

To the Graduate Council:

I am submitting herewith a dissertation written by Elizabeth Pratt Easter entitled "Decontamination of Pesticide Contaminated Fabrics by Laundering." I have examined the final copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Home Economics.

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DECONTAMINATION OF PESTICIDE
CONTAMINATED FABRICS
BY LAUNDERING

A Dissertation
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Doctor of Philosophy
Degree
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Elizabeth Pratt Easter

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DEDICATED TO

My Husband, Dewayne

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ABSTRACT

The overall objective of this research was to contribute to the development of functionally designed protective clothing by investigating the launderability of fabrics contaminated with pesticides and to determine if the variables; water temperature, storage and exposure to weather, affect pesticide removal. Fabric selection enabled the comparison of two fabrics commonly worn by the pesticide applicator, 100% cotton, denim and chambray, and alternative fabrics, Gore Tex® and Tyvek®, that have been shown to provide greater protection against pesticide penetration. Two pesticide chemicals: Captan®, a chlorinated hydrocarbon, and Guthion®, an organophosphate, were used in this research.

A pesticide spray system was used to expose fabric samples to pesticide solutions and pretreatment levels of contamination were determined. The laundry procedure utilized a launder-ometer at wash temperatures of 38, 49 and 60°C in a one-laundry cycle adaptation. The storage treatment subjected contaminated fabrics to a simulated home laundry storage condition at intervals of 4 and 7 days. The exposure to weather treatment utilized a weather-ometer to simulate outdoor exposure conditions.

The initial amount of pesticide residues contaminating the fabric samples averaged 9.3 µg/cm² which is representative of the mean deposition found on the applicators, clothing during a field spraying study. The effect of storage treatment on the initial level of pesticide residues showed a decrease in the level of contamination; in

comparison, the effect of treatment weather resulted in virtually no change in the level of pesticide residues on contaminated fabrics.

Differences in decontamination, i.e., removing pesticide residues by laundering, were dependent on pesticide chemical, water temperature and fabrics. Overall, the laundry process removed a greater percentage of Captan® residues from the fabrics when compared to Guthion® residue removal, and an increase in temperature resulted in an increase in pesticide removal. There was a significant difference in removal among fabrics; Captan® residues were more difficult to remove from denim and Guthion® residues were more difficult to remove from Gore Tex®.

The effect of storage treatment prior to laundering resulted in an increase in the percentage of pesticide residues removed. In comparison, exposure to weathering prior to laundering exhibited a decrease in pesticide removal.

TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION	1
Objectives	10
Assumptions	11
Definitions	11
Limitations	12
II. REVIEW OF LITERATURE	13
Substrate--Fabric and/or Finish	14
Soil-Pesticide Residue	17
Soil Removal--Decontamination	20
Effect of Laundering	20
Effect of Temperature	24
Effect of Exposure to Weathering	25
Effect of Storage	27
Summary	28
III. METHODOLOGY	29
Experimental Design	29
Fabrics	31
Fabric Preparation	34
Pesticides	35
Pesticide Spray Chamber	36
Contamination of the Fabrics	36
Laundering	38
Apparatus for Laundering	38
Detergent	38
Liquor	39
Temperature	39
Laundry Cycle	40
Rinse Cycle	40
Drying	41
Storage	41
Storage Procedures	41
Extraction after Storage	42
Laundering after Storage	42
Exposure to Weathering Conditions	42
Weathering Procedures	43
Extraction after Weathering	43
Laundering after Weathering	44
Extraction of Pesticide Residue	44
Gas Chromatographic Analysis	46
Statistical Analysis of Data	47

CHAPTER	PAGE
IV. RESULTS AND DISCUSSION	50
Fabric Properties	50
Initial Contamination of the Fabric	52
Effect of Storage on Initial Captan® Contamination	55
Effect of Weathering on Initial Captan® Contamination	56
Pesticide Residue Removal by Laundering	57
Effect of Fabric on Pesticide Removal	57
Effect of Temperature on Pesticide Removal	65
Interaction Effect of Fabric and Temperature on Pesticide Removal	68
Effect of Storage on Pesticide Removal	72
Effect of Exposure to Weathering on Pesticide Removal	77
V. SUMMARY AND CONCLUSIONS	81
Implication of the Results	85
Decontamination by Laundering	86
Storage	86
Exposure to Weather Conditions	87
Recommendations for Further Research	87
REFERENCES CITED	89
APPENDICES	94
Appendix A	95
Appendix B	96
Appendix C	97
Appendix D	98
VITA	99

LIST OF TABLES

TABLE	PAGE
I. Summary of Results of Guthion Penetration Study	32
II. Physical Properties of Fabrics	51
III. Summary of ANOVA for Effect of Storage on Pesticide Contamination Level	55
IV. Summary of ANOVA for Effect of Exposure to Weathering on Pesticide Contamination Level	56
V. Means of Captan® Residues Retained by the Fabrics and Percentages of Removal by Laundering as a Function of Temperature	58
VI. Means of Guthion® Residues Retained by the Fabrics and Percentages of Removal by Laundering as a Function of Temperature	59
VII. Summary of ANOVA for Removal of Captan® Residues by Laundering	61
VIII. Duncan's Multiple Range Test for Removal of Captan® Residues from Fabrics by Laundering	61
IX. Summary of ANOVA for Removal of Guthion® Residues by Laundering	62
X. Duncan's Multiple Range Test for Removal of Guthion® Residues from Fabrics by Laundering	62
XI. Means of Captan® Residues Retained by Fabrics and Percentages of Removal by Laundering: Pre- and Post-Storage-Treatment	73
XII. Summary of ANOVA for Effect of Storage of Pesticide Removal by Laundering	74
XIII. Duncan's Multiple Range Test for Effect of Storage on Pesticide Removal	76
XIV. Means of Captan® Residues Retained by Fabrics and Percentages of Removal by Laundering--Pre- and Postexposure to Weather	78

TABLE	PAGE
XV. Summary of ANOVA for Effect of Exposure to Weather on Pesticide Removal by Laundering	79
XVI. Duncan's Multiple Range Test for Effect of Exposure to Weathering on Pesticide Removal by Laundering	79
A-1. Chemical and Physical Properties of the Pesticides	95
B-1. Replication Means of Initial Amount of Pesticide Contamination	96
C-1. Captan® Contamination: Pre- and Post-Storage- Treatment	97
D-1. Captan® Contamination: Pre- and Postexposure to Weathering	98

LIST OF FIGURES

FIGURE	PAGE
1. Spectrum of Pesticide Exposure and Some Related Health Effects	4
2. Pesticide Application Sprayer System Used to Contaminate Fabric Samples	37
3. Pesticide Residues Retained by Fabrics after Laundering as a Function of Temperature	67
4. Pesticide Residues Retained by Denim and Chambray after Laundering	70
5. Pesticide Residues Retained by Gore Tex® and Tyvek® after Laundering	71

CHAPTER I

INTRODUCTION

Pesticides are a necessary component of pest management programs in today's agricultural community. The frequent application of a variety of chemicals is an important means of suppressing pest populations that exceed economic injury thresholds.

Pesticides are chemicals that are intended to destroy, prevent or control pests. Pesticide chemicals fall into broad categories such as insecticides, fungicides, herbicides, nematocides, etc. Because of this broad definition, pesticides are primarily classified according to their use or the group of organisms they are designed to control.

Synthetic pesticides, derived from organic compounds, were introduced around 1940 with the advent of DDT. The synthetic organo-pesticides were initially greeted with uncritical enthusiasm, as a triumph of modern synthetic chemistry, leading to a new era of agricultural efficiency. "In nature, however, there are no 'free lunches' and problems soon began to surface" (Epstein, 1979, p. 243).

First, it was discovered that insects can acquire resistance to an insecticide, necessitating an increase in applications and resulting in progressively smaller agricultural yields until the insect and its infestation eventually become uncontrollable. This is called the "pesticide treadmill." Second, the "broad spectrum" effects produced by many pesticides were realized; i.e., many pesticides produce a wide range of adverse effects, damaging various forms of insect, animal and

plant life other than their intended target. Third, many classes of pesticides, particularly organochlorines, are highly stable, resist degradation and have been shown to accumulate in the food chain at levels more than a million times in excess of those found in the environment. Fourth, scientists have found that pesticides can induce a wide range of toxic effects in experimental animals, including birth defects, sterility and cancer, thus posing a serious public health hazard, especially in view of the widespread environmental dissemination and persistent use of pesticides. Finally, some of the more stable pesticides have become widely dispersed in the environment, air, food, water and the human body at locations far distant from their initial application (Epstein, 1979).

Synthetic organic pesticides have been of tremendous benefit to man, and there is little doubt that pesticides have played and most likely will continue to play an important role in the production of agricultural products. But the question has been raised "In poisoning the pests that each year destroy crops worth billions of dollars are we also unwittingly poisoning ourselves?" (Boraiko, 1980, p. 145). Many believe that pesticides are now one of the most important classes of environmental pollutants and result in extensive involuntary exposure and contamination of human populations (Epstein, 1979; Carson, 1962; Boraiko, 1980).

Carson (1962) was one of the first to question the method of combatting insect-borne diseases with massive pesticide use. She contends that

we have put poisonous and biologically potent chemicals into the hands of persons largely or wholly ignorant of their potential for harm and that we have allowed these chemicals to be used with little or no advance investigation of their effect on soil, water, wildlife and man himself. Future generations are unlikely to condone our lack of prudent concern for the integrity of the natural world that supports all life. (Carson, 1962, p. 12)

The pesticide controversy has developed into a risk/benefit issue: the detrimental effects, i.e., the risks versus the benefits to society in providing sufficient food and fiber. The editor of National Geographic magazine contends that

with a steadily expanding population and a decrease in arable land, the world must use pesticides to maintain high crop yields and affordable food. At the moment there is simply no other way to farm on the scale required. (Boraiko, 1980, p. 145)

The challenge to the scientific community then becomes to find "answers to questions of environmental danger, sensible regulation with diligent enforcement, proper application and acceptable chemicals" (Boraiko, 1980, p. 145).

Information concerning the health of workers occupationally exposed to pesticide residues is limited even though agricultural production has utilized large quantities of pesticides for the past four decades. According to Dr. Kahn of Berkeley "farm workers are being exposed to space-age chemicals and protected only by Model-T standards and enforcement" (Boraiko, 1980, p. 166). No one knows for sure how many farm workers suffer pesticide poisoning or to what degree, because the symptoms--nausea, headaches, diarrhea, etc., can be mistaken for other illnesses.

Scientists have shown the population at risk to be those individuals involved in the manufacture, formulation, mixing and loading, and application of pesticides as well as those involved in harvesting operations. Figure 1 shows that occupational exposure to pesticides is greatest in the ground applicators: those individuals who apply pesticides to agricultural crops, utilizing a variety of spraying and dusting equipment.

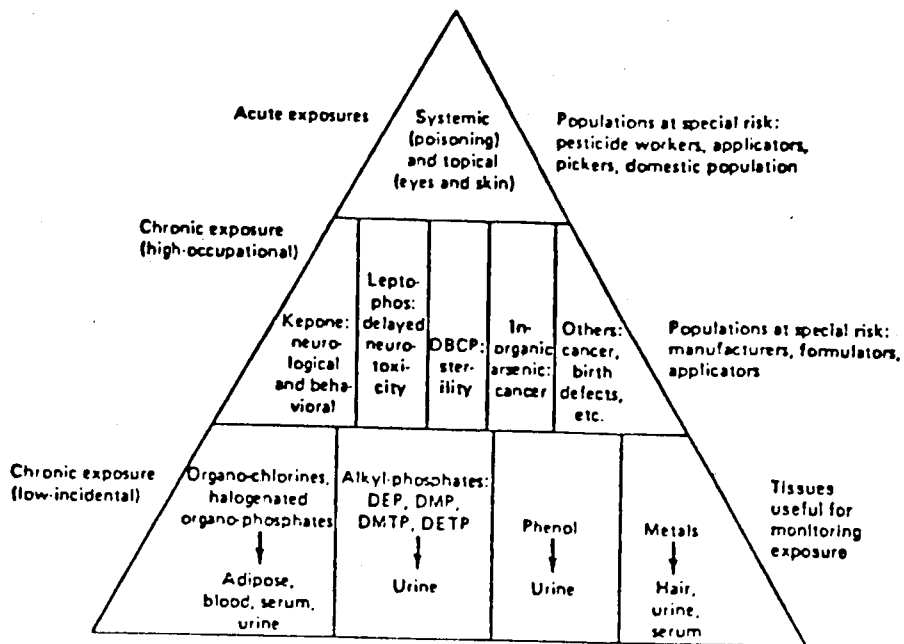


Figure 1. Spectrum of pesticide exposure and some related health effects (Davies, 1980, p. 10).

Pesticide exposure studies have determined that the routes of exposure to man are: (1) inhalation; (2) ingestion; and (3) skin absorption. Studies measuring pesticide deposition on the skin have detected between 718 and 1,755 milligrams of pesticide residue being

deposited per hour (Hansen, 1978; Nigg, 1980). Researchers have compared the dermal and respiratory routes and have determined that 87% of the total human exposure was accounted for by dermal exposure (Durham, 1972; Maibach, 1971). Both acute and chronic adverse health effects have been shown to exist in agricultural workers, resulting from exposure to pesticides. These adverse health effects of pesticide intoxication in agricultural workers are probably the result of this excessive dermal exposure. A pesticide deposition study designed to determine patterns of pesticide deposition on clothing during spray applications identified specific body areas as receiving the greater deposits; the head and shoulder area in both the front and back; as well as the front torso and upper leg area (DeJonge, unpublished).

The identification of the population at risk, as well as data on the primary routes of entry of pesticides into the body and the identification of specific areas of pesticide deposition, illustrate the need to protect the agricultural worker from pesticide residues. The cardinal principle of all occupational workers' protection has been to "make the workplace safe." The first method of making the workplace safe was the establishment of "reentry intervals." Depending upon the crop and the toxicity of the pesticide, a reentry interval was assigned which prohibited worker entry into a treated field until a specified time had elapsed between treatment and worker entry into the field. The reentry time allowed residues to dissipate to lower and presumable "safer levels."

The Task Group on Occupational Exposure to Pesticides (1974) stated that, "the agricultural field workers are justified in insisting that

their working environment be free from harmful levels of pesticide residues" (p. 69). The Task Group goes on to state that "for employees who deal directly with organopesticides . . . in mixing, loading, or applying, there may be no way of making the work environment inherently safe" (Occupational Exposure to Pesticides, 1974, p. 69). If this is the case, the only realistic protective strategy may consist of shielding the worker from the hazardous environment by creating for him a "microenvironment" inside impermeable clothes, shoes and other protective devices. Together with the establishment of realistic reentry periods, the use of protective clothing is considered foremost in managing the safety of field workers from pesticide exposure (Occupational Exposure to Pesticides, 1974).

Protective clothing, which could be used as a barrier between the worker and the environmental hazard, has received increased attention from government, industry and researchers (Davies, 1980; Kavar, 1978; Morgan, 1980). The Federal Register has defined protective clothing as: "at least a clean hat with a brim, a clean, long sleeved shirt and long legged trousers or a coverall type garment, all of closely-woven fabric . . . including the requirement of a washable fabric" (Federal Register, March 11, 1974). This definition was later redefined as "at least a hat or suitable head covering, a long sleeved shirt and long legged trousers or a coverall type garment" (Federal Register, May 10, 1974).

Aside from general characteristics, no physical description of the fabric for protective garments has come forth. No further characterization was given of the clothing to be used for protection except for the

repeated emphasis placed on the concept of "washable" and "clean." This concept relates directly to a complementary strategy proposed for farm worker safety called "improved personal hygiene." For example, California regulations require employers to provide handwashing facilities for the safety of workers as well as requiring that clean clothing be provided. The "Emergency Temporary Standard for Exposure to Organophosphorus Pesticides" proposed by United States Department of Labor, stated that

all protective clothing . . . shall be thoroughly washed or disposed of after each day's use . . . when the same clothing . . . is to be used by more than one employee in a given day, the clothing . . . shall be adequately washed or cleaned before it is passed from one employee to another. (Occupational Exposure to Pesticides, 1974, p. 69)

These regulations and the assumptions on which they are based are questionable. The proposal that workers can be protected from the harmful effects of pesticide residues by washing depends on the hypothesis that pesticide residues on the skin and/or clothing are similar to deposits of common dirt and that both are responsive to removal by commonly used soap and water. Maibach (1971) used radioactive isotopic labelled pesticides to test the "hand washing" hypothesis. The results showed that washing one minute after exposure removed from 1/4 to 1/3 of the pesticide, but after the initial washing additional washing had little or no effect.

To date, there has been little research directed toward the decontamination of pesticide contaminated fabrics. Finley (1969, 1974) found that large amounts of insecticide residues remained in fabrics after laundering and the pesticide residues remain toxic to living

organisms, even after the clothing has been subjected to repeated washings. Lillie (1981) evaluated the effects of wash water temperature on decontamination of pesticide contaminated clothing and found that a significant amount of residue was removed regardless of water temperature for all organophosphate pesticide compounds. However, the chlorinated hydrocarbon, chlordane, was more tenacious when subjected to an increase in water temperature. This finding was in agreement with the Finley (1969) study, in which methyl parathion, an organophosphorus pesticide, was removed with one laundering more efficiently than was DDT, an organochlorine pesticide.

The research that has been conducted on decontamination provides an adequate base of information upon which to build. The fabric variations tested have been limited and illustrate the need for additional research to evaluate pesticide removal from contaminated clothing.

This study is one component of an overall research project, with the major thrust aimed at limiting the dermal exposure of the operator in pesticide application while maintaining thermal comfort through the development of functionally designed apparel. Phase I of the project collected information from the agricultural worker on garment characteristics and fabric preferences, patterns of use and care of work clothing and attitudes about the use of protective clothing and the danger of pesticide exposure (Henry, 1980). Phase II involved physical testing on the penetration of Guthion® through a number of fabrics (Orlando, 1981), patterns of pesticide deposition on clothing during air blast spraying (DeJonge, unpublished), and the thermal acceptance levels of selected

garment design (Branson, 1982). Phase III involved the exposure testing of selected garment prototypes and a user's survey (Murray, 1982).

The results of the penetration study have led to the identification of two fabrics; Gore Tex® and Tyvek®, which allow minimal or no penetration of pesticides as well as to the establishment of penetration patterns through traditionally worn fabrics; chambray and denim. The results of the thermal analysis study showed that one of the protective fabrics, Gore Tex®, offered a similar thermal comfort level to 100% cotton chambray.

The findings of the research project have important implications for the development of a protective garment for pesticide applicators, thus providing thermal comfort as well as protection. However, Gore Tex® is a washable fabric that, if fabricated into protective clothing, would be reusable if it could be decontaminated. Before recommendations can be made advocating the use of Gore Tex®, research is needed to determine its efficiency of pesticide removal by laundering.

The whole issue of decontamination by laundering involves more than just the efficiency of laundering in removal of pesticides. What are the laundry storage practices? Very little is known about current laundry storage practices, but it is speculated that clothing being used by the pesticide applicator is being stored before laundering, possibly with the laundry of other family members. Another important factor that must be taken into consideration is exposure of fabrics contaminated with pesticides to environmental conditions. What happens to the pesticide residues on the fabrics when exposed to environmental

weathering conditions and does this exposure affect decontamination by laundering?

This study was undertaken to examine the launderability of fabrics contaminated with pesticides. The study examines the decontamination of Gore Tex® and Tyvek®, two fabrics found to provide protection from pesticides. In addition, chambray, a fabric shown to be ineffective as a barrier to pesticide residues but providing excellent thermal comfort, will be incorporated into the study. Denim, another fabric traditionally worn by the pesticide applicator was the fourth fabric evaluated in this study.

Objectives

The overall objective of the study was to contribute to the development of functionally designed protective clothing by investigating the decontamination of fabrics contaminated with pesticides.

1. To evaluate decontamination by determining the effectiveness of laundering in removing pesticide residues from selected fabrics.
2. To determine the rate of removal through laundering of fabrics contaminated with pesticides as a function of temperature.
3. To evaluate the effect of exposure to weathering conditions on the level of pesticide contamination of fabrics contaminated with pesticides.
4. To determine the effect of exposure to weathering conditions on decontamination by laundering of fabrics contaminated with pesticides.
5. To evaluate the effect of storage on the level of pesticide contamination of fabrics contaminated with pesticides.

6. To determine the effect of storage on decontamination by laundering of fabrics contaminated with pesticides.

Assumptions

1. Laundry procedures used in the Launder-Ometer are equivalent to the laundry cycle in a home laundering situation.

2. The pesticides used in this study, as well as the concentrations used, are representative of those used commercially in agricultural production.

3. The spray chamber used in the contamination procedures approximates a field application of pesticide spraying.

4. Conditions in the Weather-Ometer are equivalent to exposure conditions in an outdoor field environment.

5. Simulated laundry storage conditions are equivalent to home laundry storage conditions.

Definitions

Pesticides--any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any insect, fungi, weeds, or any other form of life declared to be pests.

Organophosphorus Pesticides--synthetic organic compounds, which are anticholinesterase chemicals that damage or destroy cholinesterase. Examples of organophosphorus pesticides include: Guthion®, Parathion and Malathion.

Chlorinated Organic Pesticides--synthetic organic compounds containing chlorine. Examples of chlorinated organic pesticides include: Captan®, DDT, and Endrin.

Emulsifiable Concentrate--a pesticide and an emulsifying agent dissolved in an organic solvent such as xylene or cyclohexane. The addition of an emulsifier enables the formation of a homogeneous and stable dispersion of small globules of the solvent in water.

Flowable Formulation--a creamy formulation that can be mixed readily with water to form a stable suspension. The active ingredient may be practically insoluble or only slightly soluble in water.

Residue--that quantity of a substance, especially of active pesticide, remaining on or in a surface.

Limitations

1. Only two pesticides, representing two chemically different formulations, were used in the study.
2. Only four fabrics, representing four different types of fabric construction and three different fiber compositions were used in the study.

CHAPTER II

REVIEW OF LITERATURE

The purpose of this research was to evaluate the decontamination of selected fabrics by laundering and to determine if variables such as temperature, storage and weathering, affect their decontamination.

Significant levels of pesticide residues in workers' clothing have been reported by Orlando (1981) and Finley (1969, 1974). Washing has been proposed for the decontamination or removal of these pesticide residues. For example, the Emergency Standard for Exposure to Organophosphorous Pesticides, 1973, proposed by the United States Department of Labor placed considerable emphasis on the concept of clean clothing through washing.

All protective clothing . . . shall be thoroughly washed or disposed of after each day's use.

When the same clothing . . . is to be used by more than one employee in a given day, the clothing . . . shall be adequately washed or cleaned before it is passed from one employee to another. ("Occupational Exposure to Pesticides," 1974, p. 69)

These proposals are based on the assumption that clothing contamination by pesticide residues is the same as soiling with common dirt. A scientific investigation to test this assumption has not been found in the review of literature. However, literature on the subject of soil removal from textile structures is readily available. A comprehensive coverage of the research in the field of soil removal is beyond the scope of this literature review. Only a brief coverage of the most important factors reported to influence soil removal will be presented.

The word "soiling" of clothing denotes the unwanted accumulation of particulate materials or the presence of foreign matter. The extent of soil removal during the cleaning process is affected by the substrate, the soil, the cleaning method and interactions among all three (Schick, 1977). To understand soil release from textile structures, each of these factors should be altered separately and soil removal analytically determined. The literature reviewed will show how researchers have evaluated one or more of the factors in their efforts to quantify the removal of pesticide residues.

The literature review has been subdivided into three major sections. First, the substrate, i.e., a review of the fabrics and/or finishes that have been used in decontamination studies. Second, the soil (pesticide composition), studies which compare pesticide variations and the effect that pesticide composition has on decontamination. Third, the decontamination of clothing by laundering. The recommended laundering procedures will be reviewed as well as the effects of temperature and exposure to weathering and storage on decontamination.

Substrate--Fabric and/or Finish

The type of fabric, fiber content and fabric finish has been shown to affect not only penetration and retention of pesticide residues, but also their removal. Finley et al. (1969) evaluated five shirting-type fabrics: 100% cotton and cotton/polyester blends, finished with a durable press finish. One blend was finished with a soil release finish in addition to the durable press finish. The fabrics were contaminated

by exposure to cotton fields that had been sprayed with DDT and methyl parathion and then laundered to determine how much pesticide remained in the fabrics. A highly significant amount of methyl parathion residues was removed from the cotton/polyester fabrics when compared to the 100% cotton fabric, which retained six times the amount of detectable residues after laundering. The removal of DDT residues from all fabrics was not as efficient as 66% of the initial pesticide residue remained on the fabrics after laundering. With the exception of the soil release finished fabric, it was found that with an increase in the amount of cotton fiber in the fabric, there was a corresponding increase in the amount of DDT retained after laundering. The soil release finished fabric collected and retained the least amount of pesticide residue for both pesticide chemicals, this was attributed to the soil release finish on the fabric.

The finding that pesticide residue retention increased with an increase in cotton fiber content for the pesticide DDT was attributed to the similarity that exists between the chitin of the insect exoskeleton and the cellulose fiber.

The affinity of DDT for chitin may explain why DDT was absorbed and retained at a higher rate in all-cotton fabrics. This does not necessarily mean that all-cotton fabric is more hazardous to the wearer. Theoretically, cotton could be the safer material since the DDT appears to be "tightly bound" to the cellulose. (Finley, 1969, p. 351)

In later studies Finley (1977, 1979) continued the investigation of pesticide removal of methyl parathion residues by laundering. The findings of these studies showed that more pesticide residues were removed from polyester/cotton fabrics than cotton. Based on these

findings a recommendation for reducing pesticide exposure was made: "wear all-cotton clothing" since, it appears to collect less contamination than cotton/polyester blends (Finley et al., 1979, p. 595).

The results of these studies present one point of conflict dealing with the absorption, retention and extraction of pesticides from fabrics leading to confusion as to which actually is the "safer" fabric, cotton or cotton/polyester blends. Other researchers have conducted studies to examine the issue of fabric composition on pesticide retention and removal. Lillie (1981) evaluated 100% cotton and 100% polyester coveralls contaminated by pesticide applicators in the United States Air Force. The results of the study showed that cotton coveralls were superior in preventing penetration of aqueous preparations of emulsifiable concentrate pesticide residues. However, the results of washing showed little differences were detected between the two fabric types. The conclusion drawn from the study was that "100% cotton affords greater protection as it absorbed much more than the polyester, therefore less was allowed to penetrate and there were no differences in removal" (Lillie, 1981, p. 722).

Easley et al. (1981, 1982) evaluated the removal of methyl parathion from denim fabrics, including two variations; one a 100% cotton and the other a 50/50 cotton/polyester blend. The results of these studies showed that there were no differences between cotton and cotton/polyester fabrics in retention of pesticide residues during the initial contamination. An evaluation of the pesticide removal of this

contamination showed that fiber content made no difference in the efficacy of methyl parathion removal.

It is beyond the scope of this research to address the issue of which is the "safer" fabric. It has been presented here to show that there is a need for a more scientific approach to investigating the removal of pesticide residues from fabrics. Recommendations and generalizations cannot be made concerning safety and care of fabrics exposed to pesticide residues without a more holistic approach to the research design and interpretations of the findings. Taking a closer look at the studies that have been reported it is obvious that varying fabric weight and fabric construction were not taken into consideration in evaluating removal of pesticide residues from textile substrates. In addition, other factors involved in soil removal, the method of cleaning, the composition of the soil and the interaction of these factors with the fabrics, have not been taken into account when interpreting the results.

Soil-Pesticide Residue

An evaluation of soil removal from textile substrates must consider not only the chemical constitution of the fabrics in a sample, but also the composition of the soil itself. Research in the removal of pesticide residues from fabrics have shown that decontamination varies with the chemical composition of the pesticide.

In the 1969 study by Finley et al., the clothing worn by agricultural workers was subjected to direct contact with insecticide

residues of methyl parathion and DDT. The results of the study show that after laundering, methyl parathion was removed more efficiently than was DDT, as 2% of the methyl parathion residues was retained in comparison to approximately 66% of the DDT residues being retained.

Similar findings were reported by Finley et al. (1974), in which washing was reported to have reduced residue levels in fabrics, with no significant difference between fabrics in the removal of DDT, methyl parathion and toxaphene residues. The differences in residue removal were reported as being due to the differences in pesticide chemicals. Methyl parathion was much more effectively removed from fabrics when compared to the other pesticides; this finding was explained by the alkalinity of the detergent (pH 10) which could have hydrolyzed methyl parathion. Toxaphene residue levels in fabrics decreased only slightly after laundering and similar results were found for the pesticide DDT.

Differences in pesticide removal attributed to pesticide composition were also reported by Lillie et al. (1981) in a study to evaluate the removal of the pesticides: diazinon, chlordane, carbaryl and prometon. The results of the laundry study showed significant differences in the amount of pesticide residue remaining in the two fabrics after washing. Carbaryl and prometon were readily removed from both fabrics. Chlordane and diazinon were not as easily removed and their removal was dependent on other variables in the study, e.g. temperature.

In the studies reported in the first section of this chapter Easley (1981, 1982) evaluated the effects of three formulations of

methyl parathion: emulsifiable concentrate (EC), encapsulated (ENC) and wettable powder (WP). The results of the study showed that the selected laundry process removed a mean of 80-90% of methyl parathion residue. However, the mean percentage removed was higher for ENC and WP than the percentage removed for EC, which was much more difficult to remove.

In a later study Easley et al. (1982) also detected differences in removal attributed to the chemical composition of the pesticide residues. Two pesticide chemicals (2,4-D ester and 2,4-D amine) were used to contaminate denim fabrics and evaluate their removal through selected laundry procedures. The findings showed that 2,4-D ester was removed in a much lower range than the 2,4-D amine. The low (28.86-44.99%) residue removal was attributed to the insolubility of 2,4-D ester in water. For the pesticide 2,4-D amine the laundry process removed a mean percent of greater than 99.17%; this high level of removal was explained "as due in part to the extreme solubility of the amine formulation in water" (Easley, unpublished).

This review of the research evaluating the soil, i.e., pesticide residue on the textile substrate, demonstrates the need to consider not only the fabric composition but also the soil composition. A comparison of such a composition, that is, comparing the removal of chlorinated hydrocarbons to removal of organophosphates, will be an important factor in determining recommendations for removing pesticide residues from protective clothing.

Soil Removal--Decontamination

Of the three procedures currently used for removing soils from textile fabrics [laundrying (aqueous), dry cleaning (organic solvent), and vacuum cleaning (mechanical)], only the first will be covered in this review. The mechanism of aqueous soil removal involves an induction period, during which water diffuses into the soiled fabrics but soil release is slow; a rapid soil-release period, during which rolling-up and/or dislodgment of soil and water diffusion are rapid; and a final period during which soil retention remains essentially constant. The removal rate depends on the rate of spontaneous soil release and the rate of dislodgment by mechanical action (Kissa, 1971a).

There are several factors which affect the degree of soil removal, including the extent of soiling, age of the soil, type of soil and the fiber content of the soiled fabric. In addition, laundry variables can affect soil removal, e.g. detergent composition, detergent concentration, water temperature as well as water hardness. The efficiency of laundrying as a process for soil removal will be determined for the most part by a combination of two or more of these factors.

Effect of Laundrying

Laundrying has been proposed as the recommended method of decontaminating pesticide contaminated fabrics. The efficacy of laundrying on the removal of pesticide residues, has been evaluated by a limited number of researchers (Finley, 1969, 1974, 1977, 1979; Lillie, 1981; and Easley, 1981, 1982). A review of these studies showed that a

variety of laundry procedures and laundry equipment in addition to the variations in pesticide chemicals and fabrics were included in these investigations. Therefore, a more comprehensive review will be presented to show that comparisons between studies are difficult to make unless the variables are taken into consideration. Finley (1969) laundered contaminated fabric samples using an automatic washer and the procedure of AATCC Test Method 124. The findings showed a highly significant amount of pesticides was removed from the fabrics after one laundering. In 1974, Finley et al. investigated the effectiveness of a series of washings on removing pesticide residues. The procedures included the use of a small portable washer, standard AATCC detergent and the procedure of AATCC Test Method 124. The results of the study showed that laundering greatly reduces the amount of pesticide residues present; however, even three launderings were not effective in removing all residues of the pesticides. Hence, the conclusion drawn from these studies was that "it is not known how many launderings would be required to remove all residues or if they could ever be removed by laundering" (Finley, 1974, p. 273).

Continuing to address the issue of developing an effective laundry procedure to remove pesticide residues from fabrics, Finley (1977) initiated a study to develop procedures to effectively remove pesticide residue. Based on the research findings, recommended washing instructions for removing methyl parathion were reported. According to the researchers "laundering procedures suitable for removing 'methyl

parathion' residues are expected to be adequate for other organophosphates" (Finley et al., 1977, p. 7). The method was described as follows:

1. Detergent: $\frac{1}{2}$ cup heavy carbonate laundry detergent
 $\frac{1}{2}$ cup all-fabric laundry dry bleach, with
a perborate additive
2. Machine Settings: water level: regular or high
water temperature: hot, at least
140°F
wash cycle: normal--12 minutes,
agitation, 6 minutes, spin,
7 minutes, rinse and 5 minutes,
spin
3. Dryer Setting: 30 minutes, regular fabric setting
(190°F)
4. After drying, rewash garments following the same
procedures used for the first wash.
(Finley et al., 1977, p. 7)

Using the recommended laundry procedures, Finley (1979) reported that one wash was effective in removing 75-95% of methyl parathion residues in contaminated fabrics. However, as the amount of residues in fabrics increased, washing became less effective. On a percentage basis, the second washing did not remove as much pesticide as the initial washing. It should be noted that these procedures gave a wash liquor with a high alkalinity; a pH of 10 was reported. The removal of methyl parathion residues was attributed to this level of alkalinity having effectively neutralized the methyl parathion residue in the fabrics.

Easley et al. (1981) examined the effect of selected laundry procedures on removing methyl parathion residues from contaminated fabrics. The laundry procedures utilized a launder-ometer in a modification of AATCC #61 Test Method. Four laundry processes were evaluated: pre-rinse, phosphate detergent wash, phosphate detergent

plus ammonia laundry additive and phosphate detergent plus bleach laundry additive. The results of this study showed that the percentage of total methyl parathion removed by pre-rinsing was higher than for the other laundry processes. Methyl parathion removed by laundering with phosphate detergent plus ammonia additive was significantly lower than with other laundry procedures. Bleach was slightly more effective than ammonia as a laundry additive. The percentage of methyl parathion removed when the wash cycle was the first aqueous solution was significantly greater than when the pre-rinse cycle was the initial aqueous solution. This significant finding could have resulted from the assistance of detergent or detergent plus additive; attributed to the alkalinity (ph 9.7) of the phosphate detergent, since methyl parathion is hydrolyzed to 4-nitrophenol in an alkaline medium. This finding was in agreement with the Finley (1974, 1979) studies in which a comparable level of methyl parathion was removed in a high alkaline wash liquor.

In another study Easley et al. (1982) investigated the laundry procedures required to remove 2,4-D from contaminated fabrics. The laundry procedure included a 12 minute wash and 2 rinse cycles in a launder-ometer. The detergents evaluated were Dynamo® (nonionic liquid) and AATCC Standard Detergent (12% phosphates). The effect of laundering using two complete laundry cycles was investigated. The results showed that better removal was obtained using the liquid detergent and repeated washing was significantly better than single washing (Easley et al., 1982).

The results of the reported research that has been conducted in removal of pesticide residue through laundering indicate that optimum

laundering procedures and recommendations for pesticide removal remains an area that needs additional investigation. An analysis of the reported research shows that the laundry procedure that best decontaminates fabrics may depend on the chemical composition of the pesticide, the amount of contamination and the detergent used in the laundry process.

Effect of Temperature

As in all chemical and physical processes, temperature has an important influence on soil removal through laundering. Raising the temperature during laundering is generally considered to be beneficial, but a detrimental effect has also been observed.

Lillie (1981) evaluated the effects of temperature on decontamination, using both concentrated and diluted solutions of pesticides. The results of this study showed that a significant amount of residue was removed regardless of water temperature; however, diazinon and propoxar removal was the most sensitive to change in water temperature. The effect of water temperature was also more noticeable for diluted pesticide solutions. The pesticides bromacil and malathion followed a trend (as did the others) of increased residue removal with increased temperature. However, chlordane test results did not follow the trend observed for the other pesticides. Chlordane was more stable with regards to water temperature. From this study it was recommended "that wash water temperature be 60°C to achieve maximum decontamination of pesticide contaminated clothing" (Lillie, 1981, p. 722).

The effect of water temperature on decontamination of pesticide residue was a part of the evaluation in the study reported by Easley et al. (1982). Methyl parathion contaminated fabrics were laundered in a launder-ometer at 60°C, 49°C and 30°C. The findings showed no significant difference between 60°C and 49°C wash temperatures, while 30°C washing produced significantly lower removal (Easley et al., 1982).

The Easley and Lillie studies indicate a tendency for increased residue removal with increased water temperatures. This finding is dependent upon the chemical composition of the pesticide residue, which indicates that an increase in temperature will not always guarantee an increase in pesticide residue removal.

Effect of Exposure to Weathering

Weather resistance is an important consideration for many applications of textile substrates, as prolonged outdoor exposure has been shown to result in deterioration of the properties of textile fabrics. The degradation can be caused by many factors such as sunlight, atmospheric contaminants and moisture. Previous research has been aimed at evaluating the physical and chemical characteristics of the fabrics and the effect weathering has had on these characteristics. Research evaluating soil removal or pesticide removal after exposure to weathering was not found in the available literature.

The influence of the environment on degradation of pesticide residues is well documented (Ware, 1975; Nigg, 1980). Most research has been directed towards determining how long it takes for pesticide residues to dissipate to a safe "reentry level."

Several reentry studies have shown that pesticide residues on foliar surfaces undergo a rapid disappearance (Winterlin et al., 1975; Spear et al., 1975). This loss probably reflects a rapid rate of evaporation, hence a decrease in the level of contamination as the amount of active ingredient is lost. The possibility exists that pesticide residues on fabrics would follow the same trend as pesticide residues on foliar surfaces (Serat, 1982). In an attempt to show that such a process was plausible, Serat (1982) examined the behavior of pesticide residues on fabrics in the absence or presence of photochemical exposure.

The study consisted of both laboratory and outdoor exposure. In the laboratory, two sets of parathion contaminated fabrics were examined, one was exposed to ultraviolet light and the other shielded from the radiation; both were under a lab-controlled air flow of 30 m/min. The field control fabrics were treated with a spray emulsion of parathion or dicofol.

The results of the field study showed a rapid and extensive loss of parathion; in comparison, about 75% of the pesticide dicofol was recovered after outdoor exposure. In the laboratory under controlled conditions, the findings showed a rapid and sometimes extensive depletion of parathion residues on fabrics subjected to an air stream, particularly under the influence of ultraviolet radiation (Serat, 1982). The result of this study, showing the prominent effect of ultraviolet radiation in depleting parathion in the presence of oxygen, agrees with the findings of Woodrow et al. (1977) who found that parathion in the presence of sunlight undergoes a rapid conversion to paraoxion.

The effects of exposure to weathering conditions for other pesticide chemical-contaminated fabrics have not been reported in available literature. This illustrates a need to examine not only the effects of exposure on the recovery of pesticide residues but also the effect of weathering on decontamination.

Effect of Storage

One of the factors affecting soil removal is the age of the soil. The research available on aging of soiled fabrics has been directed toward the long term effect of storage during the preservation of textiles. The concensus drawn from these studies is that the harmful effect of the environment during storage may not be as drastic or as rapid as that in outdoor exposure but that degradation of the textile substrate could occur (Williams, 1977).

Utermohlen et al. (1947) studied the effect of various soiling mixtures and storage conditions on the ease of laundering soiled fabrics. It was shown that soiled cotton fabrics became more difficult to launder after they had been stored for several weeks, unless the soil composition was inert to oxidation in the presence of air and unless the storage conditions were dry. The use of soils which undergo oxidative polymerization (oils) was found to lead to permanent binding of pigment soil and fabric. This process was reported to have been aided by the presence of moisture.

The effect of storing pesticide contaminated fabrics has not been reported in the available literature. Before recommendations could be made advocating the use of any laundry process, research is needed to

examine the critical factor of storage and the effect of storage on the level of pesticide residue contaminating the fabrics as well as removal by laundering.

Summary

The review of literature illustrates the need for a more scientific approach to decontamination of pesticide contaminated fabrics. If pesticide residues are treated as "soil" then an investigation into decontamination should evaluate pesticide removal by taking into consideration the factors that affect "soil removal." The extent of soil removal during the cleaning process is affected by the substrate, the soil, the cleaning method and interactions among all three (Schick, 1977). This study evaluated the effectiveness of decontamination during the laundering process by examining the effect of the substrate (fabric); the soil (pesticide); and the cleaning process (laundering).

CHAPTER III

METHODOLOGY

Reported in this chapter are the experimental design, description of the fabrics and sample preparations. Procedures for conducting the physical tests are explained. An outline of the method to be used for contaminating the fabrics, storage of the contaminated fabrics and exposure of the contaminated fabrics to simulated weathering conditions is presented. The procedures for laundering the contaminated fabrics are covered and an outline of the analytical methods used for extracting and analyzing the pesticide residues is included. In addition, a summary of the statistical analysis is covered in the final section of this chapter.

Experimental Design

The independent variables of the research included treatments (three variations) and fabrics (four variations). The dependent variable is the pesticide residue measured in nanograms and converted to micrograms per centimeter squared. The main objective of the research was to evaluate the decontamination of fabrics by laundering and to determine if the treatments, temperature, storage and exposure to weather, affect the decontamination.

A $2 \times 4 \times 3$ factorial design was used to test the effect of temperature (independent variable) on decontamination (dependent variable).

I. Pesticides:

- a. Captan®
- b. Guthion®

II. Fabrics:

- a. 100% Cotton Chambray
- b. 100% Cotton Denim
- c. Gore Tex®
- d. Tyvek®

III. Temperatures:

- a. Wash temperature 38°C (100°F) and rinse temperature 28°C (80°F)
- b. Wash temperature 49°C (120°F) and rinse temperature 38°C (100°F)
- c. Wash temperature 60°C (140°F) and rinse temperature 49°C (120°F)

A $1 \times 4 \times 3 \times 2$ factorial design was used to test the effect of storage (independent variable) on contamination and decontamination (dependent variables).

I. Pesticide: Captan®

II. Fabrics: (same fabrics used in the temperature study)

III. Storage (time of storage):

- a. 0 days storage
- b. 4 days storage
- c. 7 days storage

IV. Stored/washed vs. unstored/washed

In addition a $1 \times 4 \times 2 \times 2$ factorial design was used to test the effect of exposure to weather (independent variable) on contamination and decontamination (dependent variables).

- I. Pesticide: Captan®
- II. Fabrics: (same fabrics used in the temperature study)
- III. Weathered versus unweathered (controlled conditions):
 - a. Humidity--65% R.H. $\pm$ 3%
 - b. Temperature--28°C (78°F)
 - c. Xenon Arc Irradiance--1.5 w/m²
 - d. Exposure Time--1 Standard Weathering Hour
- IV. Weathered/washed vs. unweathered/washed

The dependent variable, pesticide residue, was determined by analyzing the extracts from the fabric samples on a gas chromatograph. The results were measured in nanograms per microliter and converted to micrograms per centimeter squared. Two replications per fabric were evaluated for each treatment.

Fabrics

The rationale for the choice of fabrics was to enable a comparison of decontamination of fabrics commonly worn by the grower for pesticide application and alternative fabrics that offer greater protection against pesticide penetration. This choice was based on information gained through interviews with growers and observations of pesticide applicators (Serat, 1982). Denim jeans and cotton chambray shirts appeared to be most often worn by pesticide applicators.

The information gained from the penetration study (Orlando et al., 1981) provided data on the effectiveness of fabrics as barriers to pesticide penetration. Table I summarizes the results of the penetration study and clearly shows that four fabrics offered significantly better resistance to pesticide penetration than either of the chambrays. Gore Tex® and Tyvek®, two of the superior fabrics, were selected for evaluation in the decontamination study. In addition, two of the fabrics commonly worn by the pesticide applicator (denim and chambray), were selected for further evaluation to determine their decontamination. The finding that chambray was ineffective as a barrier to pesticide penetration was taken into consideration when interpretations were made of the results of this study.

Table I. Summary of Results of Guthion® Penetration Study (Orlando et al., 1981).

Fabric	Inner Fabric µg/cm ²	Guthion® µg/cm ²		Duncan's Multiple Range*
		Outer Fabric µg/cm ²	Totals	
Gore Tex® I	0.018	3.35	3.37	A
Gore Tex® II	0.018	3.35	3.37	A
Tyvek®	0.014	3.30	3.31	A
Crowntex®	0.023	3.16	3.18	A
Chambray-Treated	0.460	2.95	3.41	B
Chambray	0.564	2.83	3.39	C

*Values followed by unlike letters are different at 0.01 level.

The fabrics used in this study included:

Denim, a 100% cotton fabric of twill weave. This fabric was dyed with indigo dyes and except for the preshrunk process, no other finish had been applied to the fabric. The denim fabric selected for the study was a heavy weight, 14 oz., comparable to the denim found in men's jeans.

Chambray, a 100% cotton fabric of plain weave. This fabric was dyed with indigo dyes, otherwise the fabric was unfinished. The fabric was lightweight, comparable to the fabric found in men's chambray shirts. It is typically considered to be a very absorbent fabric.

Gore Tex®, a three layer structure consisting of an outer layer of rip-stop nylon and an inner layer of nylon tricot, laminated to a film. The film was a microporous polymeric film of polytetrafluoroethylene (PTFE). This fabric was developed for application in the area of camping and backpacking and has not been previously used for chemical protective clothing.

Tyvek®, a 100% spun bonded olefin fabric, consisting of very fine polyethylene fibers in a network structure, self-bonded under heat and pressure. This fabric has been used for chemical protective clothing in a disposable version; however, a washable variation has been used in this study.

The fabrics were characterized according to the following physical properties:

Fabric Count. Fabric count was determined with a pick counter as specified in ASTM D1910-64. Five randomly selected one-inch specimens

of conditioned fabrics were counted in the warp and filing directions. The mean count has been reported in the nearest whole yarn.

Fabric Thickness. Fabric thickness was determined as specified in ASTM D1777-64, using a Custom Scientific Instruments, Inc., apparatus. Ten randomly selected 2 × 2 inch specimens were conditioned and thickness measurements recorded. The average thickness of the fabrics was reported to the nearest 0.001 inch (mill). The applied pressure was varied in keeping with the recommendations of the test method; moderate pressure 4.38 gm/cm² was used for Tyvek®, Gore Tex® and chambray; and firm pressure 8.65 gm/cm² was used for denim.

Fabric Weight. Fabric weight was determined as specified in ASTM D1910-64. Ten randomly selected 2 × 2 inch specimens were conditioned and weighed on an analytical balance. The average weight was reported in grams per meter squared and converted to ounces per yard squared.

Fabric Preparation

The fabrics were initially stripped of sizing by washing them one complete cycle, using an adaptation of AATCC 135-1978. The washing was done in a Sears Kenmore® automatic washer and dried in the same brand dryer. The wash water temperature was 60°C for the two cotton fabrics and 49°C for Gore Tex®. Tyvek® was not subjected to prewashing.

The detergent used in the prewashing procedure was Liquid All®: ½ cup to a full load, based on recommendations on the detergent label. The procedure included a twelve minute wash cycle and a four minute rinse cycle followed by a spin drying. The fabrics were removed from

the washer and placed in a dryer where they were tumble dried at a heavy duty setting for denim, normal setting for chambray and perma-press setting for Gore Tex®.

The fabric was then cut according to ASTM D 1682-64 into a sample size of 6 × 6 inches. Denim and chambray were clean-finished with a zigzag stitch to prevent ravelling using a 100% cotton, white thread.

Pesticides

Two variations of pesticides were used to contaminate the fabrics: Captan®, a fungicide from Stauffer Chemical Company and Guthion®, an insecticide from Mobay Chemical Corporation. The chemical and physical properties of the pesticides appear in Appendix A.

To determine the quantity of active ingredient (A) required to mix with a known quantity of diluent (Q), to obtain a given concentration of pesticide spray (0.12% concentration based on the recommendation of 1 lb. per acre), the following equation was used (Matthews, 1979):

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

Captan®:

$$1000 \text{ ml} \times \frac{0.12\% \text{ concentration}}{36.40 \text{ active ingredient}} = 3.30 \text{ gm/liter}$$

Guthion®:

$$1000 \text{ ml} \times \frac{0.12\% \text{ concentration}}{22.00 \text{ active ingredient}} = 5.45 \text{ gm/liter}$$

The respective amount of pesticide formulation was diluted to 1 liter with distilled water. After thorough mixing, the pesticide solution was transferred to a plastic bottle to be used in the spraying procedure.

Pesticide Spray Chamber

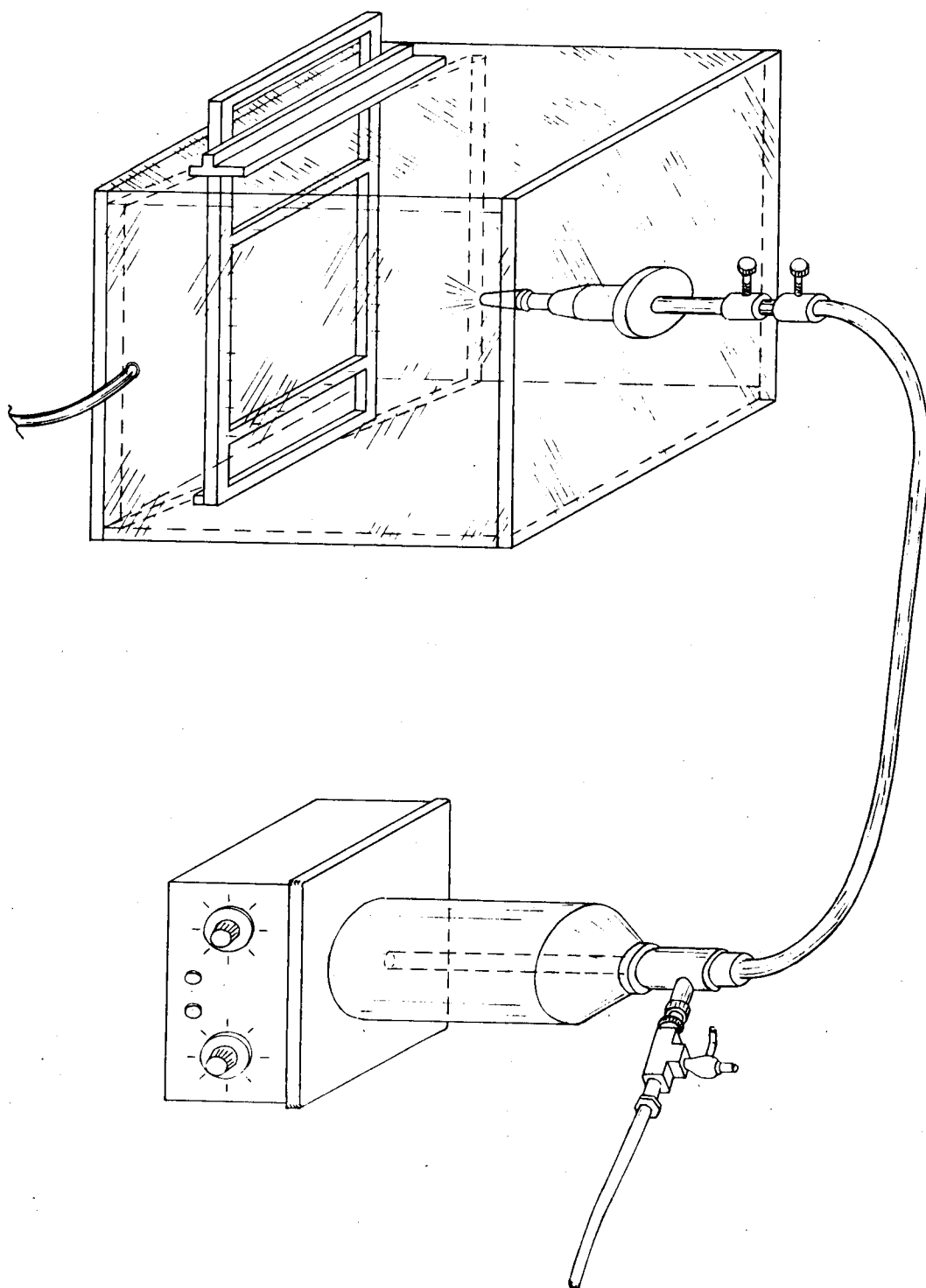
For this study a chamber was designed and built for use in exposing the fabric samples to a uniformly dispersed pesticide spray. The chamber was designed to simulate a field spray application procedure with the flexibility of nozzle size and pressure variations while maintaining equal deposition of pesticides. The chamber is illustrated in Figure 2. The plastic bottle containing the pesticide solution was placed on a magnetic stirrer and agitation provided to keep the formulation in suspension. The pressure for the spray was provided by Helium at 20 psi, enabling the delivery of a full cone pesticide spray. The nozzle used for delivery of the pesticide spray was a Bete, PT-12, R&D model. The nozzle was at a height of 10 inches above the specimen surface. The fabric samples were mounted on a tentor-frame type holder built to fit into the chamber at a 90° angle to the nozzle.

Contamination of the Fabrics

Fabric samples, two per fabric variation, were mounted on the fabric holders. The contamination of the fabric sample was accomplished by exposing the sample at ten-second intervals to the pesticide spray.

The contaminated fabric was placed on a foil-covered table and allowed to air dry on the holder for 1 hour in still-air conditions at a

Figure 2. Pesticide application sprayer system used to contaminate fabric samples.



room temperature of 25°C. The dried fabrics were either extracted or subjected to additional treatments.

Laundrying

AATCC test method #61 and the International Standard Method C-0 #6 were adapted to establish the laundrying procedures utilizing the launder-ometer to simulate one home laundrying cycle.

Apparatus for Laundrying

An Atlas Launder-Ometer, equipped with twenty stainless steel canisters, 9 × 20 cm., with teflon liners in the lids to prevent retention of pesticides by the rubber gaskets (Laughlin, 1981). Mechanical agitation was provided by the rotation of the launder-ometer rotor at a uniform rate of 42 rpm. Abrasive action was provided by the placement of 25 steel balls in each canister.

Detergent

The wash liquor was made up of 0.25% detergent dispersion. The concentration is based on the manufacturers recommendation of ½ cup per 12 gallon wash cycle. The detergent Liquid All®, a heavy duty concentrate, contained both anionic and nonionic surfactants. According to the label this was a nonphosphate containing detergent. In light of the fact that phosphates, even in trace amounts, could cause interferences in pesticide detection on the gas chromatograph, an experiment was carried out to determine if there were any interfering compounds. The procedures to check for background contaminants were according to the

Manual of Analytical Methods for the Analysis of Pesticides in Humans and Environmental Samples, Section 3A, p. 2.

The chromatogram produced by injecting the extracts from this procedure on both the electron capture and thermionic specific detectors revealed a very definite contaminant peak. Fortuitously, for the two pesticides used in this study, the contaminant peak eluted prior to either of the pesticides under investigation.

Liquor

The wash liquor was made up of 150 ml of manufactured hard water, of 150 ppm hardness, prepared according to the procedures in the article, "The Preparation of Water Samples of Known Hardness" (Easter and Lietzke, 1982). One liter of the prepared water was heated to the temperature being evaluated then 2.50 ml of detergent was added with a pipet. A magnet stirrer was used to stir the liquor for a period of 1 minute. A Beckman pH Meter, model H5, was used to measure the pH of the wash liquor prior to transferring the liquor to the launder-ometer canisters. The pH of the wash liquor was 9.20 ± 0.10 .

Temperature

Variations in water temperature were used in order to evaluate the effect of temperature on decontamination. The prepared water was allowed to reach the temperature under investigation; detergent was added and after mixing 150 ml of the wash liquor were transferred to the canister. The canisters were allowed to reach equilibrium at the respective temperature in the preheater unit of the launder-ometer before they were mounted on the launder-ometer rotor.

Laundry Cycle

Prior to preparing the wash liquor, the launder-ometer bath was filled with water and heated to the desired temperature. After the prepared canisters had equilibrated at the temperature in the preheater, they were clamped onto the launder-ometer as follows: four canisters per side, on alternate sides, to maintain a balance during the rotation of the launder-ometer. Eight canisters containing one fabric sample each were loaded during each run of the launder-ometer. The launder-ometer was then closed and rotation began. The wash cycle ran for 12 minutes. After the wash cycle was completed, the water was decanted from the canisters. A magnet was used to retain the steel balls in the canister during this decanting procedure.

Rinse Cycle

Following the completion of the wash cycle, the water level in the launder-ometer was lowered to one-half and cold water was added to the fill mark. This procedure was necessary to adjust the temperature of the launder-ometer water bath to the temperature under investigation for the rinse cycle.

The rinse water consisted of 150 ml of 150 ppm hard water prepared as covered under the "Liquor" section. One liter of water was allowed to reach the temperature under investigation and the pH was recorded. One hundred and fifty milliliters of water were transferred to each canister, which was then sealed and placed in the preheater. The loading was the same as in the laundry cycle. The rinse cycle consisted

of two 5 minute cycles; between each cycle water was decanted and a second 150 ml of rinse water added. The pH of the rinse water was 5.2 ± 0.10 .

Drying

A drip-dry procedure was used. The wet specimens were hung on a wire rack and allowed to hang in still-air conditions at room temperature ($25^{\circ}\text{C} \pm 3^{\circ}$) until dry. The drying time ranged from 4-6 hours in length depending on the temperature and humidity within the room.

Storage

The purpose of this aspect of the study was to evaluate the effect of storage on fabrics contaminated with pesticides. The effect of storage was evaluated by determining the amount of pesticide residues remaining after storage and comparing this amount to prestorage contamination amounts. The effect of storage on decontamination by laundering was also evaluated. The amount of pesticides remaining after laundering the stored fabrics was compared to the amount remaining after laundering of unstored fabrics.

Storage Procedures

Fabric samples were contaminated according to the procedures reported in the contamination section of this chapter and allowed to dry on the holders at room temperature for 2 hours or until dry. Forty fabric samples were initially contaminated; then eight samples, two per fabric variation, were chosen at random to be evaluated as the pre-storage contaminated fabrics. Thirty-two fabric samples were placed in

uncovered launder-ometer canisters, two per canister. The uncovered canisters were stored in a laboratory hood with the cover on the hood closed. The temperature and relative humidity readings within the hood were recorded on a daily basis throughout the storage period. The temperature ranged from 25°-30°C and the relative humidity level was $55\% \pm 5\%$.

Extraction after Storage

Eight randomly selected fabric samples were extracted and the extracts analyzed at the end of storage intervals of 4 and 7 days. The results of this analysis determined the effect storage had on the level of pesticide contamination. The amount of pesticide contamination after storage was compared to the amount of pesticides initially contaminating the fabrics.

Laundering after Storage

At the end of 4 and 7 days storage, eight randomly selected fabric samples were laundered at 49°C (120°F), according to the laundry procedures reported in the laundry section of this chapter. These fabric samples were extracted and analyzed to determine the effect storage had on decontamination. The results were compared to the results of laundering fabrics at this temperature with no storage treatment.

Exposure to Weathering Conditions

This experiment was designed to evaluate the effect of exposing fabrics contaminated with pesticides to simulated weathering conditions.

An adaptation of AATCC 111 A, "Weather Resistance: Carbon Arc Lamp Exposure with Wetting," test method was used. The apparatus used in the test was an Atlas, Xenon Arc Weather-Ometer, which provided a simulated sunlight exposure through a Xenon Arc lamp.

Weathering Procedures

Sixteen fabric samples were contaminated according to the procedures reported in the contamination section of this chapter and retained on the holders until dry. The fabric samples were then mounted on weather-ometer holders, using the large size holder and a cardboard frame cut to fit the 6 × 6 inch fabric sample. The entire sample, with the exception of the edges, was exposed to the weather-ometer.

The conditions of the weather-ometer had been previously set and the instrument was allowed to stabilize before the test was run. The conditions of the exposure chamber were: temperature $28^{\circ}\text{C} \pm 2^{\circ}\text{C}$, $65\% \pm 3\%$ relative humidity; Xenon Arc 1.5 lumins and exposure time 1 hour. The exposure time was 1 Standard Weathering Hour (SWH) which is equivalent to 5 hours exposure of noon-day sunlight.

Extraction after Weathering

After the fabrics had been exposed to weathering eight randomly selected samples were extracted and the extracts analyzed. This determined the amount of pesticide residue remaining after exposure to weathering conditions. This amount was compared to the amount extracted from contaminated fabrics that were not exposed to weathering, to evaluate the effect weathering had on the level of contamination.

Laundrying after Weathering

Eight randomly selected fabric samples, two replications per fabric, were laundered after being exposed to the weather-ometer. The fabrics were laundered at 49°C (120°F) according to the laundry procedures reported in the laundry section of this chapter. These fabric samples were extracted and analyzed to determine the effect exposure to weather had on decontamination. The results were compared to the results of laundrying fabrics at this temperature with no exposure treatment.

Extraction of Pesticide Residue

Preliminary testing of the extraction procedures was conducted to determine the most efficient extracting solvent. The solvents, iso-octane, toluene, benzene, ethyl acetate, hexane and acetone were tested by evaluating the percentage of pesticide removal of a known quantity from the fabrics Gore Tex® and/or chambray. In addition to evaluating the extraction efficiency, the performance of each solvent was evaluated on the gas chromatographic system that was used in the analysis. The pure solvents were evaluated according to the procedures in the Manual of Analytical Methods for the Analysis of Pesticides, Section 3C, p. 1. The results of this preliminary study showed that for the pesticide Guthion®, acetone gave the highest percentage of recoveries. This solvent also showed fairly good performance on the detector used to analyze Guthion®. For the pesticide Captan®, the most efficient solvent was hexane; in addition, this solvent showed excellent

performance when evaluated as a pure solvent on the column and detector that was used to analyze this pesticide.

The preliminary testing of solvents also included an evaluation of the number of extractions required to effectively remove the pesticide residues from the fabrics. For this evaluation 3 extracts vs. 2 extracts vs. 1 extract were used at times of 1 hour vs. 30 minutes. The results of this study showed that the third extract contained no detectable amount of pesticide. The second extract resulted in a very small detectable amount, approximately 100 picograms, for Captan® and no detectable amount for Guthion®. The amount found in the second extract for Captan® was attributed to a dilution of the extract remaining on the fabric and/or flask after the first extract had been decanted. The results of the length of time required to produce the most efficient extraction showed no detectable difference between the 30 minute vs. 1 hour extractions. Therefore, for this study the extraction procedure included one 30 minute extraction.

A 6 × 6 inch fabric sample had been exposed to the contamination chamber and this size sample was used in each treatment: laundering, storage, and weathering. However, the sample was too large to efficiently extract utilizing the equipment in our laboratory. Therefore, a smaller specimen was used in the extraction procedures. Prior to contamination or treatment a 3 × 3 inch square was marked with a permanent laundry marker. After contamination and/or treatment was completed the specimen was cut from the fabric sample with acetone rinsed scissors. This specimen was transferred to a 250 ml Erlenmeyer

flask by the use of tweezers. Fifty milliliters of the respective solvent was pipetted into the flask and the stoppered flask was placed on a Burrell Wrist-Action shaker. At the end of 30 minutes, agitation was discontinued and ten milliliters of the extract were pipetted into a sample vial and stored at -15°C until analyzed.

Gas Chromatographic Analysis

The extracts of pesticide residues were analyzed on a Varian 3700 Gas Chromatograph, equipped with a dual detection system. A nitrogen-phosphorus specific thermionic detector (TSD) was used in the analysis of the pesticide Guthion® and an electron capture detector (ECD) was used to analyze the pesticide Captan®.

Conditions for analysis of Guthion® were as follows: 0.318 cm $\times$ 1.8 m glass column [3% SE-30 (Methyl Silicone) with 80/100 gas chrom Q mesh]; carrier gas, helium, flowing at a rate of 60 ± 0.2 cc/min; air flowing at 175 cc/min; hydrogen, flowing at 4.0 cc/min; and bead current of 4.00. The operating temperatures were: column oven 240°C , inlet 250°C and detector 300°C . The sample size was 1 microliter injected using a Hamilton 5 μl syringe. Two replications per sample were injected and an average of the two reported in nanograms/microliter. Standard solutions of Guthion® in the range of the sample being analyzed were injected after every fourth sample. The gas chromatograph was recalibrated if this standard solution produced a result greater than 1% of the original calibration factor.

Conditions for analysis of Captan® were as follows: 0.318 cm ID $\times$ 1.83 m glass column [4% SE-30/6% OV 210 with 80/100 gas chrom Q mesh];

carrier gas, nitrogen, flowing at a rate of 40 ± 0.2 cc/min. The operating temperatures included the column oven at 220°C, inlet 250°C and detector 300°C. The sample size was 2 microliters injected using a Hamilton 710 10 μ l syringe. Two replications per sample were injected and an average of the two reported in nanograms/microliter. Standard solutions of Captan® in the range of the sample being analyzed were injected after every fourth sample. If the standard produced a peak greater than 1% of the original calibration factor the gas chromatograph was recalibrated.

The gas chromatograph was connected to a CDS 111 Integrator which was programmed to compute retention time, area counts and nanogram amounts of the sample being injected. The results from the integrator were manually converted into micrograms per centimeter squared.

Statistical Analysis of Data

The statistical analysis of the data was based on the computed micrograms per centimeter squared of pesticide residue remaining on the fabric specimen after contamination and/or treatment as analyzed on the gas chromatograph. A mean of contamination for each pesticide was used as the initial level of pesticide contamination before treatments.

The statistical procedures used in the analysis of the data included analysis of variance (ANOVA), least squares analysis of variance and Duncan's Multiple Range test. These statistical procedures were performed using the general linear models (GLM) procedure available in the Statistical Analysis System computer program.

Initially an analysis of variance was applied to the dependent variable (pesticide residue) to partition the effects of fabric, temperature, storage and weathering. From these analyses the residuals of the model were plotted against the predicted values of the model. Examination of subsequent plots indicated that heteroscedasticity of the error was very apparent for all response variables. The data were subsequently reanalyzed after log transformations were applied to the dependent variable. The subsequent residuals from the transformed model were also plotted against the predicted values in the transformed model. Homoscedasticity of the error was now apparent for all response variables, indicating the problem of heteroscedasticity had been discipitated. Henceforth, all subsequent analyses were made using the log transformed data.

The GLM procedure to test for main effects (temperature and fabric) and interactions was used for both Captan® and Guthion® laundry studies. The GLM procedure to test for main effects (weathering and fabric), interactions and weathered vs. unweathered was used for the data set weather. The GLM procedure to test for main effects (storage and fabric), interactions and stored vs. unstored was used for data set storage. The statistical procedure analysis of variance was used in all analyses of data sets, excluding those data sets that contained a zero measure. The data sets containing a zero measure were analyzed using a least squares analysis of variance procedure. The least squares analysis of variance procedure was selected because of the unbalanced design which resulted in unequal cells when the zero dropped out of the design after log transformations were applied to the data.

For both the analysis of variance and the least squares analysis of variance procedures, a probability level of 0.05 was selected as the criterion for significance. Means were computed for dependent variables for reference in the interpretation of findings. Further examination of all possible pairwise comparisons of treatment means for those dependent variables which produced a significant overall F test was carried out with a Duncan's Multiple Range post hoc procedure.

CHAPTER IV

RESULTS AND DISCUSSION

This study investigated the efficacy of laundering on decontamination of fabrics contaminated with pesticides. The effect of water temperature, storage and exposure to weathering on contamination and decontamination were examined.

The results are reported in three major sections: (1) physical tests used to characterize the fabrics; (2) initial contamination of fabrics with pesticides and (3) decontamination of fabrics by laundering; according to the effect of treatments: temperature, storage and exposure to weathering. A discussion of the findings has been incorporated into each section.

Fabric Properties

The mean values of the physical properties; fabric weight, fabric thickness and fabric count are presented in Table II. As this study was conducted to examine the launderability of selected fabrics the variations in fabric characteristics, weight, thickness and yarn count were anticipated and no additional analysis was conducted.

Fabric selection, although relatively limited, allowed a comparison of fabric characteristics and their effect on pesticide removal. The 100% cotton fiber is considered to be hydrophilic and nylon is known to exhibit both hydrophobic and oleophilic tendencies. The exact nature of the PTFE film in the Gore Tex® fabric was not evaluated but it was

Table II. Physical Properties of Fabrics

Fabric	Weight		Thickness ^a (in mills)	Fabric Count ^b	
	oz/yd ²	gm/m ²		Warp	Filling
Denim	16.04	543.85	41	66	48
Chambray	4.95	167.83	20	74	54
Gore Tex®	3.62	122.74	13	--	--
Tyvek®	1.42	48.15	10	--	--

^aDetermined according to standard procedure ASTM Method D1777.

^bDetermined according to standard procedure ASTM Method D1910.

expected to exhibit both hydrophobic and oleophobic properties. The oleophilic nature of Tyvek® allows oils to soak into its fibrous structure resulting in stains that impair effective cleaning procedures.

Fabric weights per unit area were not comparable for the four fabrics and should be considered as a discriminating factor. The variations in fabric thickness measurements should also be taken into consideration as increased yarn thickness leads to an increase in fabric thickness and weight. Increased yarn thickness should result in area decreases for interyarn spaces, hence changing the geometry of the fabric.

Initial Contamination of the Fabric

To establish the initial amount of pesticide residues contaminating the fabric samples, it was necessary to determine the pesticide residue retained by the fabric after exposure but before treatments; laundering, storage and weathering. Two replications of each fabric type per pesticide were subjected to ten-second exposures of the pesticide spray, air dried, extracted and analyzed as an indication of initial contamination.

For the pesticide Captan®, a ten-second exposure to the pesticide spray resulted in a fine mist of pesticide being deposited on the surface of the fabric samples. Extracts of the Captan® exposed fabrics were analyzed and it was shown that residues ranged from 9.585 $\mu\text{g}/\text{cm}^2$ to 11.395 $\mu\text{g}/\text{cm}^2$ (Appendix B).

When exposing the fabric samples to Guthion® spray, the nozzle used in the spray chamber developed a small drip in the center of the full

cone spray. This may be attributed to an increase in specific gravity of the pesticide solution over that of the Captan® solution. An effort was made to eliminate the drip by changing the pressure, nozzle size and pesticide concentration. All attempts to eliminate the drip were futile, therefore, a decision was made to expose the fabric samples to the spray in the presence of the drip. A wet weighing of the exposed fabric samples showed that approximately two times the weight of pesticide emulsion of Guthion® was being deposited on the fabrics when compared to the wet weight of Captan® exposed fabrics.

Preliminary experimentation with solutions of known concentrations of Guthion® pesticide standards involved pipetting 1 ml portions onto fabric specimens, and after being air dried the fabric specimens were extracted. An analysis of the extracts showed that recoveries were in the range of 44.95% to 51.70%. Extensive preliminary testing was conducted to examine the findings of the low recoveries with the pesticide Guthion® which included extracting fabrics immediately after exposure to the pesticide spray and comparing them to air-dried fabric samples. The fabric samples extracted immediately after exposure showed recoveries of a mean quantity of 20.00 $\mu\text{g}/\text{cm}^2$. Analysis of air-dried samples showed that approximately 50% of the pesticide residue was lost as recoveries were in the range of 6.562 $\mu\text{g}/\text{cm}^2$ to 10.944 $\mu\text{g}/\text{cm}^2$ (Appendix B).

The differences in recoverable pesticide residues of Guthion® were assumed to be loss by evaporation, but it could have also been due to a pesticide fabric interaction, such as physical or chemical bonding of

the residues with the fabrics. To determine the reason for low recoveries from air dried fabric samples, an experiment was conducted using 3" diameter circles of thin teflon. The teflon samples were subjected to the same experimental procedures as the fabric samples, two replications of exposed samples were extracted before air drying and two after being air dried.

The results of the teflon-extracted pesticide residues showed recoveries of a mean quantity of 20.00 $\mu\text{g}/\text{cm}^2$ from the undried samples and 10.00 $\mu\text{g}/\text{cm}^2$ from air-dried samples. This verified the findings from the fabric samples and led to the conclusion that Guthion® sprayed from the spray chamber in this experiment results in a loss of approximately 50% of the initial Guthion® residues. This loss was a result of evaporation and not a fiber-pesticide interaction. In determining the initial contamination of fabrics by the pesticide Guthion® it was shown that evaporation or loss of pesticide residue occurred regardless of fiber content and that fabric samples retained similar amounts of Guthion® residues.

To calculate an initial pesticide contamination for both pesticides, two replications per fabric type were analyzed, and the results were averaged and reported in $\mu\text{g}/\text{cm}^2$ (Appendix B). Taking into account the number of experimental procedures leading up to the final analysis of pesticide residues for an initial contamination, the decision was made to average the results of all four fabrics and the mean contamination was used. For the pesticide Captan®, the mean contamination was 10.493 $\mu\text{g}/\text{cm}^2$ and the mean contamination for Guthion®

was 8.056 $\mu\text{g}/\text{cm}^2$. Statistical analyses have been premised on the notion that an average of the pesticide residue extracted for each pesticide is representative of initial pesticide contamination of fabric for that pesticide.

Effect of Storage on Initial
Captan® Contamination

The mean values of pesticide residues contaminating the fabric samples pre- and post-storage-treatment are listed in Appendix C. At the end of Storage 1 (4 days) the mean level of contamination was 9.610 $\mu\text{g}/\text{cm}^2$ and a mean value of 9.246 $\mu\text{g}/\text{cm}^2$ was shown at the end of Storage 2 (7 days).

A one-way analysis of variance was used to test for differences in mean values of pesticide contamination, pre- and post-storage-treatment. The results of the analysis showed that Storage 1 was not significant at the 0.05 level. The difference in the level of pesticide contamination at the end of Storage 2 was significant at the 0.05 level (Table III).

Table III. Summary of ANOVA for Effect of Storage on Pesticide Contamination Level

Source	df	Sum of Squares	F
Storage (1)	1	0.036	2.97
Storage (2)	1	0.065	11.98*

*Significant at the 0.05 level.

The mean values showed that at the end of 7 days of storage the pesticide residue remaining on the fabrics was 88.12% of the initial pesticide contamination. This could be attributed to a slow change in chemical composition of the Captan® residue. This change might have been the result of oxidation of the pesticide residue in the presence of air, loss by evaporation or hydrolysis of the pesticide in the presence of moisture as the relative humidity of the storage environment was 50% to 60%.

Effect of Weathering on Initial Captan® Contamination

The mean values of pesticide residues contaminating the fabric samples both pre- and postexposure to weathering are listed in Appendix D. The mean contamination after weathering was 10.692 $\mu\text{g}/\text{cm}^2$, compared to the initial level of contamination of 10.493 $\mu\text{g}/\text{cm}^2$.

A one-way analysis of variance was used to test for differences in mean values of pesticide contamination: pre- and post-weathering-treatment. The results showed that treatment, exposure to weathering, was not significant at the 0.05 level (Table IV), indicating that the level of Captan® residues on contaminated fabrics was virtually unchanged during the treatment weather.

Table IV. Summary of ANOVA for Effect of Exposure to Weathering on Pesticide Contamination Level

Source	df	Sum of Squares	F	p
Exposure	1	0.002	0.43	0.522

The finding that the level of contamination of Captan® remained unchanged may be attributed to the chemical/physical properties of Captan®. Captan® has been classified as a nonvolatile fungicide with a half-life on soil in the range of 5 days to 65 days depending on the moisture content of the soil (Brown, 1978). A direct correlation cannot be made between soil and fabric; however, it appears that Captan® residues on fabrics followed the same trend as pesticide residues on soil. The behavior of Captan® residues exposed to weathering is similar to the findings of Serat (1982), in which he showed that during a field control study on fabrics sprayed with dicofol, 75% of the pesticide dicofol was recovered after outdoor exposure.

Pesticide Residue Removal by Laundering

The laundry process removed a mean percentage of Captan® residue in a range of 72.74% to 100% (Table V). A mean percentage of Guthion® residue was removed by the laundry process in the range of 86.44% to 99.94% (Table VI). Indicating that a difference in decontamination, i.e. removing pesticide residue, was shown between Captan® contaminated fabrics and Guthion® contaminated fabrics. This difference was dependent on fabric type and treatments; temperature, storage and exposure to weathering.

Effect of Fabric on Pesticide Removal

The mean values of pesticide residues retained by fabrics after laundering are given in Tables V and VI. A least squares analysis of variance was used to test for differences in fabrics on pesticide

Table V. Means of Captan® Residues Retained by the Fabrics and Percentages of Removal by Laundering as a Function of Temperature

Fabric	Wash T1 ^a		Wash T2 ^b		Wash T3 ^c	
	Residue (µg/cm ²)	Removal %	Residue (µg/cm ²)	Removal %	Residue (µg/cm ²)	Removal %
Denim	2.860	72.74	0.236	97.76	0.043	99.59
Chambray	0.469	95.53	0.016	99.84	0.004	99.95
Gore Tex®	0.235	97.76	0.030	99.70	0.025	99.76
Tyvek®	0.008	99.92	N.D.* ≈ 100		N.D.* ≈ 100	

*Below the detection limit of the gas chromatograph.

^aT1 = Wash Temperature 38°C.

^bT2 = Wash Temperature 49°C.

^cT3 = Wash Temperature 60°C.

Table VI. Means of Guthion® Residues Retained by the Fabrics and Percentages of Removal by Laundering as a Function of Temperature

Fabric	Wash T1 ^a		Wash T2 ^b		Wash T3 ^c	
	Residue ($\mu\text{g}/\text{cm}^2$)	Removal %	Residue ($\mu\text{g}/\text{cm}^2$)	Removal %	Residue ($\mu\text{g}/\text{cm}^2$)	Removal %
Denim	0.462	94.26	0.300	96.28	0.169	97.90
Chambray	0.019	99.76	0.018	99.78	0.004	99.94
Gore Tex®	1.092	86.44	0.759	90.58	0.686	91.49
Tyvek®	0.410	94.90	0.046	99.44	0.016	99.81

^aT1 = Wash Temperature 38°C.

^bT2 = Wash Temperature 49°C.

^cT3 = Wash Temperature 60°C.

removal from Captan® contaminated fabrics. "Fabrics" were found to be significant at the 0.05 level (Table VII). Duncan's post hoc analysis revealed that significant differences occurred between all fabric types and grouped fabrics according to descending order of pesticide residues retained (Table VIII).

The mean percentages removed from the 100% cotton fabrics were lower in cumulative percent Captan® removal as 72.74% to 99.59% was removed from 100% cotton denim and 95.53% to 99.95% from 100% cotton chambray when compared to Gore Tex® as 97.76% to 99.76% and Tyvek® as 99.92% to 100% removal. This indicates that Captan® residue was more difficult to remove from natural fibers than from synthetic fibers.

A two-way analysis of variance was used to test for differences in fabrics on pesticide removal from Guthion® contaminated fabrics. Fabrics were found to be significant at the 0.05 level (Table IX). Duncan's post hoc analysis revealed that significant differences occurred for all fabrics and grouped fabrics according to descending order of pesticide residues retained (Table X).

The lowest percentage removal of Guthion® residue was found in the fabric Gore Tex® as only 86.44% to 91.49% was removed when compared to Tyvek® in which 94.90% to 99.81% was removed. The natural fibers resulted in a removal from 100% cotton chambray of 99.76% to 99.94% compared to 94.26% to 97.90% for 100% cotton denim.

The differences in removal attributed to fabric type may be the result of the chemical composition of the fiber and/or pesticide, fiber and fabric geometry or the fiber morphology. Denim, a woven 100%

Table VII. Summary of ANOVA for Removal of Captan® Residues by Laundering

Source	df	Sum of Squares	F
Temperature	2	42.830	419.78*
Fabric	3	36.259	236.92*
Fabric * Temperature	4	3.471	17.01*

*Significant at the 0.05 level.

Table VIII. Duncan's Multiple Range Test for Removal of Captan® Residues from Fabrics by Laundering

(Variable)	Mean Pesticide Residue ($\mu\text{g}/\text{cm}^2$)	Groupings*
(Temperature)		
Wash T1	0.893	A
Wash T2	0.071	B
Wash T3	0.018	C
(Fabric)		
Denim	1.046	A
Chambray	0.163	B
Gore Tex®	0.097	C
Tyvek®	0.003	D

*Means with different letters are significantly different at 0.05 level.

Table IX. Summary of ANOVA for Removal of Guthion® Residues by Laundering

Source	df	Sum of Squares	F
Temperature	2	6.865	155.42*
Fabric	3	48.690	734.84*
Fabric * Temperature	6	5.476	41.33*

*Significant at the 0.05 level.

Table X. Duncan's Multiple Range Test for Removal of Guthion® Residues from Fabrics by Laundering

(Variable)	Mean Pesticide Residue ($\mu\text{g}/\text{cm}^2$)	Groupings*
(Temperature)		
Wash T1	0.496	A
Wash T2	0.280	B
Wash T3	0.219	C
(Fabric)		
Denim	0.310	B
Chambray	0.013	D
Gore Tex®	0.845	A
Tyvek®	0.157	C

*Means with different letters are significantly different at 0.05 level.

cotton, a natural fiber retained the largest percentage of Captan® pesticide residue, regardless of wash water temperature. Chambray, a woven 100% cotton, retained the next highest percentage of pesticide residue. This finding may have been the result of fabric construction as well as fiber morphology in combination with the particle size of the Captan 4F formulation.

[The ribbon-like formation of cotton fibers provides more extensive physical opportunities for particulate soils to accumulate on them than on smooth, round fibers such as nylon (Schick, 1977). In soil removal studies particulate material was more difficult to wash from cotton fabric than from nylon. Geometric bonding was considered the principal mechanism affecting the affinity of cotton toward particulate soils. That is, particles are trapped in fiber surface crevices (micro-occlusion) or trapped in fabric interstices (macro-occlusion). Compton et al. (1953a, 1953b) found that micro-occlusions were more important for rougher-surfaced natural fibers than for smooth, round synthetic fibers.]

Fabric construction, i.e. the structure of the textile fabric, can affect soil removal. Variations in spacing between individual fibers and yarns control the extent to which internal surfaces contact soils. Tight twisting of the yarns or tight packing into fabrics can keep soils away from interior surfaces, but it can also prevent wash liquors from removing soils which do penetrate. The differences between the two natural fibers, i.e. 100% cotton denim and 100% cotton chambray, could have been a result of fabric construction. The findings show that less pesticide residue was retained after laundering by chambray a low-twist,

loosely woven fabric. In contrast, denim, a high twist, tightly woven fabric retained much more residue. These findings are in agreement with the findings of Bowers et al. (1969) in which they found that less soil was retained after laundering by a low-twist, loosely woven cotton oxford cloth than by a highly twisted, tightly packed broadcloth.

Interpretation of the finding that overall Guthion® pesticide residue was more difficult to remove from fabrics must include a look at the chemical composition of the pesticide formulation as well as the fiber content. Guthion® 2S formulation is an oil based concentrate containing 43% petroleum distillates. The difficulty of removing oily soils from textile substrates through laundering has been reported in numerous articles (Kissa, 1971a, 1971b; Utermohlen, 1947). The mechanism involved in oily-soil removal includes not only the possibility of geometric entrapment of soils on the surface of the textile, but also a fiber-soil interaction. The components of oily soils can become molecularly entangled in the body of the filaments by diffusion. Variables affecting this process include the size and chemical nature of the soil, type of fiber and the temperature of interaction.

The chemical composition of Gore Tex® includes the nylon fiber as well as the PTFE film, both of which were expected to exhibit hydrophobic properties. The oleophilic tendencies of the nylon fiber could explain why this fabric retained more of the pesticide Guthion®. It was anticipated that the PTFE film would impart a low surface energy to the Gore Tex® fabric which would tend to repel aqueous based soils as well as oily soils. This might explain the increased removal of Captan®

exhibited by Gore Tex® over both cotton fabrics, but would not explain the behavior of Guthion® residue removal. Other research has shown that when the components of oily soils have diffused below the fiber surface the soil may permeate the polymer itself. When this diffusion does occur the soiled fabrics are more difficult to clean (Schick, 1977).

The increased removal for both pesticides from Tyvek® may be attributed to the chemical composition of the fabric. Tyvek®, a man-made polyolefin, has been shown to exhibit a low surface energy that can repel aqueous-based soils. Captan®, an aqueous emulsion, was easily removed from Tyvek®. The increase in pesticide residue remaining after laundering for the pesticide Guthion® could probably be attributed to the oil-based emulsion of this pesticide. The oleophilic nature of Tyvek® and the difficulty in removing oily soils from synthetic fibers has already been discussed.

Effect of Temperature on Pesticide Removal

The mean results of the data from the study; effect of temperature on the removal of pesticide residue, are presented in Tables V and VI, pps. 58 and 59. A least squares analysis of variance was used to test for differences in temperature on pesticide removal from Captan® contaminated fabrics. A two-way analysis of variance was used to test for differences in temperature on pesticide removal from Guthion® contaminated fabrics. The results of the analyses showed that temperature was significant at the 0.05 level for both Captan® and Guthion® removal (Tables VII and IX). Duncan's post hoc analysis was

used to differentiate between temperature means. The results of the analyses indicated that temperature means were significantly different at the 0.05 level and the groupings of the post hoc analyses ranked temperature in ascending order of efficacy of pesticide removal (Tables VIII and X).

The overall effect shows an increase in temperature resulted in an increase in pesticide residue removal for both Captan® and Guthion® residues. This effect is illustrated by a plot of the results shown in Figure 3, representing the common logarithm of the amount of pesticide residue remaining on the fabrics after laundering vs. reciprocal of absolute temperature (1000/Kelvin).

The overall effect of increased pesticide removal with an increase in temperature may be partially attributed to the theory that higher temperatures favor increased soil removal by increasing the kinetic energy of the particles and their Brownian motion. An increase in the temperature (expressed in degrees Kelvin) from 38°C (311 K) to 60°C (333 K) shows an increase in kinetic energy of only 7%.

$$100 \frac{(333-311)}{311} = 7.07\%$$

In addition to an increase in kinetic energy an increase in temperature may result in a reduction in the viscosity of the wash-liquor. A reduction in viscosity should intensify the Brownian motion somewhat, but the overall increase would be small (Cutler et al., 1972).

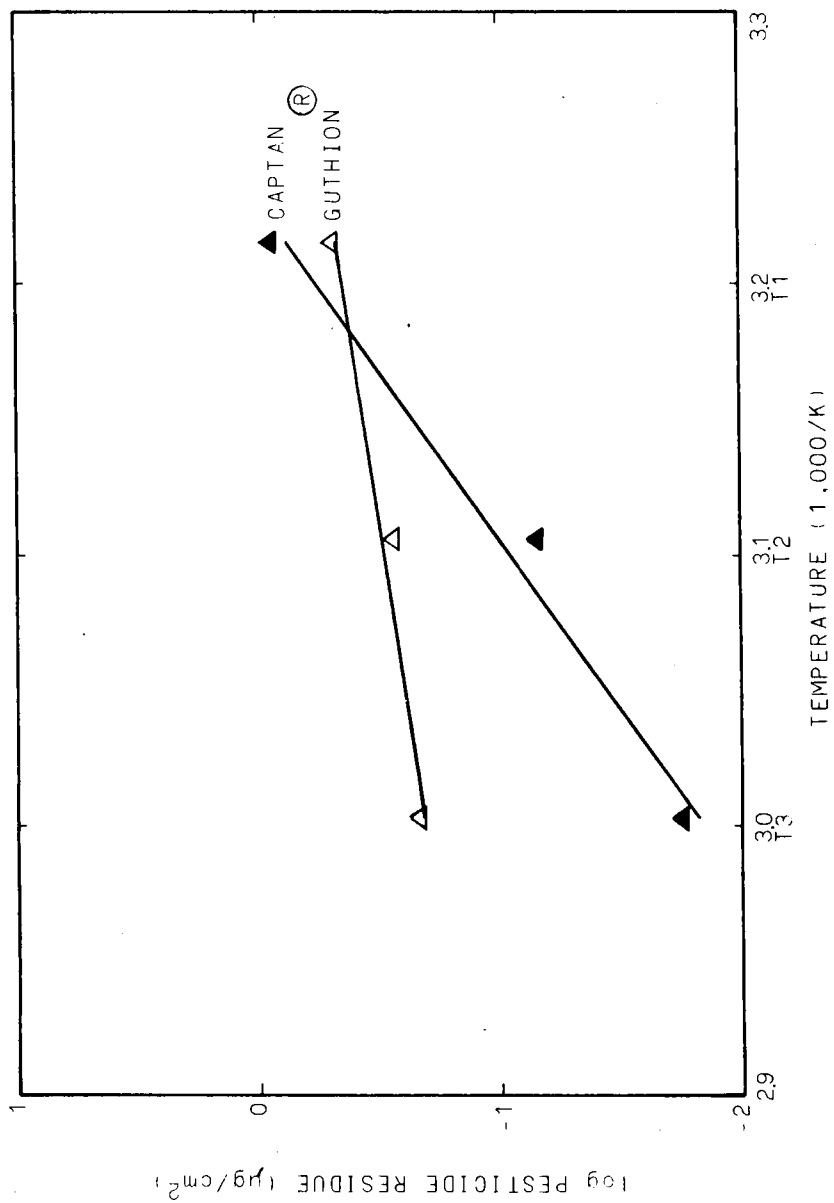


Figure 3. Pesticide residues retained by fabrics after laundering as a function of temperature.

In view of the small effect of temperature on kinetic energy and Brownian motion, it is felt that other effects due to an increase in temperature probably play a major role in soil removal. One secondary effect is the influence of temperature on the solubility of the surfactant. Nonionic surfactants are less hydrated at higher temperatures and hence more surface active, thus enhancing their cleaning power (Cutler et al., 1972). The liquid detergent All® is a combination of anionic and nonionic surfactants; therefore the increase in removal due to an increase in temperature may have been due to an increase in detergency power. This finding was not verified in this study as only one detergent formulation was used.

Interaction Effect of Fabric and Temperature on Pesticide Removal

The statistical design used to test for differences attributable to main effects of "fabric" and "temperature" was extended to examine the possible existence of an interaction between the two independent variables. In a two-way ANOVA or least squares analysis of variance an interaction is the effect on the dependent variable of the two independent variables operating together, as distinguished from the main effect of each independent variable.

The interactions were significant for both Captan® and Guthion® contaminated fabrics (Tables VII and IX, pps. 61 and 62) indicating that the differential effectiveness of the levels of one factor (temperature) will change according to how these levels of temperature are combined with the level of the second factor (fabric). Thus, the differential

effect of increasing temperature proved to be more beneficial for some fabrics than for others.

To further illustrate the interaction, graphs of the results were plotted using the common logarithm of the amount of pesticide residue remaining on the fabric after laundering vs. temperature (1000/Kelvin) (Figures 4 and 5). The slopes, at any given temperature, of these lines are proportional to an enthalpy change related to the interaction between pesticide and fabric. A sharp increase in Captan® residue removal with an increase in temperature is shown for the natural fibers, denim and chambray. In comparison, Gore Tex® shows a sharp increase in pesticide removal from 38°C to 49°C but a levelling off effect as the temperature was increased to 60°C. This illustrates that temperature alone did not explain the differences in pesticide removal, hence, the differences in removal have been attributed to interactions between fabric and pesticide as a function of temperature.

Possible mechanisms of this interaction may be due to the theory that increasing water temperature can increase swelling and softening of the surfaces of textiles being laundered. Expansion of the surface may lead to dislodgment of particulate soils. It has been shown that considerable swelling possibilities exist with cellulose which promote an increase in soil removal at elevated temperatures (Warburton, 1973; Schick, 1977). This may explain the greater increase in pesticide removal with increasing temperature shown for chambray and denim, particularly for the pesticide Captan®, in which the particle size has already been considered as a contributing factor to the removal of residues from natural fibers.

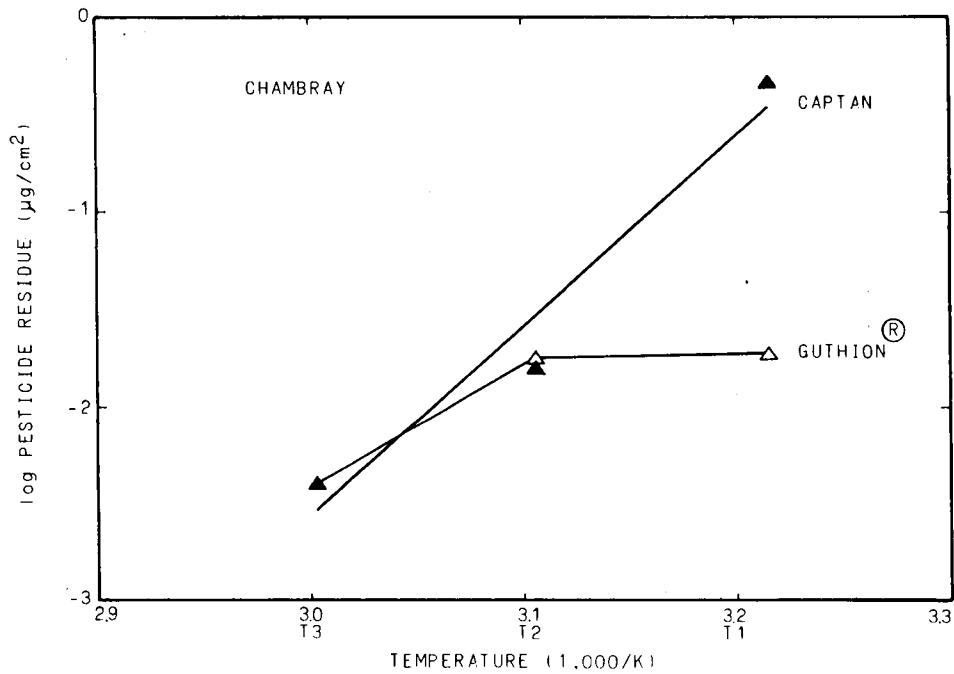
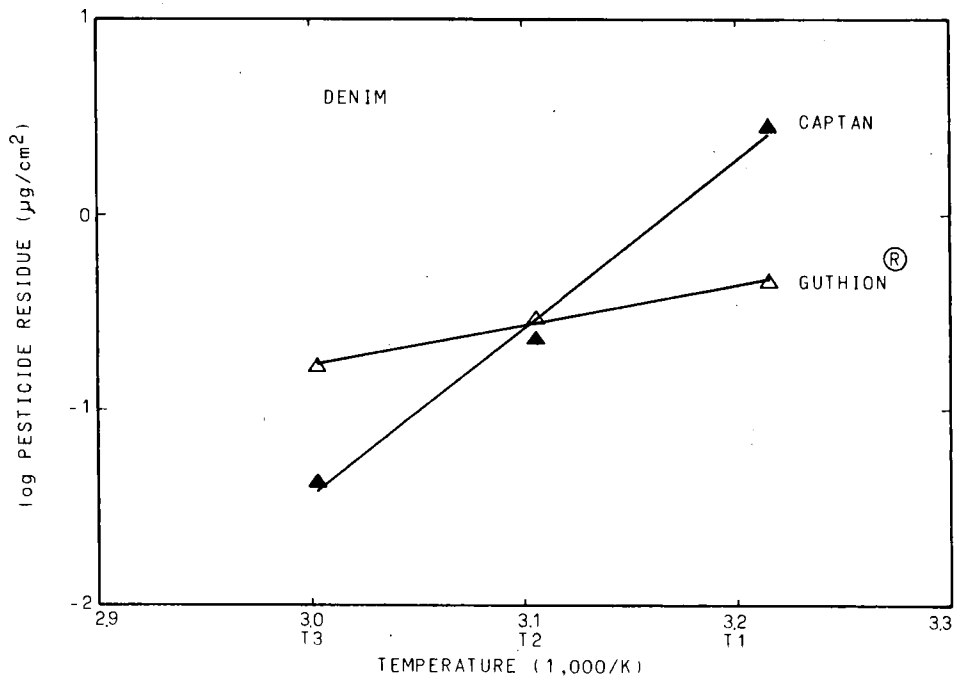


Figure 4. Pesticide residues retained by denim and chambray after laundering.

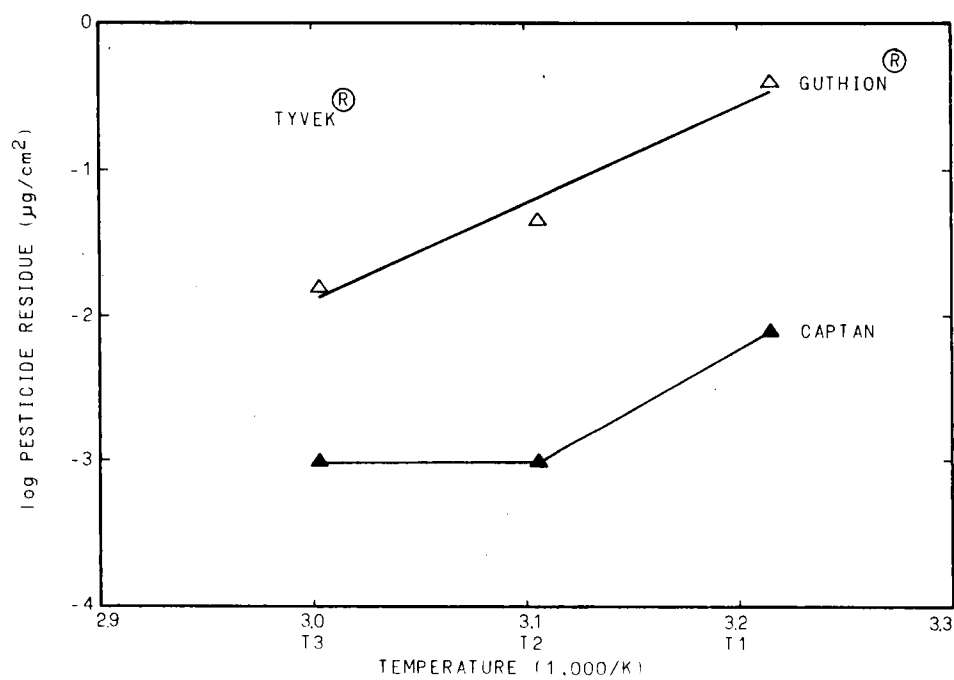
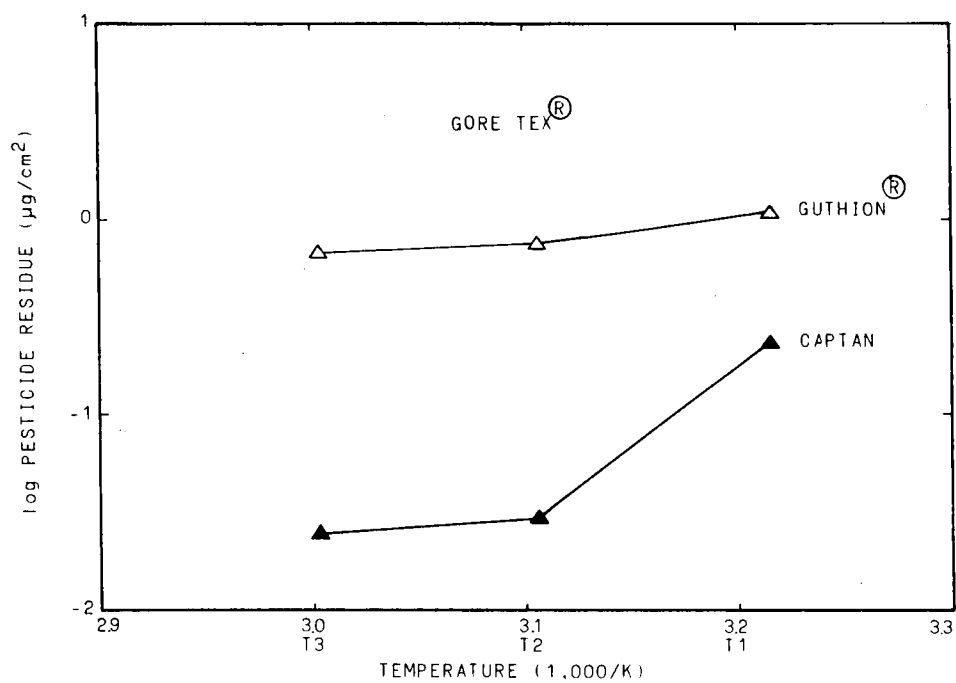


Figure 5. Pesticide residues retained by Gore Tex® and Tyvek® after laundering.

The levelling off effect as temperature increased observed for Gore Tex® and Tyvek® indicates that there is another process, other than temperature vs. soil removal, involved in pesticide removal. Research has shown that increasing the temperature for removing soils from synthetic fibers increases the amount of soil removed up to a maximum value, while higher temperatures actually cause a reduction in removal (Fort, 1966). This reduction can be attributed to an increase in the diffusion rate of soils with elevated temperatures; the deeper the soils have diffused below the surface, the more difficult it is to remove them. Fort (1966) has shown that oily soil diffusion with elevated temperature is more rapid for synthetics than with cellulose; similarly the results of this study showed that Guthion®, an oil-based emulsion, was retained by Gore Tex® and Tyvek® at elevated temperatures more so than Captan®, a water-based emulsion.

Effect of Storage on Pesticide Removal

The mean values of pesticide residues retained by fabrics after 4 days storage followed by laundering and 7 days storage followed by laundering were compared to the mean values of pesticide residues retained by fabrics that were laundered without storage. A presentation of the data is shown in Table XI. On examination of the data, it appears that the overall effect of storing Captan® contaminated fabrics results in an increase in the level of pesticide residue removed by laundering.

A least squares analysis of variance was used to test for differences in pesticide residue removal attributable to treatment storage. A summary of the analysis is presented in Table XII, which

Table XI. Means of Captan® Residues Retained by Fabrics and Percentages of Removal by Laundering: Pre- and Post-Storage-Treatment

Fabric	Storage 0 ^a		Storage 1 ^b		Storage 2 ^c	
	Residue (µg/cm ²)	Removal (%)	Residue (µg/cm ²)	Removal (%)	Residue (µg/cm ²)	Removal (%)
Denim	0.236	97.76	0.130	98.65	0.058	99.37
Chambray	0.016	99.84	0.026	99.73	0.008	99.91
Gore Tex®	0.030	99.70	0.112	98.83	0.053	99.43
Tyvek®	N.D.* ≈ 100		N.D. ≈ 100		N.D. ≈ 100	

*N.D. = below the detection limit of the gas chromatograph.

^a0 = Zero days storage; Washed T2.

^b1 = Four days storage; Washed T2.

^c2 = Seven days storage; Washed T2.

Table XII. Summary of ANOVA for Effect of Storage on Pesticide Removal by Laundering

Source	df	Sum of Squares	F
Storage	2	2.483	53.70*
Fabric	2	13.433	290.58*
Storage * Fabric	4	2.557	27.66*

*Significant at the 0.05 level.

shows that the treatment "storage" was significant at 0.05 level of significance. A post hoc analysis using Duncan's Multiple Range test revealed that significant differences occurred for Storage intervals 1 and 2 at the 0.05 level of significance. The results of the post hoc analysis are presented in Table XIII showing the grouping of storage intervals according to descending order of pesticide residues retention. The Duncan's procedure was also applied to the fabric means. The results showed that significant differences occurred for all fabrics and grouped fabrics according to descending order of pesticide residues retained (Table XIII).

The effect of storage on pesticide removal after Storage 1 showed a slight increase in pesticide removal when compared to the removal from unstored fabrics. In comparison, Storage 2 resulted in a larger increase in pesticide removal when compared to both Storage 1 and unstored fabrics.

Overall, storage of Captan® contaminated fabrics before laundering results in a significant change in the ease of pesticide removal. Both storage intervals produced an improvement in pesticide residue removal. Therefore, it was concluded that the pesticide residue did undergo chemical and/or physical changes during storage. The changes which pesticide residues might have undergone may include hydrolysis or oxidation accompanied by polymerization. In conditions of dry atmospheric exposure the most likely change to occur is oxidation; however, at a relative humidity level of 50% to 60% there is probably enough moisture available to result in hydrolysis. Of the two possible

Table XIII. Duncan's Multiple Range Test for Effect of Storage on Pesticide Removal

Variable	Mean Pesticide Residues after Washed at T2 ($\mu\text{g}/\text{cm}^2$)	Groupings*
(Time)		
0 days	0.071	A
4 days	0.067	B
7 days	0.030	C
(Fabric)		
Denim	0.142	A
Chambray	0.017	C
Gore Tex®	0.065	B
Tyvek®	0.000	D

*Means with different letters are significantly different at the 0.05 level.

changes, only oxidation resulting in polymer formation should have the effect of binding an inert pigment more tightly to a substrate (Utermohlen, 1947). Therefore, it appears that hydrolysis of the pesticide residue has occurred and the resulting compound did not interfere with the ease of removal of residues from fabrics.

Effect of Exposure to Weathering on Pesticide Removal

The mean values of pesticide residues retained by fabrics after exposure to weather conditions followed by laundering were compared to the mean values of pesticide residues retained by unexposed fabrics but laundered. A presentation of the data is shown in Table XIV.

A least squares analysis of variance was used to test for differences in pesticide residue means: pre- and postexposure to weather. The results showed that the mean residue retained after laundering of fabrics exposed to weathering was significantly higher than the mean residue retained after laundering of unexposed fabrics at the 0.05 level of significance (Table XV). Duncan's post hoc analysis was used to differentiate between fabric means. The results of the analysis revealed that fabric means were significantly different for all four fabrics at the 0.05 level (Table XVI).

The overall effect of exposure to weathering prior to laundering showed a decrease in the percentage of pesticide residues removed from fabrics by laundering, as 97.58% was removed from the weather-exposed fabrics when compared to 99.32% removal from unexposed fabrics. The largest effect was observed with denim. After exposure to weather

Table XIV. Means of Captan® Residues Retained by Fabrics and Percentages of Removal by Laundering--Pre- and Postexposure to Weather

Fabric	Preexposure		Postexposure	
	Residue ($\mu\text{g}/\text{cm}^2$)	Removal (%)	Residue ($\mu\text{g}/\text{cm}^2$)	Removal (%)
Denim	0.236	97.76	0.885	91.72
Chambray	0.016	99.84	0.039	99.64
Gore Tex®	0.030	99.70	0.106	99.00
Tyvek®	N.D.* $\approx$ 100		0.006	99.94

*Below the detection limit of the gas chromatograph.

Table XV. Summary of ANOVA for Effect of Exposure to Weather on Pesticide Removal by Laundering

Source	df	Sum of Squares	F
Exposure	1	3.738	51.94*
Fabric	3	26.373	122.14*
Exposure * Fabric	2	0.098	0.68

*Significant at the 0.05 level.

Table XVI. Duncan's Multiple Range Test for Effect of Exposure to Weathering on Pesticide Removal by Laundering

Variable	Pesticide Residue Means ($\mu\text{g}/\text{cm}^2$)	Groupings*
(Fabric)		
Denim	0.560	A
Chambray	0.028	C
Gore Tex®	0.068	B
Tyvek®	0.003	D

*Means with different letters are significantly different at the 0.05 level.

91.72% of the Captan® residue was removed; this was a 6.04% decrease when compared to the 97.76% removed from unexposed denim. A slight decrease, less than 1%, was observed in pesticide removal from chambray, Gore Tex® and Tyvek®, indicating the significant decrease in pesticide removal after exposure to weather conditions was largely attributed to denim.

The influence of weathering on natural fibers has shown that gradual deterioration of the fiber can occur. The degradation can be caused by such environmental factors as sunlight, evaporation and hydrolysis (Schick, 1975). It is speculated that this gradual degradation may have in some way bound the pesticide residue to the cotton fabrics and hence caused the decrease in removal through laundering.

CHAPTER V

SUMMARY AND CONCLUSIONS

The overall objective of the research was to contribute to the development of functionally designed protective clothing by investigating the decontamination of fabrics contaminated with pesticides. The first objective was to evaluate decontamination by determining the effectiveness of laundering on removing pesticide residues as a function of temperature. The second objective was to evaluate the effect of exposing fabrics contaminated with pesticides to weathering conditions and to determine whether this exposure affects removal by laundering. The third objective was to evaluate the effect of storage on fabrics contaminated with pesticides and to determine whether storage affects removal by laundering.

Two pesticide chemicals; Captan®, a chlorinated hydrocarbon, and Guthion®, an organophosphate, were used in the study to determine the effect of temperature on laundering. One pesticide, Captan®, was used in determining the effects of storage and weathering. Four fabrics were used in this study: 100% cotton, denim, 100% cotton, chambray, Gore Tex® and Tyvek®. The fabrics were selected on the premise of evaluating the launderability of fabrics previously used in other segments of the overall research project of developing protective clothing.

The descriptive properties determined for the four fabrics were yarn count, fabric weight and fabric thickness. As this study was

conducted to examine the launderability of selected fabrics the variations in fabric characteristics were accepted and no additional fabric analysis was conducted. The fiber content of the fabrics was considered a determining factor in evaluating pesticide removal since statistical analyses found differences by fabrics to be significant in all cases of evaluating pesticide removal.

To establish the initial amount of pesticide residue contaminating the fabric samples, two replications of fabric type for each pesticide chemical were exposed to the pesticide spray and analyzed before treatments; weather, storage and laundering. The mean contamination was calculated and all further analyses were premised on the notion that an average of pesticide residue extracted from the fabrics for each pesticide was representative of initial pesticide contamination of fabrics for that pesticide.

The level of pesticide contamination after treatment storage and weathering was considered critical to evaluating the effects of storage and weathering on pesticide removal. In the case of treatment storage, at the end of 4 and 7 days of storing fabrics contaminated with pesticides there was a decrease in the level of contamination. This indicated that a change in the chemical and/or physical composition of Captan® residue had occurred over time, explained as a loss due to evaporation and/or hydrolysis of the pesticide.

The result of an analysis to test for differences in the level of pesticide contamination, pre- and post-weathering-treatment, showed that there was no significant difference. Therefore, it was concluded that

the level of Captan® residue on contaminated fabric samples remained virtually unchanged during the treatment exposure to weathering. This indicates that either the pesticide residues of Captan® remained on the surface of the fabrics or that a pesticide chemical/fabric interaction occurred which may have bound the pesticide residue to the fabrics.

Differences in decontamination, i.e., removing pesticide residue by laundering, were dependent on pesticide chemical, water temperature and fabrics. Overall, the laundry procedure removed a lower percentage of residues of Guthion®, an organophosphate, from the fabrics than the percentage of residues removed for Captan®, a chlorinated hydrocarbon. This finding may be attributed to the oil-based composition of the Guthion® 2S formulation.

There was a significant difference in the percentage of pesticide removal among fabrics, differing according to pesticide chemical. The percentages of Captan® residues removed from the 100% cottons, denim and chambray ranged from 72.74% to 99.95% which was significantly lower when compared to the residues removed from Gore Tex® and Tyvek® in which 97.76% to 100% was removed. This may be attributed to the particle size of Captan® 4F formulation being large enough to be trapped in the surface of rougher-surfaced natural fibers than in the smooth synthetic fibers or due to a chemical/fabric interaction which bound the Captan® residues to the cotton fibers.

Guthion® residue was more difficult to remove from Gore Tex® as only 86.44% to 99.49% was removed when compared to 100% cotton, denim and chambray in which 94.26% to 99.94% was removed. To a much lesser

degree the same results were observed for Tyvek® as the laundry process did not result in complete removal of Guthion® residues while, virtually 100% of the Captan® residue was removed from this fabric. The lower percentages of removal of Guthion® from synthetic fibers may be attributed to the interaction of the oil-based nature of the pesticide with the synthetic fibers, nylon and polyolefin. The oleophilic tendencies exhibited by synthetics have been shown to allow oils to soak into their fibrous structure resulting in stains that impair effective cleaning procedures.

There was a significant difference attributable to temperature on removal of pesticide residues for both pesticide chemicals. Overall, an increase in temperature resulted in an increase in pesticide residue removal. The finding of increased pesticide removal with an increase in temperature coincides with the theory that higher temperatures favor increased soil removal. However, an increase in water temperature during the removal process does not fully explain the differences in pesticide removal from the fabrics as a function of temperature. The largest percentage increase of removal with temperature was shown for 100% cottons, denim and chambray. This may be due to an increase in swelling and softening of the cotton fiber leading to a dislodgement of the pesticide particles. Gore Tex® and to a lesser extent, Tyvek® showed a sharp increase in pesticide removal from 38°C to 49°C but a levelling off effect as the temperature increased to 60°C. This is consistent with the theory that increasing the temperature for oily-soils from synthetic fibers increases the amount removed up to a

maximum level, but beyond this level a tapering off effect can eventually lead to a reduction in removal.

The overall effect of storage on Captan® contaminated fabrics prior to laundering was observed to be an increase in the percentage of pesticide residue removal. It was concluded that the pesticide residues had undergone a chemical and/or physical change over time. This change may have been due to oxidation of the pesticide in the presence of air or to hydrolysis in the relatively high humidity of the storage environment. Whatever the mechanism of the change in the pesticide residue the resulting compounds did not interfere with the ease of removal by laundering.

The effect of exposing fabrics contaminated with pesticides to weather conditions prior to laundering indicated a significant decrease in removal in comparison to the removal without exposure. A closer look at the data revealed the significant effect of exposure to weather on pesticide removal was attributed to the removal from 100% cotton denim as a 6% decrease was shown after the treatment weather. This may be attributed to the degradation of cotton during the exposure to weather which has in some way bound the pesticide residues to the cotton fibers and hence resulted in a decrease in removal.

Implication of the Results

The overall objective of the research was to contribute to the development of functionally designed protective clothing by investigating the decontamination of selected fabrics contaminated with

pesticides. If any of the selected fabrics; Tyvek®, Gore Tex®, 100% cottons, denim or chambray were used in the final design of a garment the findings of this study have important implications. The implications pertain to the use and care of clothing that has been worn during pesticide applications and has been contaminated with pesticides. This study was limited to two pesticides, Captan® and Guthion®, therefore, all findings relate directly to these two pesticides but have implications for pesticides in the same chemical classification and/or similar formulations.

Decontamination by Laundering

Pesticide contaminated clothing should be laundered at a wash water temperature of at least 40°C for Tyvek® and Gore Tex® fabrics and 60°C for 100% cottons, denim and chambray.

Storage

The pesticide contaminated clothing may be stored without any adverse effect on the ease of removal of pesticide residues with the following considerations: (1) the contaminated clothing should be laundered before the item is reused, as wearing clothing that has been worn previously during spraying could increase the possibility of pesticide exposure; and (2) clothing used for pesticide applications should be stored in separate storage facilities as the findings of this study indicate that the possibility exists for transfer of pesticide residues to other clothing in the storage environment.

Exposure to Weather Conditions

Pesticide residues deposited on the applicators clothing during an outdoor spraying application may not dissipate to lower and presumable "safer levels" when exposed to environmental factors; sunlight, temperature and humidity. This has implications of secondary exposure, e.g. the use of protective clothing which shields the pesticide applicator from pesticides may create the danger of secondary exposure by transfer of residue to persons who come in contact with the applicator during the time he is wearing the clothing.

Recommendations for Further Research

The present study investigated the decontamination of a select number of fabrics. The study was exploratory in nature and limited in scope, therefore the researcher feels that studies incorporating the following suggestions would contribute to the area of decontamination of fabrics.

1. The biological activity of the residues remaining on the fabrics should be evaluated to determine if the residues remain toxic, hence creating a risk to the potential user.
2. The efficacy of subsequent launderings on the removal of residues retained by the fabrics during this study after one laundry cycle should be evaluated.
3. The storage treatment should be expanded to compare variations in relative humidity level and variations in temperature of the storage environments.

4. A research design to examine the possibility of pesticide transfer during storage, i.e., residues may transfer to clean (uncontaminated) clothing if stored with the family laundry.

5. The weathering conditions should be varied to include higher levels of humidity and temperature vs. lower levels of humidity and temperature, and variations in time of exposure.

6. This type of study should be conducted using other formulations for each of the pesticides as well as other chemicals used in each of the treatments; temperature, storage and weathering.

7. Fabrics other than the four selected for this study should be investigated in a similar decontamination study, such as variations of Gore Tex®, e.g., 100% cotton chambray laminated to the PTFE film.

8. Fabrics other than prewashed fabrics should be investigated in a similar decontamination study, such as fabrics that have been subjected to wear, comparable to those used by the pesticide applicator.

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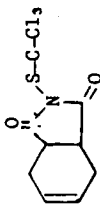
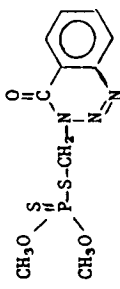
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APPENDICES

APPENDIX A

Table A-1. Chemical and Physical Properties of the Pesticides.

Name	Use	Molecular Formula (Molecular Weight)	Structural Formula	Formulation	Stability	LD ₅₀ (mg/kg)	Toxicity
Captan®	fungicide	C ₉ H ₈ Cl ₃ N O ₂ S (316.59)		4--Flowable (aqueous suspension) a.i. -- 36.4% Related derivatives 2.1% Inert ingredients 61.5%	Subject to degradation in highly alkaline medium	Slightly Toxic* 9,000	
Azinphos-methyl Guthion®	insecticide	C ₁₀ H ₁₂ N ₃ O ₃ P S ₂ (317.33)		2--Soluble Concentrate a.i. -- 22.0% Aromatic Petroleum Distillates 52.0% Inert Ingredients 26.0%	Subject to hydrolysis Relatively stable in alkaline medium	Very Toxic* 16.4	

*By the Gleason-Gosselin-Hodge Scale.

APPENDIX B

Table B-1. Replication Means of Initial Amount of Pesticide Contamination

Fabric	Replication	Captan® ($\mu\text{g}/\text{cm}^2$)	Guthion® ($\mu\text{g}/\text{cm}^2$)
Denim	1	9.585	7.941
Denim	2	10.208	6.562
Chambray	1	11.065	6.732
Chambray	2	10.992	7.258
Gore Tex®	1	10.312	8.399
Gore Tex®	2	9.619	7.669
Tyvek®	1	11.395	8.939
Tyvek®	2	10.766	10.944
Combined Means		10.493	8.056
Standard Deviation		0.672	1.415

APPENDIX C

Table C-1. Captan® Contamination: Pre- and Post-Storage-Treatment

Fabric	Replication	Storage 0 0 day ($\mu\text{g}/\text{cm}^2$)	Storage 1 4 days ($\mu\text{g}/\text{cm}^2$)	Storage 2 7 days ($\mu\text{g}/\text{cm}^2$)
Denim	1	9.585	9.624	8.186
Denim	2	10.208	9.873	8.186
Chambray	1	11.065	9.249	8.891
Chambray	2	10.992	6.966	9.208
Gore Tex®	1	10.312	9.867	9.500
Gore Tex®	2	9.619	9.811	10.468
Tyvek®	1	11.395	11.422	9.286
Tyvek®	2	10.766	10.067	9.993
Combined Means		10.493	9.610	9.246
Standard Deviation		0.672	1.241	.758

APPENDIX D

Table D-1. Captan® Contamination: Pre- and Postexposure to Weathering

Fabric	Replication	Preexposure Pesticide Residue ($\mu\text{g}/\text{cm}^2$)	Postexposure Pesticide Residue ($\mu\text{g}/\text{cm}^2$)
Denim	1	9.585	10.247
Denim	2	10.208	10.423
Chambray	1	11.065	9.915
Chambray	2	10.992	10.250
Gore Tex®	1	10.312	11.173
Gore Tex®	2	9.619	11.017
Tyvek®	1	11.395	11.699
Tyvek®	2	10.766	10.846
Combined Mean		10.493	10.692
Standard Deviation		0.672	0.591

VITA

Elizabeth Pratt Easter was born in Amburgey, Kentucky, on August 28, 1948. She graduated from Carr Creek High School, Carr Creek, Kentucky, in 1966. Undergraduate studies were undertaken at Alice Lloyd College, Pippa Passes, Kentucky and Morehead State University, Morehead, Kentucky. In 1971 she graduated, magna cum laude, receiving a Bachelor of Science degree in Vocational Home Economics from Morehead State University, Morehead, Kentucky. From January 1971 through June 1972 she taught Vocational Home Economics at Hazard High School, Hazard, Kentucky.

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