dye penetration were found among the nonwoven fabrics and between the nonwoven fabrics and the woven fabrics. Therefore subhypothesis A was accepted and subhypotheses B and C were not accepted.

Hypothesis VI. Protective value as measured by the aerosol penetration test using methylene blue dye as an indicator in water-based (with and without surfactant) and oil-based spray emulsions is not predictive of aerosol penetration by the pesticide Malathion® as measured by GLC. The results of the ANOVA comparing test fabric performance in the dye spray tests and the GLC results of the pesticide spray test were significant at the .01 level of significance; therefore, fabric performance as measured by dye penetration in the aerosol dye penetration tests using methylene blue dye as an indicator can be used to predict aerosol pesticide penetration by Malathion®. Hypothesis V was not accepted.

General Conclusions

The analysis of data resulted in the following conclusions.

1. Fabrics with high air and water vapor permeability and limited aerosol penetration were identified. These fabrics would be desirable for use in protective clothing because comfort is often chosen over protection particularly when the toxicological effects are not immediately noticeable.

2. The finished woven fabrics were found to be useable for protective clothing when spraying water-based pesticides; however, they were not resistant to penetration by the oil-based emulsion.

3. Nonwoven spun-lace fabrics were found to be desirable for disposable or limited use protective clothing due to

their high comfort factor as indicated by air and water vapor permeability test results, low dye penetration by water-based and oil-based spray emulsions, low penetration by Malathion®, and the potentially low fabric cost.

4. In the unfinished state, weight, thickness, density, air permeability, and water vapor permeability bore no relationship to protection from aerosol penetration. The presence of fluorocarbon barrier finishes on the test fabrics was a significant factor in preventing dye or pesticide aerosol penetration.

5. Fabric construction was a significant factor in limiting penetration by the oil-based spray emulsion among the fluorocarbon barrier finished fabrics. The protective value of the nonwoven finished fabrics was superior to that of the woven finished fabrics.

6. The dye penetration test is a good indicator of potential pesticide penetration.

7. The impervious fabric, polypropylene coated spun-bonded olefin, did not appear to have any improvements over functionally finished nonwoven fabrics which are air and water vapor permeable. Any low level GLC results may be

attributed to the volatility of the Malathion®, instrument "background" noise, and possible sample contamination during handling.

CHAPTER VI

SUMMARY AND RECOMMENDATIONS

Modern farming techniques rely on the use of pesticides throughout the growth and harvesting of crops. Therefore, the agricultural worker is exposed to a variety of agrichemicals. Pesticides comprise a wide range of chemical compounds of varying degrees of toxicity. Most persons risk poisoning due to dermal exposure and inhalation rather than ingestion. Exposure studies indicate that 97 percent of the pesticide a worker is exposed to is deposited on the skin (especially during liquid spray applications) (Wolfe, 1973). Most cases of pesticide-related illnesses are due to carelessness such as the failure to wear protective apparel and devices.

This research focused on the fabrics used and proposed for use in disposable clothing designed as barriers to dermal exposure to the organophosphate class of compounds. The objectives of this study were to examine various test fabrics to evaluate aerosol permeability and selected physical properties associated with garment comfort. The provision of protective garments that are as comfortable as possible under a variety of environmental conditions is important because comfort is often chosen over protection.

This study tested woven and nonwoven fabrics, with and without finishes, as protective barriers to aerosol spray for protective clothing. The research was divided into three parts: 1) the determination of the physical properties; density, air permeability, and water vapor permeability due to their relevance to human comfort; 2) the determination of aerosol dye penetration; and 3) the validation of the dye penetration test as a predictor of pesticide penetration.

Seven nonwoven and four woven fabrics were examined for resistance to aerosol spray penetration and wicking. Of particular interest were the nonwoven substrates developed for medical use which resist penetration by oils and liquids but allow water vapor transmission. Scotchgard® a fluorocarbon finish manufactured by the 3M Corporation, was applied to fabrics not commercially finished.

Four woven fabrics were selected for the study:

1. Twill weave - denim - 100% cotton ($283g/m^2$)
2. Shirting weight plain weave - 100% cotton commercially finished with Scotchgard®($157g/m^2$)
3. Shirting weight plain weave - 100% cotton finished with Quarpel® ($113g/m^2$)

4. Shirting weight plain weave - 35%/65% cotton/ polyester finished with Quarpel® (117g/m²)

The disposable nonwoven fabrics selected for the study were as follows:

1. Spun-lace - 100% polyester unfinished (90g/m²)
2. Spun-lace - rayon/polyester commercially finished (70g/m²)
3. Spun-bonded - 100% olefin unfinished (40g/m²)
4. Spun-bonded - 100% olefin, polypropylene coated (70g/m²)
5. Spun-bonded with melt blown fibers (spun-bonded/MB) - 100% polypropylene unfinished (90g/m²)
6. Spun-bonded/MB - polypropylene, unfinished (50g/m²)
7. Spun-bonded/MB - polypropylene, commercially finished (50g/m²)

The physical properties relating to the potential comfort of the test fabrics that were examined were density, air permeability, and water vapor permeability. Standard ASTM testing procedures were followed. Analysis of variance was used to test for differences among and between the woven and nonwoven groups of fabrics. Significant differences in density, air permeability, and water vapor permeability were noted among and between the woven and nonwoven groups of fabrics.

The aerosol spray penetration test developed for this research used methylene blue dye as a tracer to indicate penetration. The three spray emulsions commonly used for pesticide application were tested with the dye tracer: 1) water, 2) water/surfactant 48:1, and 3) cottonseed oil/surfactant 4:1. All carriers contained 0.1 percent methylene blue dye as an indicator. The surfactant was obtained from a pesticide manufacturer and is used in pesticide formulations (the formulation is proprietary). Filter paper (18.5cm) was used as the backing substrate.

Test failure was determined visually by noting the appearance of the methylene blue dye tracer on the backing of filter paper. The results of the spray test were recorded as either pass or fail. No relative ranking of the degree of fabric failure was made. As noted by Serat, Van Loon, and Serat (1978), the penetration of aerosol spray was dependent on the characteristics of fabric design, the fiber/yarn interstices, and the nature of the spray particles rather than a specific fiber. The presence of the surfactant and the nature of the spray medium also affected aerosol penetration.

To examine the validity of the aerosol dye spray test, the spray test was repeated using an organophosphate pesticide (Malathion®). The results of the dye penetration test correlated with the results of the Malathion® penetration as measured by gas chromatography at the .01 level of significance, indicating that the dye penetration test can be used to estimate pesticide penetration.

The results of the aerosol spray test indicated that the use of fluorocarbon-based barrier finishes was important in preventing aerosol spray penetration. The woven fabrics tested failed to meet the criterion of being resistant to oil-based spray penetration. Of the nonwoven fabrics tested, the spun-lace class of fabrics ranked highest in terms of water vapor permeability and air permeability and, when finished, were resistant to aerosol penetration by both water-base and oil-base spray emulsions.

Recommendations for Further Study

1. Test for pesticide penetration using an oil based spray emulsion and compare with oil/dye penetration results.

2. Vary the spray conditions (droplet size, spray time, distance from sprayer nozzel, and spray pressure) to include a broader range of factors.

3. Examine and compare the dye penetration of fabrics with aerosol pesticide penetration by classes of pesticides other than the organophosphate class.

4. Include field testing to test the significance of the laboratory results when compared with wear test data.

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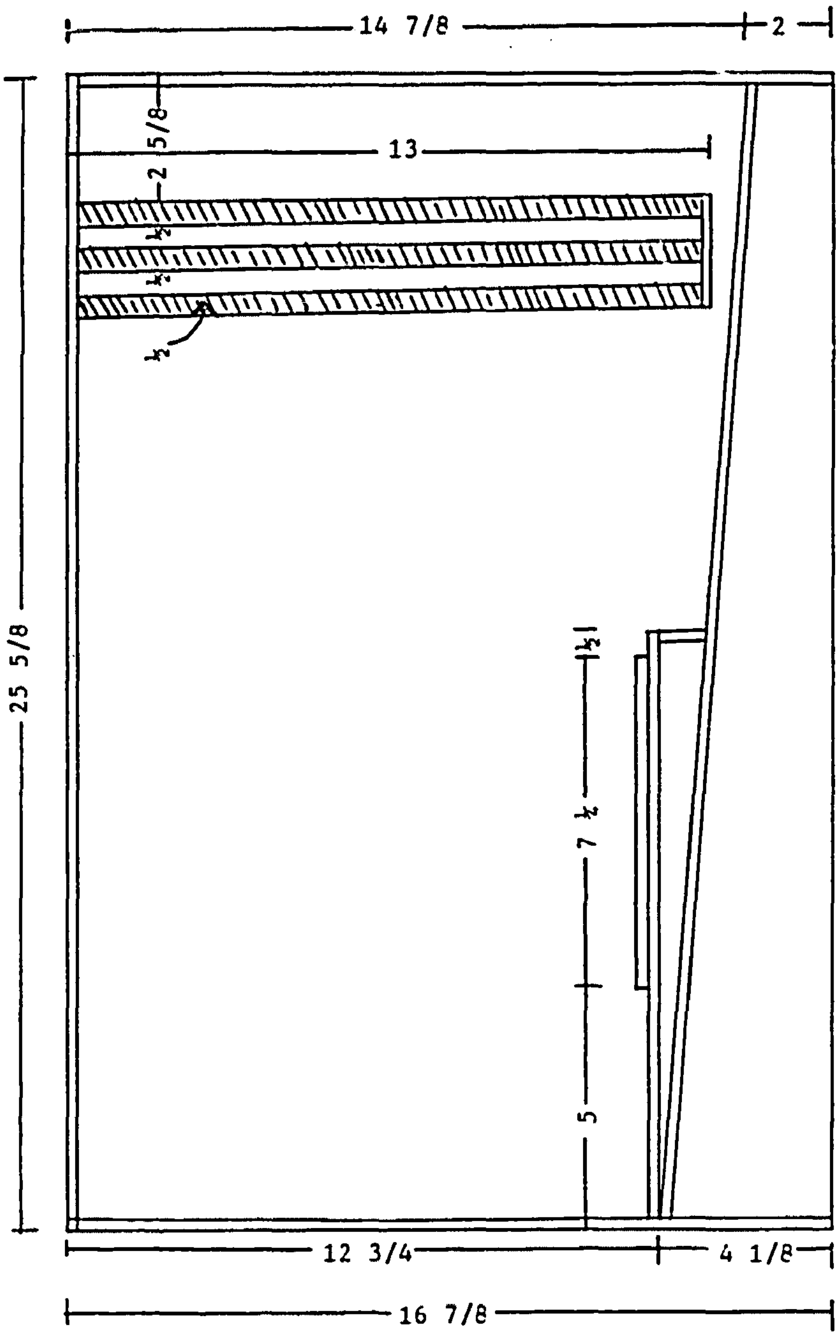
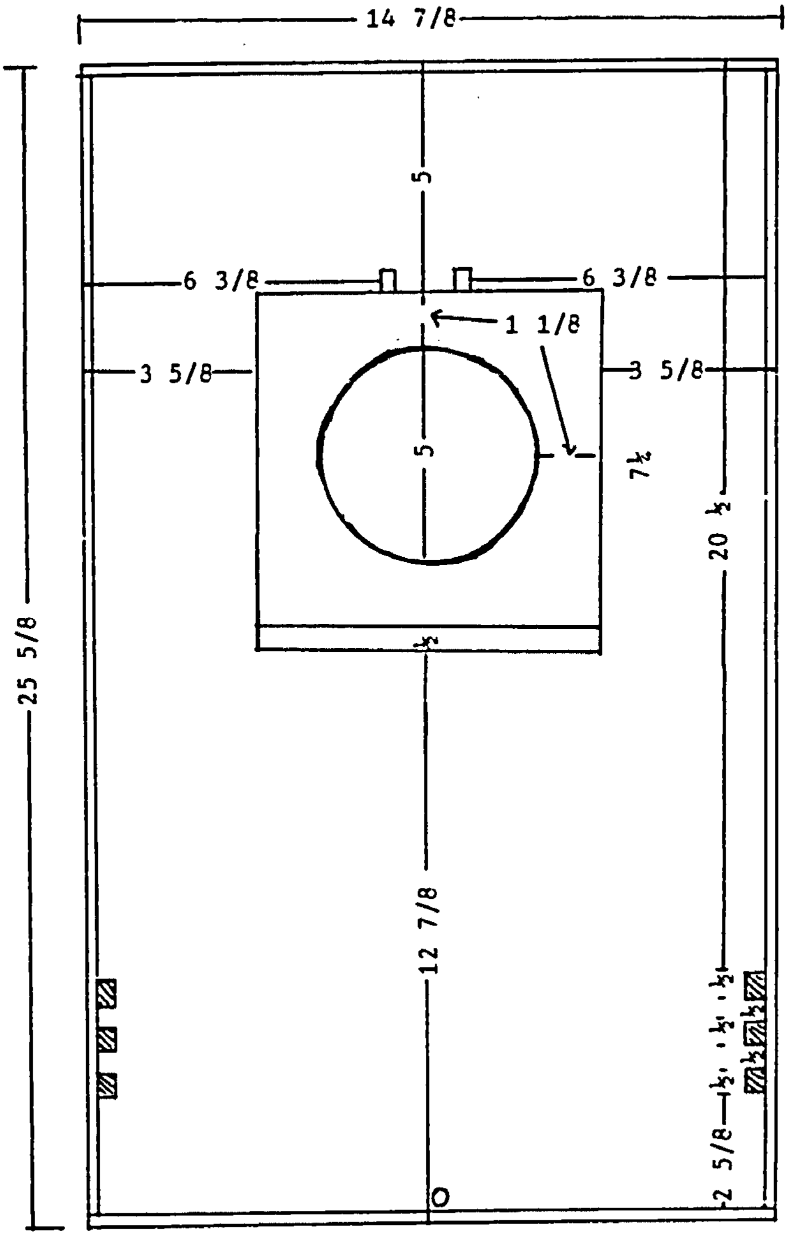
APPENDIX A.

AEROSOL SPRAY BOX

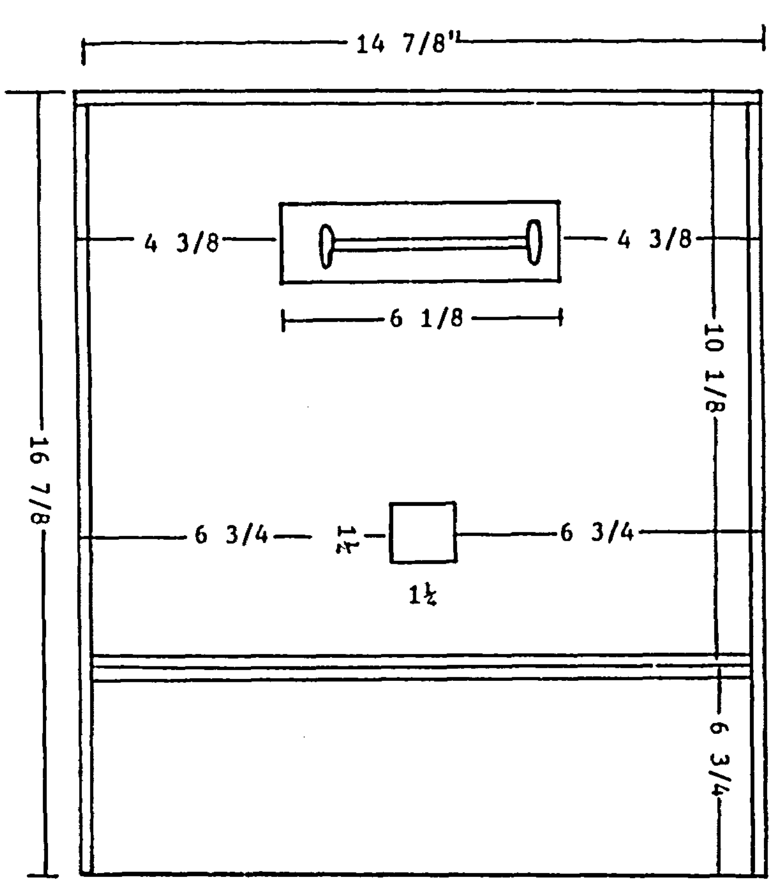


Spray Box - Side View

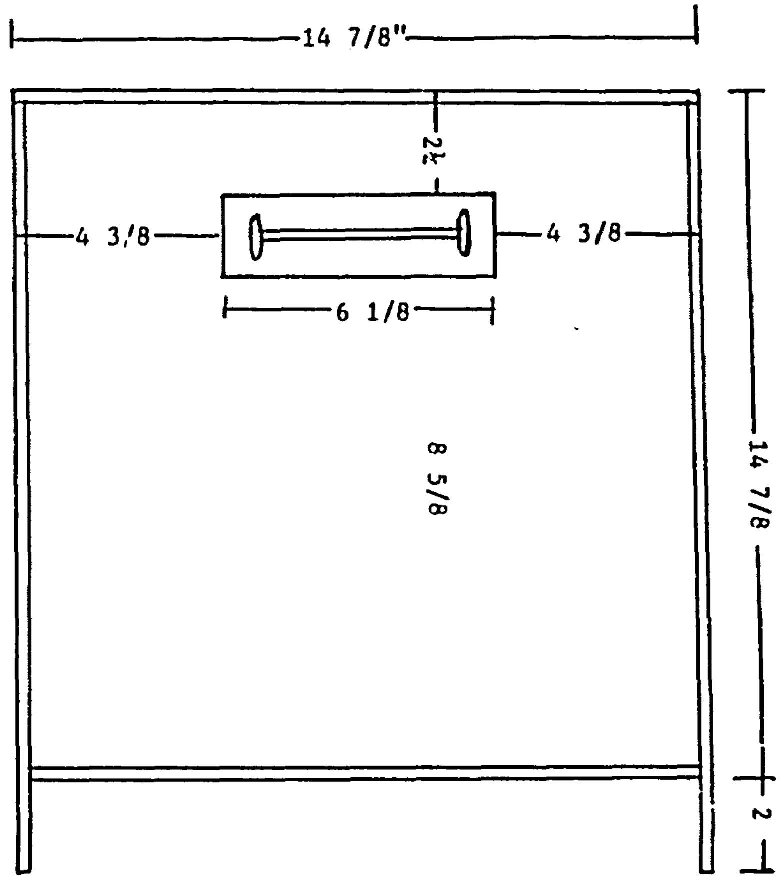


Spray Box - Top View

Spray Box - End Views

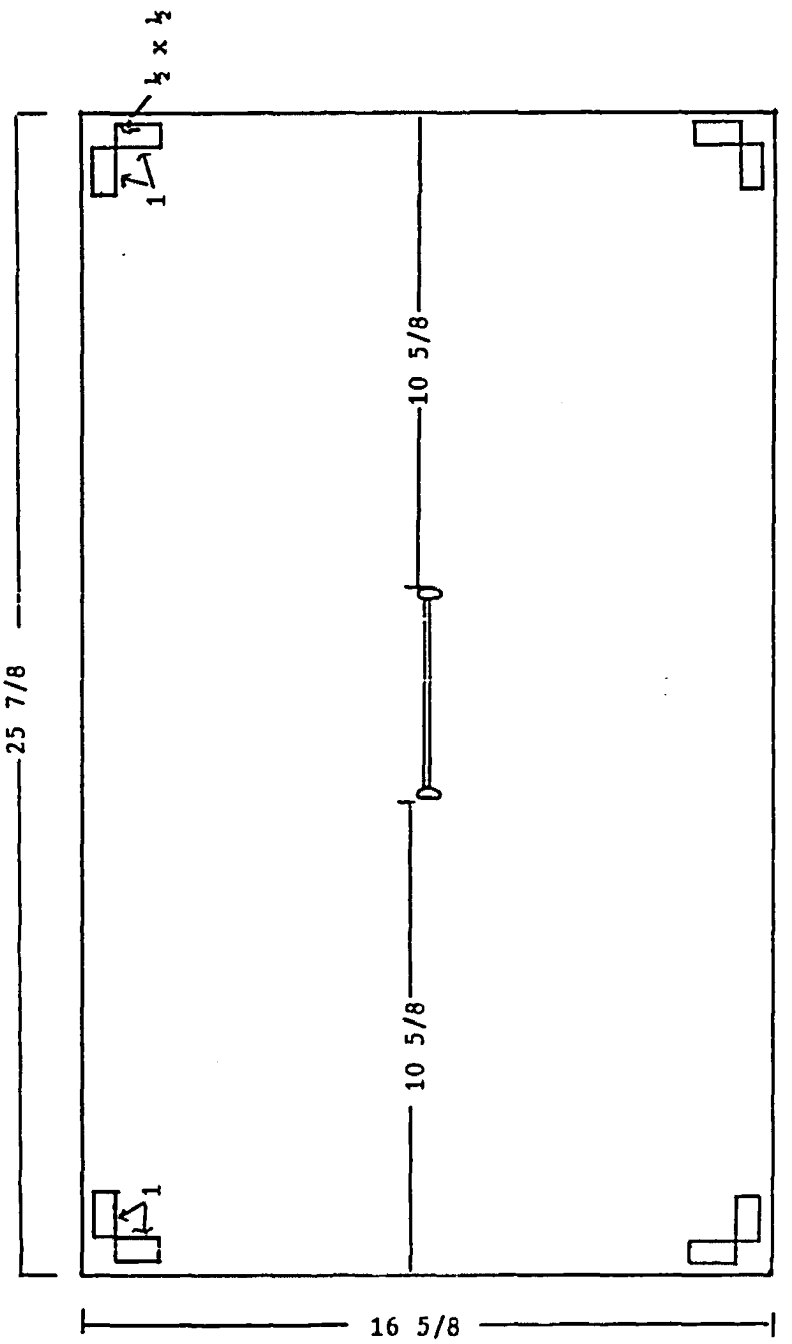


Sprayer End



Fabric End

Spray Box - Removable Top



APPENDIX B.

TEST FABRIC FRAME

Hinged Frame For Holding Test Fabric