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THE UNIVERSITY OF ALBERTA

THE EFFECT OF ABRASION ON PESTICIDE PENETRATION THROUGH DISPOSABLE COVERALL FABRICS

BY

(C)

SHERRI MARTIN-SCOTT

A THESIS

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FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled The Effect of Abrasion on Pesticide Penetration Through Disposable Coverall Fabrics submitted by Sherri Martin-Scott in partial fulfilment of the requirements for the degree of Master of Science in Clothing and Textiles.

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ABSTRACT

The durability of disposable coveralls must be examined before recommendations can be made about their use by farmers working with pesticides. The purpose of this study was to examine the effect of abrasion on the penetration of tri-allate through two disposable coverall fabrics: 1. Kleenguard® EP and 2. Tyvek®; both are 100% spunbonded olefin fabrics.

Testing was conducted on two laboratory instruments: 1. the Brush Pilling Tester; and 2. the Taber Abraser in order to establish laboratory abrasion which simulated abrasion observed on Kleenguard® EP coveralls after 12 hours' use in a field trial. The laboratory abrasion was evaluated through tensile strength tests and visual observations of scanning electron microscope photos. The Brush Pilling Tester produced abrasion on Kleenguard® EP more similar to that observed on field trial garments than did the Taber Abraser. Saranex®-coated Tyvek®, also included in the abrasion testing, was removed from the study because the Brush Pilling Tester only scratched its surface. Tyvek® and Kleenguard® EP specimens abraded at 0, 3 and 6 minutes on the Brush Pilling Tester were contaminated with 0.5 mL of a field strength dilution of tri-allate. The percentage of pesticide penetration through the coverall fabric to a 100% cotton under layer was analysed by gas chromatography.

The mean percentage of tri-allate which penetrated

both fabrics was less than 1%, even after abrasion. The penetration of tri-allate through Tyvek®, however, was about three times higher than the penetration through Kleenguard® EP. There was a significant increase in the penetration of tri-allate through Kleenguard® EP as the level of abrasion increased. For Tyvek®, there was no significant difference in pesticide penetration at all three levels of abrasion.

Pesticide penetration increased significantly when the initial thickness of unabraded Kleenguard® EP decreased, but there was no correlation between thickness and penetration when the fabric was not abraded. At all three levels of abrasion on Tyvek®, pesticide penetration increased as the initial thickness of the specimen decreased. There was no significant correlation between the initial weight of the specimen and pesticide penetration for either fabric.

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1. INTRODUCTION

1.1 Background

"Pesticide" is a general term for a wide variety of chemical compounds which are used "for controlling, preventing, destroying, repelling or mitigating any pest" (Ware, 1978, p.9). Pesticides are classified according to their use or the group of organisms they are designed to control. The major classes of pesticides include insecticides, herbicides and fungicides: these control insects, plants and plant diseases respectively.

Over the last four decades, agricultural technology has depended increasingly upon the extensive use of pesticides. In the United States, 196.4 million kilograms of herbicides and 26.8 million kilograms of insecticides were used on crops in 1982 (Young, 1987). In 1985, Canadian farmers spent approximately $689 million [illegible] pesticides (Agriculture Economic Statistics, 1987). The benefits of pesticide use in agriculture are high crop yields, blemish free produce and decreased losses during growth, harvesting and storage. Pesticides are justified as indispensible components of a crop production program designed to provide the nutritional needs of a rapidly growing world population (Ware, 1978; Barrons, 1981). But there are also risks involved in the heavy application of pesticides. The individuals who formulate, manufacture, mix and load, and apply pesticides, as well as those who harvest by hand, comprise the group at greatest risk of both acute and chronic pesticide poisoning because they experience repeated exposure to the toxic chemicals (Easter, 1982). This high-risk group is very large; in the United States, an estimated four to five million agricultural workers come into direct contact with pesticides (Sinclair, 1985). This figure excludes those individuals involved in pesticide manufacture.

The relationship between pesticide use and cancer has been the subject of several investigations. Burmeister, Everett, Van Lier and Isacson (1983) linked elevated cases among Iowa farmers of non-Hodgkin's lymphoma (NHL) to herbicide use and multiple myeloma to herbicide and insecticide use. Kansas wheat farmers who mixed and applied herbicides themselves and those who did not wear protective equipment had higher rates of NHL. The risks also increased as the years of herbicide use and the number of days of pesticide exposure per year increased (Hoar et al., 1986). A high use of insecticides and herbicides by Wisconsin farmers was significantly related to an elevated incidence of reticulum-cell sarcoma, a subtype of non-Hodgkin's lymphoma (Cantor, 1982).

The public has become increasingly concerned about the possibility of cancer and other chronic effects resulting from residues of pesticides in food. The adverse effects of pesticides on soil fertility and non-target organisms are major concerns as well (Barrons, 1981). Silent Spring (Carson, 1962) was one of the earliest documentations of the dangers of massive pesticide use. Carson states, "we have put poisonous and biologically potent chemicals into the hands of persons largely or wholly ignorant of their potential for harm ... [and] we have allowed these chemicals to be used with little or no advance investigation of their effect on soil, water, wildlife and man himself" (p. 12).

By definition, pesticides are poisons, but the degree of toxicity to humans varies greatly among the classes of pesticides and the mechanisms by which the particular chemical compounds produce their effects. Of the major classes of pesticides, insecticides are most toxic to humans because they are animal poisons and man belongs to the animal class (Hussain, 1983).

The toxicity and chronic effects of pesticides are determined through various experiments on animals and the results of the tests are extrapolated to humans. Toxicity is expressed as the LD_{50} which "is the one single dose of the pesticide that will kill 50% of a group of test animals when the pesticide is given ... orally .... The LD_{50} is usually measured as the amount in milligrams of active ingredient of the nearly pure pesticide per kilogram of body weight of animal" (Hussain, 1983, p. 1). The lower the LD_{50}, the higher the toxicity and the lower the safety of the pesticide. The symptoms of pesticide poisoning vary from mild reactions (headaches, skin rashes, and nausea) to severe reactions (vomiting, change in heart rate, convulsions and even death) (Hussain, 1983). These reactions generally occur within 12 hours of exposure. Little is known about the long term effects of continued exposure to small quanities of pesticides.

Undoubtedly, pesticides will continue to play a major role in agricultural production, but the reduction of the adverse effects of pesticides on humans and the environment is of vital importance. A reduction may be achieved in part through the discovery and utilization of more effective, more selective and safer pesticides and the increased use of integrated pest management programs which utilize timed pesticide applications for increased effectiveness, along with cultural, biological and genetic methods of pest control (Barrons, 1981).

It is also imperative that the accidental exposure of pesticide workers be reduced. The effect of pesticides on the health of agricultural workers in particular has become a significant governmental and public concern. Researchers perceive the need to provide adequate guidelines and recommendations for the selection and care of clothing worn by pesticide workers in order to increase the occupational health and safety of these workers.

1.2 Pesticide Exposure and Absorption

Exposure to pesticides occurs through (1) inhalation; (2) ingestion; and (3) skin absorption. Wolfe, Durham and Armstrong (1967) determined that the principal route of exposure is through the skin; they claim the amount absorbed in the respiratory tract is generally much less than that absorbed dermally. Although chemicals which are inhaled are absorbed more rapidly and more completely than those absorbed through skin surfaces, the respiratory exposure for various work situations ranges from only 0.02% to 5.8% (mean 0.75%) of the total exposure, that is, dermal exposure accounts for approximately 95% of the total exposure (Wolfe et al., 1967). Maibach, Feldmann, Milby and Serat (1971) determined that although the degree of penetration varied for different parts of the body, "all anatomic sites studied show significant potential for penetration of pesticides and, hence, systematic intoxication" (p. 211).

Dermal contamination can occur in two ways. Either the pesticide comes into direct contact with exposed skin or the pesticide is absorbed into skin that is in contact with contaminated clothing. In this way, clothing is an important factor in dermal exposure. It can protect the body by providing a barrier between the skin surface and the chemical. If it is contaminated, however, clothing can contribute to dermal absorption and contamination long after application has ended. Clothing has been found to pick up and retain pesticide residues from spray and drift during the application process (Findley & Rogillio, 1969; Freed, Davies, Peters, & Parveen 1980). Also, Wicker, Williams, Bradley and Guthrie (1979) found that clothing worn by cotton scouts became contaminated with pesticide residues dislodged from foliage. The pesticide may remain biologically active in the clothing (Freed et al., 1980). Residues of toxaphene, DDT and methyl parathion remained biologically active even after three launderings (Finley, Metcalfe, McDermot, 1974). The clothing worn by the pesticide worker does have an effect on the degree of dermal exposure that is experienced.

Protection from accidental exposure is vitally important for pesticide workers, but for a number of reasons, a fully effective protective program has not yet been achieved. First, many pesticide workers do not sufficiently reduce their exposure when using pesticides. Typical workers wear ordinary work clothes when handling, mixing ~~and~~ applying pesticides (Davies, Enos et al., 1982; Branson, DeJonge & Munson, 1986). Recent research findings suggest that the ~~typical~~ clothing worn by pesticide workers may not provide adequate protection (Orlando, Branson, Ayres & Leavitt, 1981; Wicker et al., 1979). Second, specially designed protective clothing is recommended, but the ideal protective garment has not yet been designed. Totally encapsulating suits of a moisture impenetrable substance would offer the highest level of protection

(Stull, 1985), but they are neither comfortable, economical nor functional; all of these are important characteristics in protective clothing. Third, any clothing worn while working with pesticides should be decontaminated after use; however, not all pesticides are readily removed from regular work clothing or specially designed protective clothing by cleaning (Easter, 1983; Finley & Rogillio, 1969; Kim, Stone, Coats & Kadolph, 1986). Further research must be conducted to provide adequate guidelines and recommendations for the selection and care of clothing worn by pesticide workers.

These issues explain the parameters of the research that has been conducted on protective clothing for pesticide workers. Some studies centre on the typical clothing worn by pesticide workers to determine what the dangers of contamination are and to see what laundry procedures best remove pesticides from contaminated clothing. Other research tests a variety of fabric structures to determine which types provide the most protection, with the aim of producing recommendations about the type of clothing that should be worn. Recently, attention has been focussed upon the use of disposable or limited-use, nonwoven coveralls for work with pesticides. There are many reasons for the interest in disposable garments. These coveralls provide an extra layer of protection, but are lighter in weight, and hence more comfortable and functional than traditional impermeable protective clothing; they exhibit a high degree of resistance to chemical penetration; they are economically priced; and they do not require decontamination (Moraski & Nielsen, 1984).

The advantages of disposable coveralls do make them seem extremely attractive for use with pesticides; however, there are still some questions which must be answered before knowledgeable recommendations can be made about their use. In Alberta, depending upon the size of a farm, pesticide application may continue for 2-3 days or up to a week at a time. It does not seem unreasonable to assume that a worker may wish to wear the same disposable coverall for this period and then discard it. If this is the case, how does wear affect the resistance to penetration of these garments? What is the effect of abrasion on pesticide penetration? For what length of time or to what point of wear or abrasion is the original level of protection maintained?. The durability of disposable coveralls for this end use must be examined.

The purpose of this study was to examine the effects of abrasion on the penetration of a liquid pesticide formulation, tri-allate, through selected disposable garment fabrics. Two disposable garment fabrics were chosen for the study: Kimberly-Clark's Kleenguard® Extra Protection (EP) fabric and Tyvek®, a trademark of Du Pont. Saranex®-coated Tyvek® fabric was also included in abrasion testing, because both Saranex® and Kleenguard® EP are recommended by the manufacturers for use with liquid chemicals and pesticides. Of the many disposable garments which are now marketed, those made from Kleenguard® EP and Tyvek® were chosen because both types of garment were determined, in a preliminary survey, to be readily available to Alberta farmers from local stores. Also, the relationship between pesticide penetration and abrasion has not been reported for either fabric. The study of this relationship contributes to previous research on nonwoven disposables.

This project addresses two areas which Moraski and Nielsen (1984) indicate are current research needs in protective clothing for pesticide workers. The research needs are stated as follows: (1) To conduct laboratory evaluation of the permeability and penetration of various fabrics by different classes of pesticides and formulation types. The pesticide chosen for this study, tri-allate, has not been used previously in penetration studies. (2) To determine the effects of material durability and degradation or wear on the efficacy of protective clothing.

1.3 Problem Statement

To determine the effect of abrasion on pesticide penetration through selected disposable garment fabrics.

1.4 Objectives

The primary objective of this research is to contribute to the development of recommendations and guidelines for the selection and care of clothing for pesticide users.

The specific objectives are as follows:

1. To compare the effectiveness of two abrasion instruments, in terms of tensile strength tests and visual appearance, at simulating field trial abrasion.

2. To use one laboratory abrasion instrument to produce two levels of abrasion which simulate moderate and severe levels of abrasion on field trial garments.

3. To determine the effect of three levels of abrasion on the penetration of a liquid pesticide formulation through selected disposable garment fabrics.

4. To compare the resistance to penetration of two disposable garment fabrics.

5. To determine the relationship between the initial weight of the fabric specimen and pesticide penetration.

6. To determine the relationship between the initial thickness of the fabric specimen and pesticide penetration.

1.5 Assumptions

1. The pesticide and concentration used in this study are representative of those used commercially in agricultural production.

2. The contamination procedure approximates a liquid spill or splash which may occur during mixing and loading of pesticides prior to field application.

1.6 Limitations

1. Only one pesticide and one formulation were tested.

2. Only a field strength dilution of the pesticide formulation was tested.

3. Only two disposable garment fabrics were tested.

4. Only one underlayer fabric was used.

5. Because of the complex nature of abrasive wear, the abrasion produced in this study cannot predict, or be equated to, actual wear effects in specific end uses.

6. The effect of the pressure of spray on penetration is not addressed by the contamination procedure used.

2. REVIEW OF LITERATURE

The purpose of this study was to examine the effects of abrasion on the penetration of a liquid pesticide formulation through selected disposable or limited use garment fabrics.

The literature review is composed of three sections. In the first section, reasons for the recent interest in disposable garments for pesticide workers are presented. In the second section, penetration is defined, the factors which affect penetration are discussed, and the methods used in penetration studies to contaminate specimens are reviewed. The third section includes a definition of abrasion, as well as a discussion of the types of abrasion, the effects of abrasion on fibers, yarns, fabrics and finishes and a discussion of relevent abrasion studies. Also, the limitations of abrasion test methods are presented.

2.1 Disposable Garments

In most cases, the garments which are classified as "disposable" are constructed from spunbonded, nonwoven fabrics of olefin fibers: polypropylene or polyethylene. The fabrics, which are produced directly from fibers rather than yarns, are manufactured rapidly and economically and therefore are suitable for using once and then discarding (Joseph, 1981). An alternative name, "limited-use garments," emphasizes the fact that the garments are not made to be durable for more than a limited wearing time.

Recently, researchers have become increasingly interested in the use of disposable coveralls for pesticide workers. In 1984, Laughlin, Easley, Gold and Hill stated that disposable coveralls are a means of protection which should be considered for the pesticide applicator. Orlando et al. (1981) tested the pesticide penetration of two disposable garment fabrics, Tyvek® (spunbonded, 100% polypropylene) and Crowntex® (a single ply polypropylene web laminated between two layers of facial grade tissue). In 1986, Branson et al. designed and tested three prototype protective garments for pesticide users. One of the test fabrics was Tyvek®. Nonwoven fabrics have been tested for their resistance to penetration of pesticide laden soil dust (Kawar, Gunther, Serat and Iwata, 1978). Staiff, Davis and Stevens (1982) evaluated the resistance to pesticide penetration of four types of lightweight spunbonded olefin (SBO) fabrics. The olefin fabrics are described as "ordinary white SBO, white and yellow SBO coated with polyethylene and perforated SBO" (p. 392). In the same study, jackets made from the white SBO, the yellow polyethylene coated SBO and a white, lightweight, water repellent cellulostic [sic] were worn in a field test to determine worker acceptance. Lloyd, Bell, Howarth and Samuels (1985) evaluated Kleenguard® Extra Protection (EP) coveralls for the protection of pesticide spray operators. In pesticide penetration studies, Hobbs (1985) included seven types of nonwoven fabrics and Leonas (1985) included six nonwoven fabrics.

There are a number of reasons for this recent research on disposable garments. First, the definition of protective clothing for pesticide workers previously included the recommendation that the clothing be of a washable fabric (Easter, 1983); however, research has not yet developed procedures for decontamination which are effective for all pesticide classes, formulations and strengths in combination with all fabric and fiber types. Second, in studies of pesticide penetration through garment fabrics, nonwoven disposable fabrics generally have achieved much greater resistance to penetration than regular clothing fabrics. Third, in wear trials, lightweight disposable garments are more comfortable than vinyl coated impermeable garments.

2.1.1 Decontamination of pesticides from fabric

Various care procedures have been examined to determine which are most effective in pesticide decontamination. The care procedures include laundry variables such as wash temperature (Easley, Laughlin, Gold & Schmidt, 1982; Easter, 1982; Kim et al., 1986; Lillie, Livingston & Hamilton, 1981; Rigakis, 1985), detergent type (Easley, Laughlin, Gold & Schmidt, 1982; Kim et al., 1986), pretreatments (Kim et al., 1986; Rigakis, 1985), prerinses

(Janacek, Fleeker, & Olsen, 1984) and multiple washes (Finley, Metcalfe, & McDermott, 1974; Rigakis, 1985). Variations in drying (Fehringer, 1985) and storage techniques (Fehringer, 1985; Kim, Stone & Sizer, 1982) have also been researched. The combined results of these tests are inconclusive. No one decontamination system has been found which is effective for all pesticides tested. Research continues to be conducted in search of the most effective decontamination techniques.

Since decontamination studies cannot be conducted for all types of pesticides, researchers have attempted to simplify the issue by determining whether pesticides within chemical classes exhibit similarities in their ease of removal from fabrics. Keaschall, Laughlin and Gold (1984) studied the removal during laundering of three chemical classes of insecticides: organophosphates, carbamates and organochlorines. The results were inconclusive. In general, the relative difficulty of removal is organochlorines > organophosphates > carbamates, but there were also significant differences between pesticides within each class. Easley, Laughlin, Gold & Tupy (1981) studied three formulations of pesticides. They found that the emulsifiable concentrate (EC) formulation was more difficult to remove than the wettable powder or encapsulated formulations. Researchers are now concluding that the water solubility of the formulation is an important factor in laundry removal (Keaschall, Laughlin &

Gold, 1984). The emulsifiable concentrate is an oil-based formulation, which is difficult to remove by laundering because of its low water solubility. In most laboratory studies field strength dilution of the pesticide is used. In the concentrated form, less than 20% of methyl parathion was removed by laundering (Easley, Laughlin, Gold, & Hill, 1982). As a result, recommendations have been made that clothing contaminated with concentrated pesticide formulations should be discarded. Although these studies are not extensive, they do suggest that simple decontamination recommendations which apply to all pesticides cannot be made.

Effective decontamination procedures also vary with fabric geometry and fiber content. There is some indication that pesticide removal from fabric is dependent upon factors similar to those affecting the removal of other soils. The oleophilic or hydrophilic characteristic of the fiber type affects the retention of oily or water based soils. Easter (1983) found that Goretex® (a three layered fabric of polytetrafluoroethylene film laminated between woven nylon and a nylon tricot liner) retained more Guthion® (an oily based EC insecticide) than did cotton. In contrast, 100% cotton fabric retained more Captan® (a fungicide in an aqueous suspension of particles) than did the Goretex® fabric. The clay-like particles in the formulation of Captan® may have become bound to the cotton. The surface of a cotton fiber has many crevices where particulate soil may become trapped. The oil based Guthion® was bound to the oleophilic, hydrophobic nylon outer layer of Goretex®.

Fabric geometry, including factors such as fabric weight, weave structure and yarn twist, contributes to the ease of pesticide removal in laundering. Kim et al. (1982) found that alachlor was more readily removed from lightweight cotton than from heavyweight cotton. These limitations and problems of decontamination demonstrate one reason for the interest in disposable garments. A garment which can be discarded after use will avoid the decontamination issue effectively.

2.1.2 Pesticide penetration through disposable coveral fabrics

The resistance of a fabric to penetration of pesticides is an important factor in dermal protection for pesticide workers. In several studies, nonwoven disposable fabrics have provided greater resistance to pesticide penetration than fabrics typical of regular work clothing. Orlando et al. (1981) tested the penetration of the insecticide Guthion® through seven fabrics. Included in these fabrics were 100% cotton chambray (a typical shirt fabric) and Tyvek® (a spunbonded olefin). The Tyvek® fabric gave about 25 times more protection than the 100% cotton. Staiff et al. (1982) included four types of spunbonded olefins (SBO) and a pant weight 10 oz. cotton drill in a study on pesticide penetration. The mean penetration by eight pesticide sprays applied as light and heavy drifts was significantly less for the regular SBO and the white polyethylene-coated SBO than the cotton. However, the yellow polyethylene-coated SBO and the perforated SBO did not provide resistance to penetration equal to the cotton fabric. In this study, no one fabric resisted all formulations of all eight pesticides tested. Penetration appeared to depend upon the active ingredient, the formulation and application regimen of the pesticide, as well as the fabric type. Stull (1985) observed that no one suit material has been developed which will resist all chemicals.

Kawar et al. (1978) tested knitted, woven and nonwoven fabrics for their resistance to pesticide laden dust particles from soil and foliage. The knitted fabric allowed dust penetration of 87% to 96% and the woven fabric allowed 0.3% to 5.8% penetration. The nonwovens allowed less than 0.5% of the dust through.

Hobbs (1985) determined that, of seven nonwoven and four woven fabrics tested, spun-laced nonwovens with a fluorocarbon finish were resistant to aerosol penetration by both water-base and oil-base spray emulsions. In a study conducted by Leonas (1985) two spunbonded olefin fabrics with impermeable coatings (Saranex® and polyethylene) provided excellent protection against all four pesticides tested. Both an untreated, nonwoven 100% spunbonded olefin (Tyvek®) and a three layer composite nonwoven of spunbonded/ meltblown/ spunbonded (SMS) polypropylene fibers, with a fluorocarbon finish provided excellent resistance to two pesticides.

In summary, the potential for nonwovens to provide more dermal protection than regular work clothing is an important reason for their use in protective clothing for pesticide workers.

2.1.3 Worker acceptability

Traditionally, protective clothing for pesticide applicators has consisted of: rubberized cotton coveralls or raingear; vinyl coated nylon garments (Staiff et al., 1982) or polyvinyl chloride (PVC) coated jackets and trousers (Norton and Drake, 1985). Although these fabrics provide much greater protection from pesticide penetration than regular work clothing (Davies, Enos et al., 1982) the vapour impermeable garments become very uncomfortable in hot temperatures. As a result, there is a tendency for workers to discard the garments in hot conditions and risk pesticide poisoning. Staiff et al. (1982) claim that "spraymen ... would rather risk exposure to pesticides than swelter in misery and risk possible heat stroke due to wearing conventional protective clothing" (p. 391). Similar attitudes were discovered by Henry (1980): Michigan fruit growers, fully aware of the hazards of handling pesticides, refused to wear protective clothing because currently available garments lacked thermal comfort. Branson et al. (1986) summarized the problem by noting that "there is a need for clothing that offers thermal and social acceptability as well as chemical protection to those individuals occupationally exposed to pesticides" (p. 27).

Several studies have been conducted to determine the physical and perceptual thermal comfort of various disposable garments. Staiff et al. (1982) distributed white spunbonded olefin (SBO), yellow polyethylene coated SBO and white, lightweight, water repellent cellulostic [sic] jackets to orchard applicators for evaluation during use. The white SBO and the cellulostic jackets were perceived to be very comfortable. Although the polyethylene coated SBO jackets were considered to be cooler than conventional protective garments, some users reported that these jackets were still too hot to be worn in very high temperatures. In preliminary testing, however, Kawar et al. (1978) found coveralls made from one nonwoven fabric to be no less comfortable than light weight cotton work clothes. The nature of the comfort tests and the fiber content of the fabric were not stated in the report. In a user evaluation of Tyvek®, Stormshed® (a composite fabric containing vapor-permeable polyurethane film) and Goretex® (a composite fabric containing a vapor-permeable fluorocarbon film), the Tyvek® garments were considered highly satisfactory (DeJonge, 1983). Branson et al. (1986) evaluated the thermal response of subjects to prototype garments of Tyvek®, Goretex® and 100% cotton chambray. Thermal response was measured in a controlled environmental chamber by physiological measures of skin and rectal temperatures and two perceptual measures of thermal sensation and thermal comfort. In this study, Tyvek® was perceived as being less comfortable than Goretex® and cotton. The results of the physiological tests correlated well with the perceptual tests: the subjects wearing Tyvek® garments exhibited significantly higher skin temperatures than subjects wearing Goretex® and cotton. In contrast, there was no significant difference in mean skin temperatures and mean thermal comfort responses for subjects wearing the Goretex® and cotton garments. The excellent test results of Goretex® have caused many researchers to become interested in this fabric for protective garments. Goretex® has been shown to be a good barrier to several pesticides, but decontamination can be a problem (Easter, 1983), and because the fabric is expensive, it cannot be considered disposable. In a laboratory analysis of the thermal comfort of fabrics, spun-laced nonwoven fabrics with a fluorocarbon finish ranked highest in terms of water vapour permeability and air permeability in a test of 7 nonwoven and 4 woven fabrics (Hobbs, 1985).

The advantages of disposable garments for pesticide workers cannot be denied: they do not require decontamination after use; they are relatively comfortable; and their resistance to penetration of pesticides is good. Despite these advantages, two limitations of disposable coveralls must be observed. First, proper use of these garments for pesticide spraying purposes would require disposal at an adequate waste disposal site. It would be most logical and convenient to dispose of the garments in the same locations where empty pesticide containers are disposed. Second, these garments cannot be considered the solution to all situations. Freed et al. (1980) observed that a limited-use garment is not appropriate to the needs of all users. They state, "the clothing is intended for relatively few wearings and then [is] discarded. Such practice would probably be followed for the most part in the affluent western countries such as the United States, but may not be observed in the less developed countries of the world where conservation and reuse are an economic necessity" (p. 160).

2.2 Penetration of Pesticides Through Fabric

In most studies, the penetration of the pesticide formulation through a fabric structure is defined as the amount of the applied pesticide which passes through the upper layer fabric--the fabric being tested--and is deposited on an underlayer (Laughlin et al., 1984). The penetration of a liquid through a fabric structure is dependent upon (1) the interfacial surface tension between the liquid and the fabric and (2) capillary forces or wicking.

2.2.1 Interfacial tension

Orlando et al. (1981) state that the "interfacial tension between fabric surfaces and the pesticide emulsion can influence passage of pesticide sprays" (p. 627) through fabric structures. They discovered that pesticide penetration through fluorocarbon treated 100% cotton chambray was significantly less than through the untreated chambray. In explanation of this finding, they stated, "fabric with a fluorocarbon finish will lower the surface free energy of the fabric structure, thereby increasing the difference between the surface energy of the pesticide spray and the fabric. The increase in the interfacial tension between the two substances should decrease the likelihood of penetration" (p. 627).

Interfacial tension describes the forces which act at the junction between phases (Trottman, 1975). The surface area of a liquid, in an air/liquid interface, is characterized by "unbalanced forces of molecular attraction" which cause "the molecules at the surface [to be] attracted into the body of the liquid because the attraction of the underlying molecules is greater than the atraction by the vapor molecules" (Daniels & Alberty, 1966, p. 277). The cohesive forces of the liquid reduce the surface area and produce an arrangement of low free energy (Barrow, 1973). In a similar way, a high interfacial tension between a liquid and a fabric surface means that the attraction between adjacent liquid molecules is greater than the attraction between the liquid and the fabric surface. The liquid beads up on the fabric surface and little wetting occurs. The opposite is true for low interfacial tension. In this case, the liquid spreads out over the surface. Measurement of the contact angle between a liquid droplet and a fabric surface is a means of quantifiying the interfacial tension between the liquid and the fabric. The size of the angle determines the wettability of the material by the liquid. Leonas (1985) found that spray ratings of droplet size and formation and the surface energy of twenty-three fabrics did not necessarily predict pesticide penetration rates. She hypothesized that this inconsistency may have been due to testing procedures. Penetration is also a function of time. The repellency test rating and the surface energy were determined within 30 seconds while the penetration was measured after one hour. Leonas also found that a fluorocarbon finish did not increase resistance to pesticide penetration for all fabrics or all pesticides and in explanation, she suggested that the surface energy was not altered in all cases. Other researchers have studied the ability of a repellent finish to reduce pesticide penetration through a fabric structure (Davies, Freed et al., 1982; Freed et al., 1980). The Kleenguard® EP fabric used in this study has an oil-water repellent finish.

2.2.2 Capillary forces and wicking

Penetration of a liquid pesticide formulation through a fabric structure depends in part upon capillary action. Most fabric structures contain very small channels between fibers and yarns, and a liquid can force its way into these capillaries (Morton & Hearle, 1975). Orlando et.al. (1984) state "the process of penetration through the interior yarns of a fabric is largely governed by capillary forces owing to the tight packing of fibers; the yarns act as wicks" (p. 619). Raheel and Gitz (1985) define wicking as the rate at which "a fabric transports liquid water (or solution) from one surface to the other. It involves migration of a liquid vertically through the interfiber and interyarn capillaries of the fabric" (p. 276).

The rate of wicking is affected by the weave of a fabric. Orlando et al., (1981) state that "a tightly woven fabric with long smooth fibers 'wicks' more quickly and easily than a fabric with either randomly arranged fibers in its yarns or in fabrics without yarns" (p. 619). This effect of fabric weave on wicking was observed by Raheel and Gitz (1985). They observed that "after 10 min., cotton broadcloth exhibited a statistically significant ... higher wicking level in both warp and filling directions compared to twill and poplin" (p. 276). Of these three fabrics, the broadcloth had the tightest weave. Leonas (1985) observed that the meltblown layer of microfine fibers in one nonwoven fabric she tested may trap the pesticide to prevent its movement through the fabric.

2.2.3 Other factors in penetration

Other factors are known to affect the penetration of liquids through textile structures. These factors are: the droplet size, velocity and pressure of the liquid and time of contact between the liquid and the surface. Orlando et al. (1981) hypothesized that body perspiration and abrasion may affect penetration levels. They also considered the effect of the underlayer on penetration, suggesting that some fabrics, such as gauze, may increase wicking through the upper fabric. Laughlin et al. (1984) found a higher level of pesticide deposition on sweatshirt fabric than any other underlayer fabric evaluated in their study. They proposed that the acrylic/cotton fabric, known for good wicking tendencies, enhanced the movement of pesticides from the outer garment layer to the underlayer.

2.3 Methods of Specimen Contamination

Research procedures used to collect pesticide penetration data include both field tests and laboratory experiments. Although both field studies and laboratory studies are valuable methods of data collection, they may not produce similar results. Orlando et al. (1981) observed that a "laboratory method of comparing fabric penetration does not replicate field evaluations" (p. 628). The field study is employed because contamination occurs in a realistic situation and the amount and distribution of the contaminant can be assessed. However, it is not possible to control the amount of contamination each specimen receives. In field tests, patches of gauze or fabric (Serat, Van Loon & Serat, 1982), blotter paper (Hansen, Schneider, Olive & Bates, 1978), filter paper (Norton & Drake, 1985) or alpha cellulose pads (Davies, Freed et al., 1982) are attached to the outside and/or inside of subjects' clothing. The specimens become contaminated as the subject proceeds through the activities of a typical work routine. Serat et al. (1982) demonstrated that patches used in field studies are not "reliable collectors of impinging pesticide sprays or disloged foliar residues" because "substantial quantities of the chemicals [are lost] within four to six hours" (p. 227).

The advantage of laboratory studies is that the variables affecting penetration are known and can be controlled. Primarily, two methods of specimen contamination are used in laboratory studies on pesticide penetration. A quantity of the liquid formulation is either (1) sprayed or (2) pipetted onto the specimen. Orlando et al. (1981) developed the "Beltsville Experimental Sprayer" in an effort to establish a standardized, reproducible laboratory method to measure pesticide penetration. In this system, 0.5 ml of spray is deposited on each specimen as it moves along a conveyor belt. The spray continues for 9 seconds. An improved version of this chamber was used by Leonas (1985). Other spraying systems are used by Freed et al. (1980), Staiff et al. (1982) and Davies, Enos et al. (1982). All researchers employed a timed application of the spray. These spraying techniques are designed to simulate contamination which may result from pesticide spray during application.

Laughlin et al. (1984) contaminated specimens by pipetting 0.2 ml of the pesticide formulation onto the fabric surface. The technique simulated contamination which may occur from liquid spills or splashes during mixing and loading procedures prior to application. Pipetting and spraying procedures test the penetration of liquid pesticide formulations through fabric structures. Kawar et al. (1978) tested the penetration of pesticide particles by shaking pesticide contaminated dust through fabric specimens stretched in a holder.

2.4 Abrasion

Stanley Backer (1951) defined abrasion by establishing a distinction between the "serviceability" and "abrasion resistance" of fabrics, stating that "serviceability should relate to the overall durability of textile materials under conditions of intended use. 'Abrasion resistance', on the other hand, should be restricted in meaning to the ability of a fabric to withstand direct rubbing under conditions of intended use" (p. 453). In this definition, abrasion is only one of the factors which contribute to the wear performance or durability of a material. NcNally and McCord (1960) define abrasive wear as "the physical destruction of fibers, yarns and fabrics resulting from the contact with and relative motion of a textile surface over that of another surface" (p. 721). While the two previous definitions emphasize a rubbing contact between surfaces in the definition of abrasion, Booth (1969) describes it in a more general sense: abrasion is the repeated application of stress. Sarma, Maji, Ranganathan and Chipalkatti (1968) observe that in wear conditions, abrasion may or may not be the predominant factor in fabric failure. They call this the "weakest link principle" (p. 701). Failure of the fabric is determined by the feature which fails first. Depending upon fabric characteristics such as tensile strength or tear strength, the weak point will vary from one fabric to another. In summary, abrasion is one of the stresses that a textile is exposed to, which ~~may~~ or may not predominate in the serviceability or durability of that textile.

2.4.1 Types of abrasion

Fabrics can be subjected to three types of abrasion: flat or plane abrasion; flex abrasion; and edge abrasion (Joseph, 1981). Flat or plane abrasion occurs when a flat area of the material is rubbed. Flex abrasion results from the repeated flexing or folding of a fabric upon itself or other fabrics. Edge abrasion, which occurs at areas like collars, folds and cuffs, is affected by the same factors applicable to both flex damage and the rubbing of a flat surface (Booth, 1969; Joseph, 1981). In a garment, a complex mixture of all types of abrasion occurs.

2.4.2 Effects of abrasion

Abrasion causes the component fibers and yarns of a fabric to break down. The effects on fabric structure can include: frictional wear, cutting, and plucking or snagging of fibers and yarns (Galbraith, 1975). Fibrillation and transverse cracking may also occur in the fibers and eventually, as the yarns are rubbed away, tears, holes and splits occur in the fabric. Abrasion may cause a repellent finish on a fabric to wear away, and as a result, penetration may occur more readily (McNally & McCord, 1960). Pilling is a common effect of abrasion, most often associated with synthetics and staple fib[illegible] Both the conditions and type of abradant as well as fabric characteristics will affect the type of damage which occurs to the fabric structure.

2.4.3 Factors affecting abrasion

Characteristics of the Abradant. In his classic work on abrasion, Backer (1951) stated that characteristics of the abradant will affect the kind of abrasion that is produced; he described three types of abradants. First, an abradant with a smooth surface will subject the fiber to frictional wear. Kirkwood (1974) called this type of abrasion adhesive wear. Second, an abradant with sharp but small surface projections relative to the fiber diameter will cause surface cutting of the fibers. And third, when the surface projections of the abradant are large compared to the fiber diameter, the fibers will be plucked, causing rupture of the fiber or slippage from the yarn (p. 455). It is in this latter case that pilling can occur. Several researchers observed that pilling occurred when fibers, particularly synthetic fibers, were teased up out of the fabric structure. Instead of breaking off or wearing away with increased abrasion, these plucked fibers tangled to form pills (Galbraith, et al., 1969; Warfield et al. 1977).

Characteristics of the Fabric. Various characteristics of the fabric also will affect the abrasion which results. Backer and Tanenhaus (1951) argued that the degree of abrasive wear between two surfaces is dependent upon the load between them and when fabric characteristics such as weave structure, yarn diameter, fabric thickness, yarn twist and crimp interchange contribute to reduce the load, the amount of abrasion that is produced will be affected. Ericson and Baxter (1973) related the fabric structure of spunbonded nonwoven fabric to abrasion resistance. They measured filament separation, which is the distance between fibers in the spunbonded web. It is the filament separation which affects the uniformity or non-uniformity of the web. High "blotch" areas and "ropes" can occur where filaments are massed together; on the other hand, thin areas occur where filaments are spread apart. The data were somewhat scattered, as is typical of abrasion results, but an approximately linear relationship was established between abrasion resistance and filament separation.

Fabric characteristics have also been associated with pill formation: "the formation of fuzz has been attributed to interfiber friction and bending stiffness of fibers; the entanglement of fibers is strongly affected by fiber linear density, cross-sectional shape, and stiffness and the pill wear-off is influenced by the abrasion resistance, bending stiffness and flex-life of fibers" (Goswami et al., 1980). Galbraith et al. (1969) identified two fabric characteristics as contributors to pill formation in synthetics: longer fiber length and greater strength.

2.4.4 The mechanism of pilling

Brand and Bohnfalk (1967) divided the process of pilling into three stages: (1) fibers are drawn to the fabric surface as a result of some mechanical action and these form a fuzz; (2) the fuzz entangles into pills; and (3) the pills wear off under continued mechanical action (p. 119). A mathematical model of pilling was proposed first by Brand and Bohnfalk (1967) and later simplified by Conti and Tassinari (1974):

$$\underset{\text{pillable fuzz}}{W} \xrightarrow{\alpha} \underset{\text{pills}}{X} \xrightarrow{\omega} \underset{\text{pills worn off}}{Y}$$

Where:

α = the rate of pill build up and
ω = the rate of pill wear off

In this model, the rate of pilling at each step depends upon the number of pills at that given stage and a rate constant for that step. With the model established, each aspect can be measured and pilling resistance results can be compared among different fabrics. In some studies, the number of pills are counted after various periods of mechanical action until pill wear-off is completed (Conti & Tassinari, 1974).

In a 1980 study, researchers Goswami, Duckett, and Vigo suggested that the entanglemant of fibers into pills appeared to be a "result of the interlocking of the surface scale like structure produced by slow and gradual cyclic torsional deformation of the fibers" (p. 481). They observed helical lines and cracks on the polyester fiber skin which caused an entanglemant of the fibers, resulting in pilling, much in the way that the scales on wool fibers contribute to pill formation.

In response to this paper, Cooke (1981) argued that in the Goswami et al. SEM photos, pills examined from worn garments did not demonstrate torsional fatigue damage within established pills; in fact, "the fatigue damage within pills appeared to be either transverse cracking or kink-band cracking with a certain amount of skin shedding in the crack zones" so that the "link between torsional fatigue and pill initiation is extremely tenuous" (p. 364). Evidently the mechanisms of pill formation are still being determined and disputed.

Baird, Hatfield and Morris (1956) observed that fibers protruding from the fabric surface formed pills and in loosely constructed fabrics, rubbing raised fibers to the surface where they were readily available for pill formation. Spunbonded, nonwoven fabrics such as the Kleenguard® and Tyvek® used in this study, are particularly loose structures, where fibers are not held tightly in yarns or a weave pattern; they tend to be heat melded or bonded in regular patterns. The fibers are rigidly held in the bonded areas, but they are loose everywhere else.

Gintis and Mead (1959) argued that loose fiber ends on the surface do not become involved in pill formation because they can align themselves in the direction of the force, thereby minimizing the effect of the force; on the other hand, a loosened loop will initiate pill formation because it cannot give with the abrasion: initially, both ends are held. Cooke (1983) carried the argument further and noted that if two (or more) loose fiber ends became entangled, then they would no longer be able to align themselves with the abradant force and pilling would begin. Cooke's observation appears reasonable, although it is possible that the researchers were working with different types of abradants and/or different types of fabrics. The direction of the abradant (e.g. unidirectional vs. rotational) and the frequency and proximity of the free fiber ends would appear to affect their involvement in pill formation. In any case, both fiber ends and loops are readily available in a nonwoven structure such as Kleenguard® EP or Tyvek®.

2.5 Abrasion Test Methods

2.5.1 Types of abrasion test instruments

Many abrasion test instruments have been developed in an attempt to simulate types of abrasive wear. Bird (1984b) observes that the first recorded attempt to simulate wear on textiles was in 1858 and since that time over 100 abrasion machines have been developed. In general, the instruments vary in several ways:

1. the type (plane or flex), direction (unidirectional or multidirectional), and manner (frictional-adhesive or abrasive) of abrasion or rubbing that is produced;
2. the mount or backing for the specimen;
3. the material used to produce the abrasion (e.g. abrasive paper, steel blade or emery cloth);
4. the load and/or tension placed on the specimen being tested;
5. the manner in which the end point is assessed; and
6. the manner in which the abrasion is assessed (Bird, 1984b).

This variability among testing instruments is illustrated in a study conducted by Galbraith et al. (1969) who used the Accelerotor, Schieffer, and Stoll (inflated diaphragm) abrasion testers to produce nine progressive levels of abrasion damage to 100% cotton and 100% nylon fabric. In this study, the three instruments differed greatly in the type and rate of fabric damage which they caused. The researchers concluded that the "three instruments would measure different facets of a fabric's total abrasion resistance" (p. 337). Similarly, in a study conducted by Bird (1984a) the Stoll (flex), Martindale and Accelerotor abrasion instruments did not rank the 64 fabrics tested in the same order. On the other hand, Bird (1984b), in a thorough review of laboratory abrasion testers, states that some researchers found increased correlation between machines of similar actions and abradants. The issue is complicated further when the ability of an abrasion tester to predict or simulate "real life" wear is considered. [illegible]ny studies do not attempt to relate the abrasion testing to actual wear of the fabrics; rather, they use the testing only as a means of comparison among fabrics (Bird, 1984b).

As mentioned above, a variety of methods is used to evaluate the abrasion and to determine the end point of an abrasion test. Abrasion can be evaluated by subjective and objective means. Subjective means of evaluation depend on visual observations of the changes in the fabric appearance. Observations are made through microscopes (Galbraith et al., 1969) and scanning electron microscopes

(SEM) (Raheel & Lien, 1985). Evaluations are made of the pilling and fuzzing on the fabric surface, colour changes are rated and the overall fabric integrity is noted (Warfield, Elias & Galbraith, 1977) including observations of the changes in the yarns and fibers (Greaves, 1981). Objective methods of evaluating the abrasion include measurements of the residual breaking load and the percentage loss in the breaking load or tensile strength (Raheel, 1983; Galbraith, 1969); the change in thickness; percent weight loss from the abraded area (Lloyd et al., 1985; Warfield, et al., 1977); or changes in fabric weight, thread count, yarn strength and elongation. Elias et al. (1977) measured the length distribution of fibers removed from yarn segments. Ideally, the evaluation would be used to relate the simulated abrasion produced by a machine to abrasion produced in actual wear situations.

The end point of an abrasion test can be set: at an arbitrary level, such as 400 cycles on the Stoll Quartermaster (Raheel & Lien, 1982); at timed intervals (Shealey, 1965; Warfield & Stone, 1979); at a point of specified destruction: such as fabric rupture, i.e., the cycles required for failure of the fabric (Miller, Friedman & Turner, 1983; Ericson & Baxter, 1973). Lloyd et al. (1985) set cycles on the Taber Abraser at 300, 1000 and 2000 cycles, ending the test when holes appeared on Kleenguard® EP. In some cases the end point is determined in part by the testing instrument and in other cases a readily distinguishable point is chosen.

2.5.2 Limitations of abrasion test methods

Abrasion tests have several inherent limitations. Conditions of the test and changes in the abradant during specific tests cause variations in abrasion test results. The Annual Book of ASTM Standards (1983) states that "all the test methods and instruments so far developed for abrasion resistance may show a high degree of variability in results obtained by different operators and in different laboratories"; also, "technicians frequently fail to get good agreement between results obtained on the same type of testing instrument both within and between laboratories and the precision of these methods is uncertain" (p. 1011).

A second problem with abrasion test methods is that the results do not correlate well with actual wear conditions. Many studies have compared abrasion test results on a variety of test instruments to determine which best reproduces field wear. Kirkwood (1974) compared the abrasion results of the Accelerotor, Schieffer, Stoll (flex) and Taber abrasion instruments. The Accelerotor best reproduced the surface characteristics of field wear in the three fabrics analyzed. Raheel and Lien (1982) found the results of the Stoll flex abrasion under wet conditions to be similar to that of multiple washings. In contrast, Lord (1971) reported that not one of 15 laboratory abrasion tests on 7 commonly used machines was capable of predicting wear in five bedsheet fabrics. Abrasion is just one of the factors which causes fibers to wear out and the actual contribution of abrasion alone is not known (McNally & McCord, 1960). According to Galbraith (1975) "actual wear usually [includes] ... mechanical stresses other than rubbing" (p. 194) and no one abrasion instrument has been devised which will either simulate or correlate with all of the various types of abrasive stresses (Morton & Hearle, 1975) or other types of stresses in wear. Despite these restrictions, abrasion testers are a useful method to simulate wear in the laboratory.

3. MATERIALS AND METHODS

3.1 Experimental Design

The dependent variable is the percentage of pesticide which penetrated through the upper fabric layer of a two-layer assembly to the under layer of fabric. The independent variables are the upper layer fabrics (two variations), and abrasion (three levels).

1. Fabrics
   - a. Kleenguard® Extra Protection (EP)
   - b. Tyvek®

2. Abrasion
   - a. 0 minutes (no abrasion)
   - b. 3 minutes brushing and 2 minutes pilling on the Brush Pilling Tester
   - c. 6 minutes brushing and 2 minutes pilling on the Brush Pilling Tester

3.2 Fabrics

The inadequate protection from pesticides provided by regular work clothing has led researchers and agricultural workers alike to consider the use of specially designed protective garments (Davies, Freed et al., 1982; Branson et al., 1986). Kleenguard® and Tyvek® garments were selected for this study because they are readily available to farmers in Alberta. A preliminary survey on the availability of protective garments, distributed to 63 District Home Economists in Alberta, indicated that

Kleenguard® EP coveralls were available in local stores in 40 (83%) of the agricultural districts and Tyvek® coveralls were available in 12 (25%) districts. There were 48 responses.

Since they are economically priced, these garments can be discarded after use, and therefore, do not require laundering or other decontamination. Agricultural workers in Alberta have indicated an interest in disposable garments for this reason. The laundering of contaminated garments in a separate wash load and the subsequent decontamination of the washing machine requires excess water which is not available to those living in areas where water is in limited supply (B. Eggertson, personal communication, June 10, 1986).

The fabrics used in this study are from two coveralls:

1. Kleenguard® Extra Protection (EP) Coverall:

The white coverall is made of nonwoven, 100% polypropylene and is manufactured by Kimberly-Clark. The fabric (Plate 1) has a three layer construction: two outer layers of spunbonded polypropylene and an inner layer of microfine, meltblown polypropylene (SMS). The EP coverall is specially treated to resist liquid penetration. Although the fabric has a repellent finish on both sides, it is calendered on one side only, and this side is placed to the outside in coverall construction. The calendered side of the fabric was abraded and placed face

Plate 1 Kleenguard® EP fabric with no abrasion showing the bonding pattern and smooth surface of the fibers

Plate 2 Tyvek® fabric with no abrasion, showing the bonding pattern and the arrangement of regular and microfine fibers

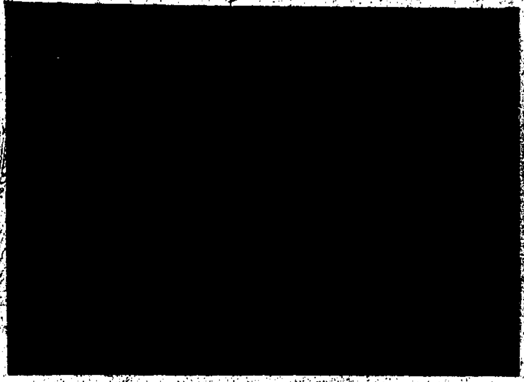


Plate 3 Moderate pilling on Kleenguard® EP fabric abraded in the field showing loosened and flattened fibers

Plate 4 Very severe pilling on Kleenguard® EP fabric abraded in the field showing entanglement of fibers

up in the penetration study.

Cost of coverall: approximately $7.00 - $10.00

2. Tyvek®

Tyvek®, a trademark of E. I. Du Pont de Nemours, is manufactured into garments by a variety of companies. The fabric (Plate 2) is spunbonded, 100% olefin. The fabric used in this study was supplied by Seams Enterprises, Ltd., Brockville, Ontario.

Cost of Coverall: $7.00 - $10.00

Saranex®-coated Tyvek® (from here on, Saranex®) was also included in the abrasion testing because it is recommended by the manufacturer for use with liquid pesticides. The fabric was later omitted from the study for several reasons: it could not be abraded on the Brush Pilling Tester; the cost of the coverall is higher than the Tyvek® or Kleenguard® EP ($25.00 - $35.00) and it is readily available in only one district in Alberta. Also, the impermeable Saranex® coating may cause the coverall to be uncomfortable in hot weather. In a test of water vapour transmission, based on the ASTM Test Method E96-80, Saranex® transmitted water vapour at a rate of 1.39 g.h^{-1}m^{-2} in contrast to 85.36 g.h^{-1}m^{-2} for Kleenguard® EP (H. Perkins, personal communication, September, 1987). For these reasons, it is unlikely that farmers would choose Saranex® coveralls for pesticide use.

The Saranex® fabric is Tyvek®, 100% spunbonded olefin, coated with Saranex®, a saran film produced by Dow Chemical, which provides the Tyvek® with extra chemical resistance. The Saranex®-coated Tyvek® fabric used in this study was supplied by Pro-Tec-Tion Garments, Vancouver, British Columbia.

A 100% cotton twill (#423 from Testfabrics Inc.) was used for the underlayer. The twill represented a fabric commonly used in garments such as jeans, that may typically be worn under a disposable coverall. The function of the underlayer was to collect any pesticide residue which penetrated through the upper layer. The effect of the underlayer on penetration was not examined in this study.

3.3 Fabric Preparation

The fabric was not laundered prior to contamination or the abrasion treatment. The manufacturers recommend that the Kleenguard® EP fabric not be laundered because the liquid barrier properties will not be retained. The specimens were cut from yardage in squares measuring 23 x 23 cm. This specimen size is required by the ASTM D 3511 - 82 test method (Pilling Resistance and Other Related Surface Changes of Textile Fabrics: Brush Pilling Tester Method). All specimens were weighed prior to the abrasion treatment. The 45 Kleenguard® EP specimens used in this study weighed between 2.2887g and 2.5253g (mean: 2.4090g; SD. 0.0598). All 45 Tyvek® specimens weighed between 1.5441 g and 1.8054 g (mean: 1.6775 g; SD. 0.0638). Two thickness measurements (Table 3.3) are reported: one taken at the centre of the specimen; and the second, an average of five measurements taken around the centre of the specimen. Thickness measurements were made with a C&R Tester Model CS-55 (Custom Scientific Instruments) according to CGSB Can 2-4.2 37 M77 (Method of Test for Fabric Thickness) with the small foot (diameter 28 mm) and no weights added to produce a pressure on the specimen of 0.838 kPa.

TABLE 3.3 INITIAL THICKNESS (cm) OF SPECIMENS (n=45)

FABRIC	MEAN THICKNESS AT CENTRE	SD	MEAN* THICKNESS	SD
Kleenguard® EP	0.0378	0.0025	0.0368	0.0157
Tyvek®	0.0196	0.0030	0.0193	0.0020

* Average of five measurements taken around the centre of specimen.

3.4 Abrasion

In a preliminary field trial, 40 Alberta farmers were given Kleenguard® EP coveralls to wear for an 8 hour period during the 1986 spring spraying season. These coveralls were then analysed for signs of wear and abrasion. The coveralls were worn for 1 to 32 hours, with an average of 12 hours of wear. Farmers were told to remove the coveralls if they tore or if a major spill occurred. Many farmers wore the coveralls longer than requested, which suggests either a misunderstanding of the requirements of the study or satisfaction with the coverall (H. Perkins, personal communication, August 10, 1987). Two judges ranked the abrasion observed in designated areas of the coveralls using the following five levels or degrees of abrasive wear:

5. no abrasion	
4. slight abrasion	broken fibers, fuzzing, no pilling
3. moderate abrasion	fibers tangled and beginning to pill
2. severe abrasion	pill formation
1. very severe abrasion	larger, more severe pills, holes

Designated areas included upper torso front and back, lower torso front and back, right arm front and back, left arm front and back, right thigh front and back, left thigh front and back, right lower leg front and back, and left lower leg front and back.

Laboratory abrasion instruments were used to try to replicate the type of abrasive wear found on the Kleenguard® EP coveralls worn in the field. Two instruments were used to produce the abrasion: 1) the Taber Abraser and 2) the Brush Pilling Tester. The testing with the Taber Abraser, Model 174 (Taber Instrument Corporation) was conducted according to the ASTM test method D 3884-80 (Abrasion Resistance of Textile Fabrics--Rotary Platform Double Head Method). The CS-10 wheel was used with a load of 250 grams on the specimens. Two levels of abrasion consisted of 100 and 300 cycles. The abrading wheels were resurfaced (25 cycles on resurfacing disc) after every 300 cycles. The ASTM Test

Method D 3511-82 (Pilling Resistance and Other Related Surface Changes of Textile Fabrics: Brush Pilling Tester method) was modified to produce four levels of abrasion on the Brush Pilling Tester, Model CS-53 (Custom Scientific Instruments). Brushing times of 2, 3, 4, and 6 minutes of brushing were followed by 2 minutes of pilling time. The test fabric was pilled with specimens of 100% cotton twill. Lint was removed from the brushes after each test and protruding bristles were clipped as required. For both tests, all specimens were conditioned prior [illegible] the test for at least two hours in standard conditions of 21°C and 65% RH.

Two methods were used to evaluate the specimens abraded in the laboratory: 1. residual tensile strength and 2. visual evaluation of scanning electron microscope (SEM) photos. The abrasion study was conducted on Kleenguard® EP, Saranex® and Tyvek® fabrics. Kleenguard® EP specimens taken from garments worn in the field trial and Kleenguard® EP specimens abraded on the abrasion instruments were compared visually in order to obtain a similar appearance. The Kleenguard® EP fabric abraded in the laboratory was used as a reference standard, or indicator, and both other fabrics were abraded for the same length of time or number of cycles.

The residual tensile strength of the abraded specimens was determined in accordance with ASTM Test Method D 1682-64 (Breaking Load and Elongation of Textile Fabrics) on an

Instron model 4202 (Instron Corporation). The specimens were conditioned, and cut into 2.5 cm strips in the lengthwise direction of the fabric. The clamps were lined with cork to prevent specimen slippage during the tensile test. Specimens abraded on the Brush Pilling Tester were tested with an initial clamp separation of 7.5 cm and for Taber Abraser abraded specimens, because of the smaller specimen size, the inital clamp separation was 2.5 cm. For comparative purposes, specimens from the field trial garments were also tested at these two clamp separations.

Specimens abraded on the Brush Pilling Tester and Taber Abraser were compared visually with worn areas found on garments. Representative abraded samples were observed with the aid of a Cambridge Stereoscan 100 Scanning Electron Microscope (SEM). Specimens approximately 1 cm^2 were mounted on stems, silver conductive paint was painted around the outside of the stems and then the specimens were sputter coated with gold.

The Brush Pilling Tester was chosen for laboratory abrasion in this study because it produced abrasion more similar to that found on the field trial garments, both in terms of the degree of abrasion and the range of abrasion than did the Taber Abraser. Two levels of abrasion were used in the study: three minutes brushing time with two minutes pilling time and six minutes brushing time with two minutes pilling time. The two levels approximate the moderate and severe levels of abrasion found on the field trial garments, although assumptions cannot be made about direct correlations. While the majority of the specimens subjected to the Brush Pilling Tester were abraded to a degree typical of that level, some specimens were abraded more or less severely than typical. To reduce the variability of the abrasion levels used in the penetration study, three trained judges selected Kleenguard® EP and Tyvek® specimens which were representative of the two levels of abrasion, rejecting specimens which appeared to be more or less abraded than typical. Saranex® was not used in the pesticide penetration study because it could not be abraded on the Brush Pilling Tester.

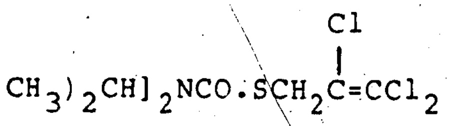
3.5 Pesticide

The fabric specimens were contaminated with tri-allate (Avadex BW®), manufactured by Monsanto Canada, Inc. Tri-allate is used in Alberta for the control of wild oats in cereals.

Molecular Formula: $C_{10}H_{16}Cl_3NOS$

Molecular Weight: 304.7

Structural Formula:



$$CH_3)_2CH]_2NCO.SCH_2\overset{\overset{Cl}{|}}{C}=CCl_2$$

Formulation: Emulsifiable concentrate. The product used in this study was calculated as containing 423.6 g of active ingredient/liter.

Stability: Stable to light, - Decomposition temperature >200°C

Toxicity: Acute oral LD_{50}: 1675-2165 mg/kg (rat) The product may cause eye irritation.

Solubility: 4 mg/L in water at 25°C, soluble in most organic solvents.

(Alberta Agriculture Guide, 1984).

Although Avadex BW® is not considered a highly toxic pesticide formulation, in a survey of 187 Alberta farm families, Avadex BW® was listed as one of the three pesticides most frequently associated with symptoms of moderate pesticide poisoning. Only one case of severe pesticide poisoning was reported and the pesticide was not named (Rigakis, et al., 1985).

3.6 Contamination of the Fabric

For pesticide contamination, an 8 cm square specimen of Tyvek® or Kleenguard® EP was cut from the centre of the abraded specimen and used as the upper layer. The specimen was sandwiched together with an 8 cm square underlayer of 100% cotton twill, and a 12 cm square of aluminum foil placed directly beneath the cotton under layer to trap any formulation which passed through the under layer. Masking tape (2.5 cm wide) was placed over the outer 0.5 cm edge of the upper layer fabric and the 2 cm extension of the aluminum foil. The masking tape held the three layers securely together and prevented penetration of the pesticide to the under layer around the outside edge of the upper layer fabric. A similar technique was used by Leonas (1985).

The specimens were placed horizontally on the floor of a fume hood which was covered with a layer of aluminum foil. Clean foil was laid down for each replication to prevent cross contamination from one specimen to another. The specimens were contaminated by pipetting with an Oxford micropipette 0.5 mL of field strength tri-allate (9 mL of concentrate in 200 mL of distilled water) onto the centre of the upper fabric, from a height of 2.5 cm. Although other procedures are used to simulate contamination which might occur through exposure to spray during pesticide application (Orlando et al., 1981), pipetting simulates a liquid spill or splash which may occur during mixing and loading or equipment repair. A magnetic stirrer provided uniform agitation of the pesticide dilution during the contamination process. The contaminated specimens were dried horizontally for 5 hours, at room temperature (21-23°C). The upper and under layers were separated by cutting around the inside edge of masking tape. The scissors were rinsed in acetone after separation of each specimen to prevent cross-contamination. The upper layer fabric was placed in a labelled vial, and the under layer and foil were placed in a second labelled vial. The specimens were stored in a refrigerator, for no longer than one week, prior to extraction.

Fifteen specimens (five per replication) of each fabric type were evaluated for each of the three levels of abrasion (Table 3.6). 90 specimens were analysed.

TABLE 3.6 NUMBER OF SPECIMENS ANALYSED FOR PESTICIDE PENETRATION

	FABRICS					
	KLEENGUARD® EP			TYVEK®		
LEVEL OF ABRASION (min)	0	3	6	0	3	6
# OF SPECIMENS	5	5	5	5	5	5
# OF REPLICATIONS	3	3	3	3	3	3
TOTAL SPECIMENS		45			45	

3.7 Extraction

The under layer fabric and aluminum foil were extracted as described below and analysed together using a procedure which proved effective in preliminary research. The upper layer was analysed for control purposes only.

1. The specimen was placed in a 500 mL erlenmeyer flask. The screw cap of the flask was lined with foil to prevent contamination.
2. 100 mL of distilled-in-glass acetone was added, and the Flask was shaken for 15 minutes on a Wrist Action Shaker to facilitate extraction.
3. The acetone was decanted quantitatively to a boiling flask.

4. Steps 2 and 3 were repeated.

5. The erlenmeyer flask was then rinsed with 75 mL of acetone and this extract also was added quantitatively to the boiling flask.

6. The three combined extractions were flash evaporated.

7. The concentrated pesticide was diluted in hexane in preparation for injection on the gas chromatograph.

3.8 Gas Chromatography Analysis

A Hewlett-Packard 5710A gas chromatograph equipped with a nitrogen/phosphorus Flame Ionization Detector was used for the analysis. The chromatograph was equipped with a 0.64 cm by 122 cm glass column packed with 5% OV on gas chrom Q. The carrier gas was helium at 30 mL/min. Operating temperatures were:

Oven:	175°C
Injection Port:	200°C
Detector:	300°C

Two injections were made for each specimen and these were averaged. Injections of the standard were made after every two specimen injections. The amount of pesticide extracted from the specimens was expressed in milligrams per specimen. The total amount of tri-allate (milligrams) delivered to the upper layer specimens was calculated by analysing 0.5 mL of the formulation pipetted into five 500 mL erlenmeyer flasks for each replication. The percent tri-allate which penetrated through to the under layer fabric was calculated from this value (see section 3.9.3).

3.9 Calculations

Each specimen was contaminated with 0.5 mL of a field strength dilution of Avadex BW® (a tri-allate formulation). In the concentrated Avadex BW® formulation there are 423.6 grams of tri-allate (the active ingredient, a.i.) per litre. Nine milliliters of the concentrated formula was diluted to 200 mL with distilled water. Thus, each 200 mL of the diluted formula contained 3.812 g of active ingredient.

3.9.1 Grams tri-allate in 0.5 mL dilution

Each specimen was contaminated with 0.5 mL of the diluted formula. Let Y equal the amount of active ingredient (g) in 0.5 mL of the diluted formula:

$$Y/0.5\ \text{mL} = 3.812\ \text{g ai}/200\ \text{mL}$$

$$Y = 9.531 \times 10^{-3}\ \text{g}$$

Thus, theoretically, each specimen is contaminated with 9.531×10^{-3} [illegible] of tri-allate, or 9.531 mg.

3.9.2 Penetration (mg)

The amount of tri-allate (milligrams) which penetrated through the disposable coverall fabric to the under layer was calculated from the recorder charts of the gas chromatograph using the equation:

$$\text{mg tri-allate} = \frac{\dfrac{\text{PH SPEC}}{\text{PH STD}} \times \begin{array}{c}\text{std}\\ \text{injected}\\ \text{(mL)}\end{array} \times \begin{array}{c}\text{std}\\ \text{conc}\\ \text{(g/mL)}\end{array}}{\dfrac{\text{specimen injected (mL)}}{\text{dilution factor of specimen (mL)}}} \times 1000 \text{ where}$$

PH SPEC = peak height of specimen (mm)
PH STD = peak height of the standard (mm)

3.9.3 Penetration (%)

The amount of tri-allate which penetrated through the upper layer and was deposited on the under layer was expressed as a percentage of the total amount of tri-allate which was applied to the upper layer fabric.

PENETRATION (%) = UN/TOTAL x 100

UN = the amount of tri-allate (mg) extracted from under layer specimen

TOTAL = the amount of tri-alllate (mg) extracted from 0.5 mL dilution delivered directly into a 500 mL erlenmeyer flask

3.10 Statistical Analysis

The effect of abrasion on field trial garments was compared to abrasion produced by two laboratory instruments through comparison of residual tensile strength measurements. The tensile data were subjected to analysis of variance tests and when significant differences existed among the abrasion treatments, the means were separated by Duncan's Multiple Range Test.

The two fabrics, Kleenguard® EP and Tyvek® were analysed separately for the effect of abrasion on the percentage of pesticide penetration. The penetration data were subjected to one-way analysis of variance tests and Student-Newman-Keuls Multiple Range Test was used as a post hoc test when significant between-group variance existed. A two-way ANOVA was performed on measurements of the dependent variable, pesticide penetration, by the independent variables abrasion (three levels) and fabric (Tyvek®, Kleenguard® EP). Log transformations of the Kleenguard® EP data were required to achieve homogeneity of variance. The correlations between initial thickness and initial weight and pesticide penetration were measured with Pearson's Correlation Coefficients. In all cases, indication of significance was set at 95% probability. The SPSSX computer program was used to calculate the statistics.

4. RESULTS AND DISCUSSION

The purpose of this study was to determine the effects of abrasion on the penetration of an emulsifiable concentrate formulation of tri-allate through selected disposable coverall fabrics. The relationship between the initial thickness and initial weight of the fabric specimens and pesticide penetration was also observed in order to determine the effect of fabric variability on the penetration results. Comparative testing was conducted to establish laboratory abrasion which simulated abrasion observed on Kleenguard® EP garments after they were worn in a field trial.

4.1 Abrasion on Field Trial Coveralls

Thirty-three Kleenguard® EP coveralls were examined for wear and abrasion after they were worn by Alberta farmers for an average of 12 hours in a field trial. Abrasion was observed in designated areas which included upper torso front and back, lower torso front and back, right and left arm front and back, right and left thigh front and back, and right and left lower leg front and back. A summary of the observations is recorded in Table 4.1. The designated areas of abrasion are grouped for simplicity of interpretation (e.g. right and left thigh front are designated as thigh front and the values for the two areas have been averaged).

TABLE 4.1 LOCATION AND SEVERITY OF ABRASION ON FIELD TRIAL COVERALLS

LOCATION	% ABRADED*	% ABRADED AT LEVELS 3 - 1	% ABRADED AT LEVEL 1
ARM FRONT	50.0	6.0	-
ARM BACK	92.4	38.4	-
THIGH FRONT	86.4	60.6	-
THIGH BACK	71.2	41.0	6.1
LOWER TORSO BACK	87.9	57.6	6.1
UPPER TORSO BACK	24.2	6.0	-
LOWER TORSO FRONT	66.7	21.2	-
UPPER TORSO FRONT	57.6	3.0	-

VISUAL SCALE

5 = NO PILLING
4 = SLIGHT PILLING
3 = MODERATE PILLING
2 = SEVERE PILLING
1 = VERY SEVERE PILLING

* % Abraded is percentage of 33 coveralls abraded in a given location and/or at a given level

The abrasion on the field trial coveralls was expressed in terms of pilling because this term best describes the visual appearance of the abrasion. All 33 coveralls were abraded in at least one designated area and all designated areas were abraded on some of the coveralls, ranging from a low of 24.2% on the upper torso back to a high of 92.4% on the arm back. The thigh front, arm back and lower torso back were the areas which were consistently abraded on the majority of the coveralls. The thigh front (60.6%) and the lower torso back (57.6%) were the garment areas showing moderate to severe pilling (levels 3 to 1) in more than 50% of the garments, while the arm front and thigh back were abraded to this extent in approximately 40% of the garments. Very severe pilling (level 1) was noted only on the thigh back and lower torso back. Both areas were abraded in only 6.1% or two of the 33 garments.

There was no significant correlation between abrasion on the coveralls and the length of time that the coveralls were worn. Bird (1984a) observed that personal differences, both in behaviour and body build, affect the degree of wear produced on a garment. In this study, neither the environment nor the activities of the participants was controlled; personal differences undoubtedly contributed to the abrasion patterns.

4.2 Comparison of Abrasion on Field Trial Coveralls with Abrasion Produced by Laboratory Instruments

Although Kleenguard® EP, Saranex® and Tyvek® specimens were all included in the abrasion testing conducted on laboratory instruments, only Kleenguard® EP specimens were actually compared to the specimens cut from field trial coveralls in statistical tests. Tyvek® and Saranex® garments were not worn in the field trial. The abrasion on the Kleenguard® EP field trial garments was used as a reference or standard to establish the levels of abrasion chosen for this study. In this way, the laboratory abrasion was based upon the kind and degree of abrasion which was produced in actual wear situations.

4.2.1 Comparison of field trial abrasion with abrasion produced by the Brush Pilling Tester

Specimens abraded by the Brush Pilling Tester (2-6 min brushing time, 2 min pilling time) were tested for residual breaking strength. The results are presented in Table 4.2.1 Specimens representing the five levels of abrasion were cut from the Kleenguard® EP field trial garments and tested for residual tensile strength in the same manner (Table 4.2.1). In both the field trial and laboratory abraded specimens, there was a reduction in tensile strength as the abrasion level increased. The mean tensile strength ranged from 41.59 N (no pilling) to 26.59 N (very severely pilled) for field trial specimens and from 37.28 N (2 minutes brushing) to 26.09 N (six minutes brushing) for specimens abraded on the Brush Pilling Tester. In terms of tensile strength, field trial specimens with no pilling (level 5) and slight pilling (level 4) were significantly different from laboratory specimens abraded at all levels on the Brush Pilling Tester. The tensile strength of field trial specimens judged to have slight pilling (level 4) and moderate pilling (level 3) was not significantly different from the strength of laboratory specimens given 2 and 3 minutes brushing time on the Brush Pilling Tester. Field trial specimens with severe pilling (level 2) and laboratory specimens given 4 minutes on the Brush Pilling Tester were not significantly different. Finally, very [illegible] pilling (level 1) on field trial specimens and laboratory specimens given 6 minutes on the Brush Pilling Tester were not significantly different.

TABLE 4.2.1 TENSILE STRENGTH OF KLEENGUARD® EP SPECIMENS ABRADED ON THE BRUSH PILLING TESTER AND IN THE FIELD TRIAL

NUMBER OF SPECIMENS	BRUSH TIME/ ABRASION LEVEL	MEAN TENSILE STRENGTH (N)	SD (N)	GROUPINGS
14	0 min	41.59	5.00	A*
11	2 min	37.28	5.20	B
14	3 min	35.81	3.34	B
11	4 min	31.00	4.12	C
16	6 min	26.09	4.73	D
12	level 4	38.65	4.81	A B
15	level 3	37.08	5.49	B
16	level 2	32.18	4.02	C
17	level 1	26.59	4.81	D

CLAMP SEPARATION ON INSTRON: 7.5 cm

LEVEL OF ABRASION ON FIELD TRIAL SPECIMENS
5 = no pilling
4 = slight pilling
3 = moderate pilling
2 = severe pilling
1 = very severe pilling

* groups designated with the same letter are not significantly different

The Saranex® fabric could not be abraded by the brush apparatus on the Brush Pilling Tester in the brushing times used in this study. Even after 6 minutes' brushing time, only a few random scratches were produced on the surface of the Saranex® coating. For this reason, Saranex® was not tested for tensile strength after abrasion on the

Brush Pilling Tester.

Tyvek® specimens were abraded on the Brush Pilling Tester at 0, 3 and 6 minutes of brushing time. The mean tensile strength values (Table 4.2.2) ranged from 39.30 N (no brushing) to 35.94 N (3 minutes). Although the mean tensile strength value of specimens given 3 minutes' brushing time dropped below that of specimens given 6 minutes, 38.66 N, there was no significant difference among the mean tensile strength values for specimens given 0, 3 and 6 minutes brushing time.

TABLE 4.2.2 TENSILE STRENGTH OF TYVEK® SPECIMENS ABRADED ON THE BRUSH PILLING TESTER

NUMBER OF SPECIMENS	BRUSHING TIME (min)	MEAN TENSILE STRENGTH (N)	SD (N)	GROUPINGS
10	0	39.30	4.99	A*
9	3	35.94	5.42	A
10	6	38.66	7.71	A

CLAMP SEPARATION ON INSTRON: 7.5 cm

* Groups designated with the same letter are not significantly different

4.2.2 Comparison of field trial abrasion with abrasion produced by the Taber Abraser

Kleenguard® EP specimens were abraded for 100 and 300 cycles on the Taber Abraser and then tested for residual tensile strength (Table 4.2.3) according to a modification of ASTM Test Method D1682-64 (Breaking Load and Elongation of Textile Fabrics). The clamp separation was 2.5 cm rather than the standard 7.5 cm which was used for specimens abraded on the Brush Pilling Tester. Specimens representing the five levels of abrasion were cut from the Kleenguard® EP field trial garments and tested for residual tensile strength in the same manner (Table 4.2.3).

The mean tensile strength decreased as the amount of abrasion increased for Kleenguard® EP specimens abraded both in the wear trial and on the Taber Abraser. There was no significant difference in tensile strength for field trial specimens without pilling (0 cycles) and specimens with slight pilling (level 4). There was no significant difference in tensile strength for field trial specimens with moderate pilling (level 3) and field trial specimens with severe pilling (level 2). Finally there was no significant difference in the tensile strength of specimens abraded at 100 and 300 cycles on the Taber Abraser and field trial specimens with very severe pilling (level 1).

Lloyd, Bell, Howarth and Samuels (1985) tested Kleenguard® EP on the Taber Abraser with somewhat different results. They used the Taber Abraser, with S-35 tungsten-carbide abrading wheels and a mass of 500 g. The specimens were observed after 300, 1000 and 2000 cycles, after which the appearance was described as "scuffed", "well worn", and "holed", consecutively. These are not very descriptive or precise terms, but the impression certainly is that, at 300 and 1000 cycles, the fabric was

TABLE 4.2.3 TENSILE STRENGTH OF KLEENGUARD® EP SPECIMENS ABRADED ON THE TABER ABRASER AND IN THE FIELD TRIAL

NUMBER OF SPECIMENS	CYCLES/ ABRASION LEVEL	MEAN TENSILE STRENGTH (N)	SD (N)	GROUPINGS
12	0 cycles	46.21	6.18	A*
12	100 cycles	31.20	3.04	C
11	300 cycles	29.04	3.92	C
11	level 4	45.71	5.40	A
10	level 3	40.51	3.63	B
12	level 2	39.04	7.06	B
8	level 1	26.98	4.61	C

CLAMP SEPARATION ON INSTRON: 2.5 cm

LEVEL OF ABRASION ON FIELD TRIAL SPECIMENS
5 = no pilling
4 = slight pilling
3 = moderate pilling
2 = severe pilling
1 = very severe pilling

* groups designated with the same letter are not significantly different

damaged but not so severely as to obtain holes. The S-35 tungsten carbide wheel is described in the manufacturer's literature as likely to produce "a severe cutting and tearing action of the specimen surface ... [to be] ... used only on tough resilient material". The CS-10 wheel used in this study is described as an abradant which produces "a mild abrading action". In contrast with the Lloyd et al. study, holes were produced on some samples after 100 and 300 cycles of abrasion with the CS-10 wheel. This would appear to be an extreme case of a lack of reproducibility between labs and testing instruments; the S-35 abrasive wheel should produce more severe damage, sooner, than the CS-10 wheel. In personal correspondence, Lloyd clarified the terms they used: "scuffed" means considerable damage to the fabric surface and "holed" meant a tear or rip right through the material. What is most informative, however, is that in repeat tests, they found holes occurred after 200-300 cycles. Probably the most significant factor contributing to the difference in results between the two studies is the manner in which the specimen was mounted. Lloyd explained that the specimens were not clamped to the circulating disc, in the standard manner, because this tends to cause "rucking"; rather, they were secured "to a thin cardboard base-plate by means of a light tacky adhesive which then allows the abrasive wheels to pass over the surface of the material without bumping" (G. A. Lloyd, personal communication, June 18, 1987). Since the two studies were not conducted using the same testing conditions, direct comparisons of the results cannot be made.

There was a slight increase in tensile strength with an increase in abrasion for Saranex® specimens abraded on the Taber Abraser (Table 4.2.4). Although the mean tensile strength increased from 76.52 N for controls to 80.74 N for 300 cycles of abrasion, there was no significant difference in the mean tensile strength of specimens given 0, 100 and 300 cycles of abrasion.

TABLE 4.2.4 TENSILE STRENGTH OF SARANEX® SPECIMENS ABRADED ON THE TABER ABRASER

NUMBER OF SPECIMENS	CYCLES OF ABRASION	MEAN TENSILE STRENGTH (N)	SD (N)	GROUPINGS
9	0	76.52	6.08	A*
8	100	79.26	9.12	A
10	300	80.74	8.24	A

CLAMP SEPARATION ON INSTRON: 2.5 cm

* groups designated with the same letter are not significantly different

The mean tensile strength decreased as abrasion increased for Tyvek® specimens abraded on the Taber Abraser (Table 4.2.5). There was a significant difference between the unabraded control specimens (57.89 N) and specimens given 300 cycles of abrasion (45.01 N), but the controls and 100 cycle specimens (51.50 N) were not significantly different.

TABLE 4.2.5 TENSILE STRENGTH OF TYVEK® SPECIMENS ABRADED ON THE TABER ABRASER

NUMBER OF SPECIMENS	CYCLES OF ABRASION	MEAN TENSILE STRENGTH (N)	SD (N)	GROUPINGS
9	0	57.89	10.88	A*
8	100	51.50	12.32	A
12	300	45.01	7.28	B

CLAMP SEPARATION ON INSTRON: 2.5 cm

* groups designated with the same letter are not significantly different

4.2.3 Discussion of tensile strength testing

Tensile strength measurements are frequently used as an evaluation of abrasive damage (Bird, 1984a; Warfield et al., 1977; Galbraith et al., 1969). In this study, there was a loss in tensile strength in most cases as the degree of abrasion increased. This pattern was also observed by Warfield et al. (1977) who found a general trend toward losses in fiber strength as a result of abrasion. Bird (1984a) also observed a relationship between tensile strength and abrasion. Testing 64 woven fabrics on three abrasion instruments, namely the Martindale, Stoll (flex) and Accelerotor, Bird found weft yarn tensile strength an important factor in abrasion resistance.

Not all levels of abrasion tested produced significant differences in residual tensile strength within specific abrasion treatments or between abrasion treatment procedures. In most cases, the standard deviation in tensile strength was very large, whether the specimens were abraded in the laboratory or in the field. This large variability is typical and arises from at least three possible sources: 1. the variability in the nonwoven fabric itself; 2. the tensile strength test; and 3. the abrasion test. These three sources make it difficult to detect significant differences among various levels of abrasion.

In terms of the residual tensile strength, the abrasion produced with the Brush Pilling Tester is within the range of the abrasion found on garments from the wear trial. In contrast, as few as 100 cycles on the Taber Abraser produced a reduced tensile strength similar to that found on field trial specimens abraded at level 1 (very severe pilling), a degree of abrasion found only in two areas of field trial coveralls and in only 6% (i.e. two out of 33) of the coveralls (Table 4.1). In summary, a range of abrasion could be produced on the Brush Pilling Tester that was not possible on the Taber Abraser.

Saranex® fabric was abraded more successfully on the Taber Abraser, than on the Brush Pilling Tester, though in terms of tensile strength, the abrasion was not significant on either instrument. The increase in tensile strength observed with Saranex® when abraded on the Taber Abraser can be related to an increased mobility of the fibers after abrasion. In the control fabric, the fibers were immobilized by the coating and only those fibers lying lengthwise shared the tensile load. The abrasion treatment reduced the coating and the fibers could then align in the direction of the tensile stress, thus sharing the load.

Tyvek® was abraded by both instruments, but not as severely as Kleenguard® EP. Only at 300 cycles on the Taber Abraser was there a significant change in tensile strength.

4.2.4 Visual Evaluation: SEM

In this study, the scanning electron microscope (SEM) observations were simplified to pertain to two aspects: 1. characteristics of the general fabric appearance and changes in that appearance with abrasion; and 2. characteristics of the fiber surface and changes in the surface appearance with abrasion.

Kleenguard® EP: In Kleenguard® EP controls (plate 1), fibers were arranged in the random web in criss-crossed layers which were bonded together at regular intervals. Each fiber surface was smooth and had a round cross-section.

In field trial specimens, at slight and moderate levels of pilling, very little change had occurred to the structure of the fabric (plate 3). Some fibers were pulled out and above the fabric surface; this can be observed in areas where the loosened fibers lie above the bonded spots. These loosened fibers were not highly twisted or tangled with each other. In general, the surface of the fibers was still smooth, though some loosened fibers seemed to be mashed or flattened in areas.

As the abrasion increased in severity, to the severe and very severe levels of pilling (levels 1 and 2), the fibers were pulled up out of the fabric structure and became a tangled mass (plate 4). The surface of some fibers exhibited cross-markings (Plate 5), a distinctive change from the original fibers.

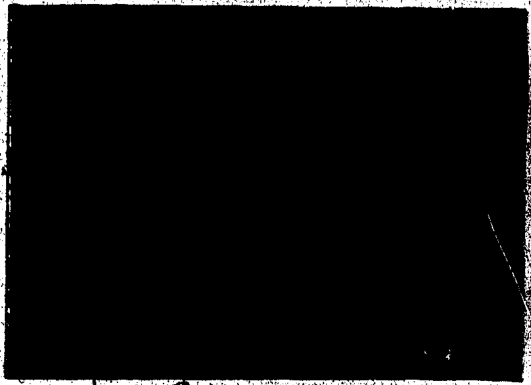


Plate 5 Crossmarkings on surface of Kleenguard® EP fibers abraded in the field at very severe level.

Plate 6 Tangled fibers on Kleenguard® EP fabric after 6 minutes abrasion by the Brush Pilling Tester

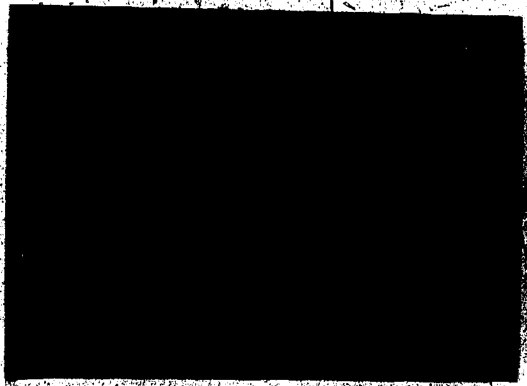


Plate 7 Cross-markings on surface of Kleenguard® EP fibers after 4 minutes abrasion by the Brush Pilling Tester

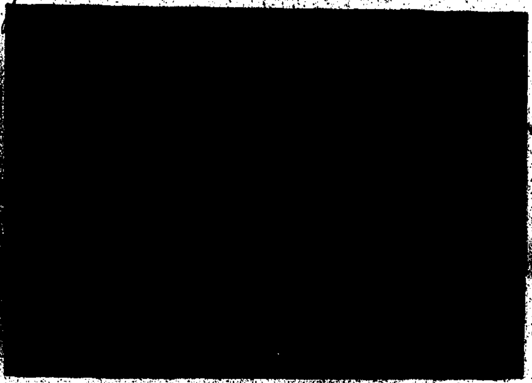


Plate 8 Tangled fibers on Kleenguard® EP fabric after 100 cycles abrasion by the Taber Abraser.

A very similar pattern developed on Kleenguard® EP specimens abraded on the Brush Pilling Tester. At 2 and 3 minutes' brushing time, little change occurred to the structure of the fabric; only a small percentage of the fibers were pulled up from the fabric structure and they were not highly twisted or tangled. Some mashing and flattening of fibers was observed, but in general, the fiber surface was still smooth. After 4 to 6 minutes of brushing, the fibers were a tangled mass, the original structure of the fabric was destroyed (Plate 6) and the fiber surface was cross-marked (plate 7).

The abrasion produced by the Taber Abraser is similar to that observed at the more extreme levels of the field trial specimens and the Brush Pilling Tester. At both 100 and 300 cycles (plate 8) the fibers were a tangled mass and fiber surfaces had become cross-marked (plate 9).

The overall appearance of the abrasion produced by the Taber Abraser differed significantly from that of the abrasion produced in the field and on the Brush Pilling Tester; the raised fibers tended to be twisted or spun into a "yarn" (plate 10). This seems to be a peculiarity of the the abrasion instrument; the specimen revolves horizontally, at right angles to the abrasion wheels. Also, the abrasion produced by the Taber Abraser tended to penetrate deeper into the fabric structure, pulling microfine fibers from the inner layer to the surface (plate 11).

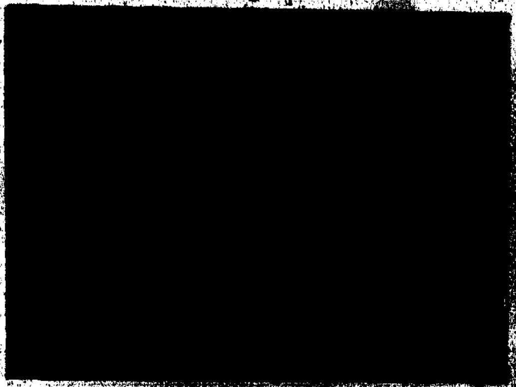


Plate 9 Cross-markings on the surface of Kleenguard® EP fibers after 100 cycles of abrasion by the Taber Abraser.

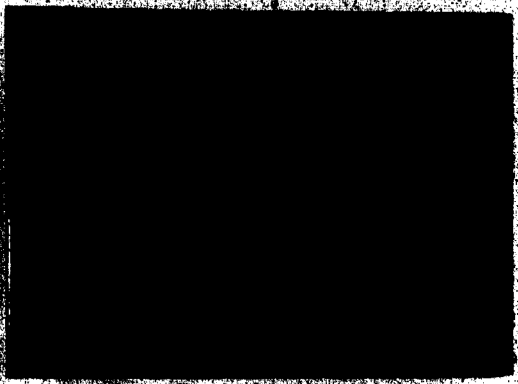


Plate 10 Kleenguard® EP fibers twisted into "yarn" after 300 cycles of abrasion by the Taber Abraser

Plate 11 Meltblown micro-fine fibers from inner layer of Kleenguard® EP fabric pulled out to surface after 300 cycles abrasion by the Taber Abraser

Plate 12 Kleenguard® EP fabric abraded by the Brush Pilling Tester for 4 minutes showing mashed and flattened fibers lying in front of a torn melded spot

Mashed and flattened fibers were observed, to varying degress, on the majority of abraded specimens (plate 12). In plate 12, mashed and flattened fibers can be seen in the foreground and a melded area, in the process of being torn apart, is in the background. The cause of this fiber modification cannot be determined without further reseach, but several causes seem possible. First, it is possible that heat of friction and pressure may cause this fiber change; however, it is unlikely that the abrasive instruments would produce the heat required. Second, it is possible that some of these fibers have been torn from the bonded areas through the course of the abrasion. As suggested in plate 12, the fabric structure did tend to break at the melded points. In that case, the fiber modification was caused not by the abrasion process, but, rather, by the bonding process during fabric formation. The action of the abradant separated and tore apart the melded areas.

The tangled massing of fibers observed in this study at more severe levels of abrasion was discovered in a wool and polyester blend fabric by Cooke (1985) who calls it "complete fabric breakdown". The fabric structure of spunbonded nonwoven fabrics such as Kleenguard® EP would seem to contribute to the development of these "super-pills". The fact that the fibers are not held tightly in yarns or a woven structure, means that they are loose and readily available for entanglement. Successive layers of fibers in the fabric web can be plucked up and tangled together, causing a complete breakdown of the original fabric structure. The fibers in the nonwoven structure are held together only by spots of bonding.

In this study, the most common evidence of fiber fatigue observed on the Kleenguard® EP fibers was horizontal cross-markings. Tucker suggested these markings were a wrinkling of the fiber skin or surface caused by the repeated application of stress and release of stress from the abrasive source (Paul Tucker, personal communication, September 9, [illegible]). Goswami et al. observed helical cross-markings on the surface of polyester fibers. Sze, Spruiell and White (1976) observed regular, helical twists in the fibrils of drawn and twisted polyethylene fibers. Kitao, Spruiell and White (1979) found twist marks on drawn and twisted polypropylene filaments, that were less uniform in their appearance than those observed by Sze et al. Bosley (1968) identified shearing stress as the cause of oblique strain markings in poly(ethylene terephthalate) fibers. The cross-markings on the Kleenguard® EP fibers are not spiral, and for that reason do not appear to be caused by direct twisting along the length of the fibers. The appearance of the cross-marks seems to be more similar to what Ford (1963) called transverse lines or strain bands. Ford suggested that the strain-rate of the fiber and the time under the load may be important factors in the formation of the transverse bands; the bands may be connected with stress decay.

The fiber deformation evident in plate 5 was unique to the field trial specimens judged to be severely or very severely pilled (levels 2 and 1). In this case, the fiber skin appears to have cracked and split exposing the inner core. This fiber damage appears to be more severe than any observed on specimens from the two test methods.

Goswami, Duckett and Vigo (1980) observed a skin-core phenomenon in polyester fibers exposed to cyclical torsional deformation. They suggested that the helical cracks were initiated by the complex rolling action of the surface abrasion; and the peeling-off of the skin layer was caused by shearing stress.

Saranex®: After 6 minutes on the Brush Pilling Tester (plate 13) only surface scratches appeared on the Saranex® fabric. In contrast, 100 and 300 cycles on the Taber caused the coating to begin to wear away. While the surface of the control fabric was unbroken and smooth, after 100 cycles, the outline of the fibers beneath the coating began to be visible (plate 14). The effect after 300 cycles remained the same.

The Saranex® coating almost completely withstood the abrasive forces of both the Brush Pilling Tester and the Taber Abraser under the given testing conditions. In this study, Saranex® was more durable to abrasion than the Tyvek® and Kleenguard® EP. Presumably, a much more

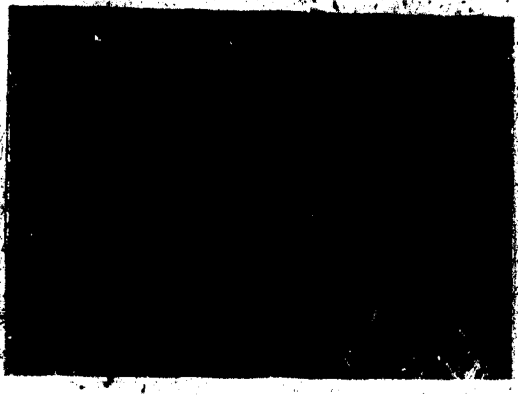


Plate 13 Scratches on the surface of Saranex® fabric after 6 minutes abrasion by the Brush Pilling Tester

Plate 14 Coating on Saranex® partially worn away after 100 cycles of abrasion by the Taber Abraser

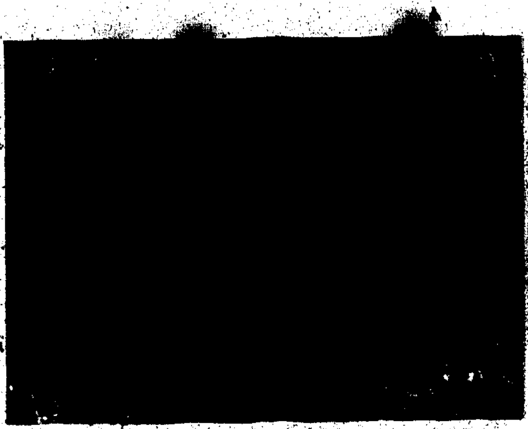


Plate 15 Tyvek® fabric abraded for 6 minutes by the Brush Pilling Tester showing entanglement of fibers

Plate 16 Tyvek® fibers twisted into a "yarn" after 100 cycles abrasion by the Taber Abraser

abrasive test or a longer abrasion time would be required to cause fabric breakdown. The saran coating on Saranex® protected the fibers in the nonwoven fabric structure, preventing any fiber damage or pilling from occurring. Although Saranex® is a nonwoven fabric and is considered a disposable fabric, the thick saran coating caused the fabric to respond to abrasion in a manner qualitatively different from that of Tyvek® or Kleenguard® EP. For these reasons, and because Saranex® is more expensive and less readily obtained, Saranex® was eliminated from the project after abrasion testing.

Tyvek®: In the Tyvek® control fabric, which was not abraded (plate 2), fibers of varying sizes, both regular and microfine, were randomly arranged in a web that was melded at regular intervals. After 3 and 6 minutes of abrasion on the Brush Pilling tester (plate 15), the fibers were pulled up out of the fabric structure, and were tangled and twisted. After 100 and 300 cycles of abrasion on the Taber Abraser (Plate 16), the fibers were pulled up out of the fabric structure and twisted into a "yarn", similar to that observed on Kleenguard® EP specimens abraded by the Taber Abraser.

Both abrasion instruments caused noticeable damage to the fabric surface appearance. After abrasion, the regular pattern of melding was obscured by the fibers that were pulled up out of the fabric structure and twisted together. The Taber Abraser caused more severe twisting of the fibers at both the 100 and 300 cycles, than did the Brush Pilling Tester. Neither instrument caused noticeable damage to the fiber surface. Unlike the Kleenguard® EP fabric, there were no cross-markings on the Tyvek® fibers after abrasion.

4.2.5 Summary of abrasion testing

Two abrasion instruments were tested for their simulation of field trial abrasion. The abrasion was evaluated objectively with measurements of residual tensile strength and subjectively by examining SEM photos. Although Tyvek® and Saranex® fabrics were included in the tensile testing, only Kleenguard® EP was compared statistically to specimens abraded in the field. Tyvek® and Saranex® were not worn in a field trial.

Both methods of evaluation demonstrated that the Brush Pilling Tester was better suited than the Taber Abraser, in this study, to simulate field trial abrasion. The mean tensile strength values for Kleenguard® EP on the Brush Pilling Tester fell into a pattern that was similar in range to that produced in the tensile strength tests of field trial specimens. The visual appearance of the abrasion caused by the Brush Pilling Tester was more similar to that of the field trial abrasion than was the Taber abrasion. The severity of the Taber abrasion was demonstrated in both the objective and subjective evaluations. The tensile strength of specimens abraded only 100 cycles on the Taber was lower than all levels on field trial specimens except the most severe level.

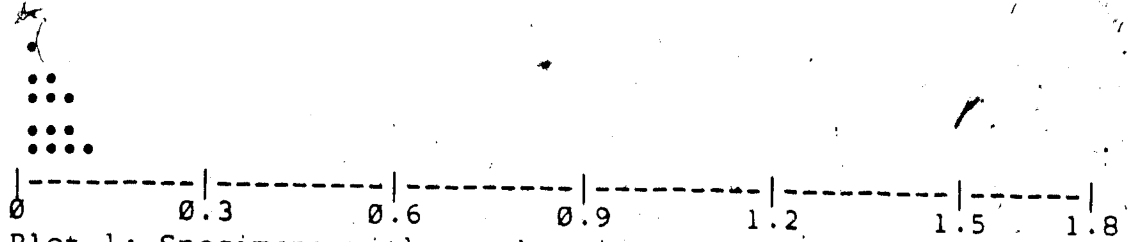
Compared to field trial abrasion, the appearance of the Taber abrasion was more severe also, both in terms of the peculiar twisting of fibers into "yarns" and the depth of the damage, where microfine, meltspun fibers from the inner layer were drawn out to the surface. The abradant wheel and conditions of the Taber test were chosen for their relative gentleness in terms of the degrees of abrasion possible on the Taber Abraser, yet the results are still too severe for the requirements of this study.

4.3 Pesticide Penetration

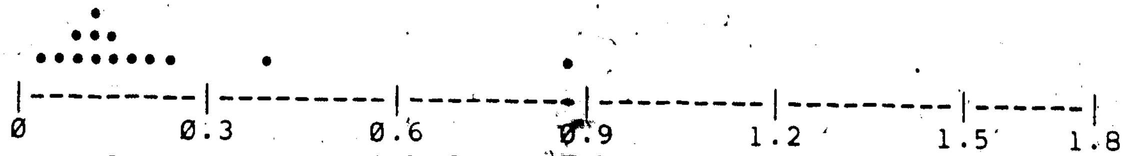
The percentage of tri-allate which penetrated through the disposable coverall fabrics, Kleenguard® EP and Tyvek®, was very low at all levels of abrasion tested. Both fabrics maintained essentially 100% resistance to tri-allate penetration, even at the most severe level of abrasion (see Table 4.3.1 Mean Percent Penetration of Tri-allate). Individual values for percent penetration for all specimens analysed are arranged visually in dotplots on a scale from 0.00% to 1.80% penetration (Figures 4.3.1 and 4.3.2). The three abrasion levels of Kleenguard® EP and Tyvek® are displayed separately. (Refer to Appendix II for individual values.)

Several observations can be made about the Kleenguard® EP values (Fig. 4.3.1). First, a general trend is readily visible in the three abrasion treatments. The percent penetration of tri-allate increased as the abrasion increased. Second, there is a noticeable difference in the

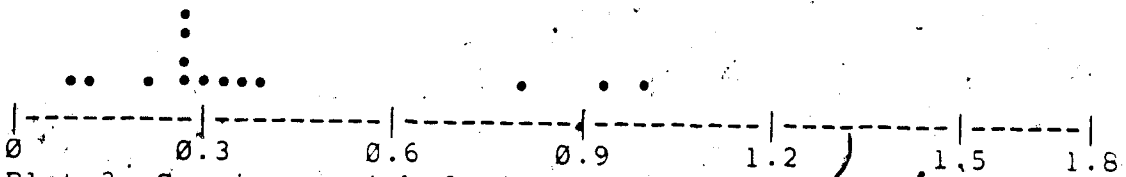
FIGURE 4.3.1 DOTPLOT OF % PENETRATION OF TRIALLATE THROUGH KLEENGUARD® EP FABRIC



Plot 1: Specimens with no abrasion

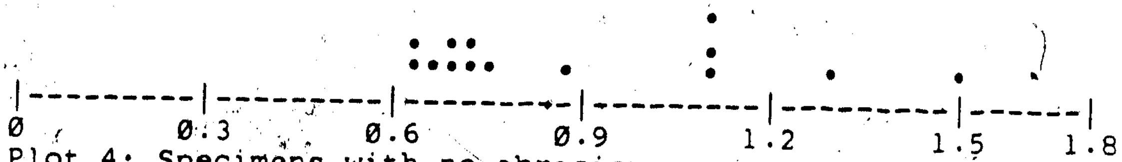


Plot 2: Specimens with 3 minutes pilling

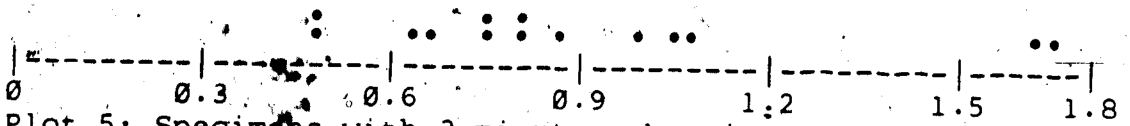


Plot 3: Specimens with 6 minutes pilling

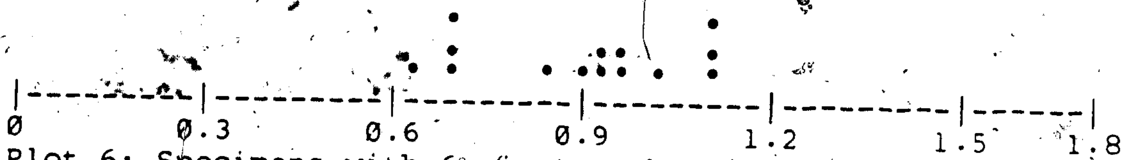
FIGURE 4.3.2 DOTPLOT OF % PENETRATION OF TRI-ALLATE THROUGH TYVEK® FABRIC



Plot 4: Specimens with no abrasion



Plot 5: Specimens with 3 minutes abrasion



Plot 6: Specimens with 6 minutes abrasion

distribution of values for the unabraded control as compared to the two abraded levels. The values for the controls are relatively tightly clustered, ranging from 0.031% to 0.12%. There are no outlying values. In the two abrasion groups (3 and 6 minutes), the clusters of percent penetration values are not as tight and both groups have outlying values. Penetration through specimens abraded 3 minutes ranged from 0.037% to 0.87% and the percent penetration values for 6 minutes ranged from 0.10% to 0.97. For the Kleenguard® EP fabric, the variability of the fabric itself (as demonstrated by penetration in the unabraded fabric) is not as significant as that caused by the abrasion.

There is no significant trend in the distribution of the Tyvek® data (Fig. 4.3.2). There is a scatter in the values from all three abrasion levels. Penetration ranged from 0.69% to 1.51% for the controls, 0.48% to 1.62% at 3 minutes' abrasion and 0.64% to 1.10% after 6 minutes' abrasion. In the case of Tyvek®, the variability of the fabric had a greater influence on the distribution of the values than the abrasion treatment.

Log transformations were performed on the Kleenguard® EP data to achieve homogeneity of variance; however, for convenience of comparison to Tyvek®, the results are reported in non-transformed percent penetration values (Table 4.3.1).

In a one-way ANOVA test, all three levels of abrasion on Kleenguard® EP fabric significantly differed from one another in percent penetration at 95% probability. The means were separated with Student Newman Keul's Multiple Range test. There was a significant increase in pesticide penetration as abrasion increased.

TABLE 4.3.1 PERCENT PENETRATION OF TRI-ALLATE

FABRIC	n	LEVEL OF ABRASION (min)	MEAN % PENETRATION	SD %	GROUPINGS
KLEENGUARD® EP	13	0	0.07	0.03	A*
	14	3	0.20	0.21	B
	14	6	0.40	0.29	C
TYVEK®	14	0	0.93	0.26	D
	14	3	0.89	0.33	D
	14	6	0.90	0.16	D

* groups designated with the same letter are not significantly different

In a one-way ANOVA test on the Tyvek® penetration data, there was no significant difference in the percentage of pesticide penetration for the three levels of abrasion at 95% probability.

Davies, Enos et al. (1982) stated that the amount of pesticide which penetrates a fabric to the underlayer is far smaller than the surface deposit; this observation is certainly true of the fabrics tested in this study. For both fabrics, the mean percent penetration of tri-allate, for all levels of abrasion, was less than 1%. For this pesticide and the conditions of this study, both Tyvek® and Kleenguard® EP provide essentially 100% protection.

Tyvek® maintained the original level of protection, even after it was abraded at levels simulating moderate and very severe field trial wear. In contrast, there was a significant loss in the original protection provided by Kleenguard® EP after both levels of abrasion. Despite this, the mean penetration through Tyvek® at all levels of abrasion is higher than that which penetrated through Kleenguard® EP, even at the most severe level of abrasion. In other words, even when it was abraded, Kleenguard® EP was more resistant than Tyvek to the penetration of tri-allate.

It is possible that the difference in interfacial tension between the fabrics and the pesticide may have an effect on the different penetration rates. During the contamination procedure, droplets of the dilute tri-allate formulation tended to bead up on the surface of the Kleenguard® EP fabric, suggesting a high interfacial tension. In contrast, the droplets of tri-allate readily spread out and wetted the surface of the Tyvek fabric, suggesting a lower interfacial tension. The Kleenguard® fabric used in this study was coated with a repellent "Extra Protection" finish which may contribute to the high interfacial tension and repellency exibited by this fabric.

The two-way interaction of abrasion (three levels) and fabric (two fabrics) on percent tri-allate penetration was significant at 95% probability. When the main effects were separated, the effect of the levels of abrasion was not significant, but the effect of the fabric was significant.

In other words, there is a significant difference in the percent of tri-allate which penetrated the two fabrics that was independent of the abrasion treatment. In order to examine this finding, correlations between thickness and penetration were calculated. The results are presented below.

Effects of fabric weight and thickness on penetration: The initial weight of all specimens was measured prior to pesticide contamination. Also, the initial thickness of the specimen was determined by the calculation of the average of five thickness measurements taken around the specimen centre, where contamination would occur. The thickness at the centre of the specimen was isolated and recorded separately to provide a second indicator of thickness.

For the Kleenguard® EP unabraded controls, there was a significant negative correlation (r= -0.5085) between the average thickness and percent penetration; in other words, the thinner the fabric, the greater the penetration of pesticide. There was no significant correlation between thickness at the specimen centre or initial weight of the specimen and percent pesticide penetration. After 3 and 6 minutes of abrasion, the percent tri-allate penetration correlated with neither thickness (average or at specimen centre) nor initial weight.

As observed in the dotplots and in the ANOVA test, abrasion significantly increased the pesticide penetration on Kleenguard® EP. On this fabric, abrasion contributed more significantly to pesticide penetration than did the variability of the fabric itself. It would appear that the abrasion on the Kleenguard® EP fabric was severe enough to make the variability in the fabric thickness insignificant in terms of its effect on pesticide penetration.

For the Tyvek® specimens which were not abraded, there was a significant negative correlation (r= -0.4990) between the thickness at the centre of the specimen and the percent pesticide penetration. After three minutes of abrasion, there was a significant negative correlation between thickness at the centre and percent tri-allate penetration (r= -0.6861), and average thickness and percent penetration (r= -0.4602). At 6 minutes' abrasion, there was a significant negative correlation between average thickness and percent penetration (r= -0.6072). At all three levels of abrasion on Tyvek®, the initial weight of the specimen did not significantly correlate with the percent pesticide penetration.

At all three levels of abrasion on Tyvek®, either average thickness or the thickness at the specimen centre significantly correlated with the percent penetration, indicating that variability of the fabric (specifically fabric thickness) is a significant factor in pesticide penetration for this fabric. This trend was suggested by the dotplot; the correlation tests confirmed that, of the two fabric characteristics tested, thickness is the significant one.

In this study, initial weight of the specimen was not a significant indicator of pesticide penetration for either fabric. This result differs from the study of DeJonge and Anastasakis (1987) who found fabric weight a better predictor of pesticide penetration than thickness. The weight of the fabric was measured prior to the abrasion treatment on a specimen measuring 23 cm square, which is an area much larger than the 8 cm square specimen used in pesticide penetration. Given the variability in fabric weight over relatively small areas on these nonwoven fabrics (as suggested in the standard deviations for the weight measurements, Section 3.3) it is possible that fabric weight may have been a more significant indicator of pesticide penetration if it had been measured on a smaller specimen.

For both fabrics, prior to abrasion, the penetration of tri-allate increased as the thickness of the specimen decreased. On Tyvek® specimens, the relationship between thickness and pesticide penetration was maintained even after abrasion. In contrast, after abrasion, there was no relationship between thickness and pesticide penetration on Kleenguard® EP. It is possible that the Tyvek® fabric was more resistant to the abrasion than was the Kleenguard® EP fabric. This is suggested in the results of the tensile tests; while there was a significant loss in strength with increased abrasion for Kleenguard® EP specimens abraded on the Brush Pilling Tester, there was no significant difference in tensile strength among unabraded Tyvek specimens and those abraded on the Brush Pilling Tester. Also, in visual observation, the abrasion on Tyvek® did not appear to be as severe as that on the Kleenguard® EP fabric. The pills were small and the fibers were not severely tangled in the "super-pills" observed on the Kleenguard® EP fabric (plate 4).

Several other studies have examined the penetration of pesticides through nonwoven fabrics. Using a spray chamber, Hobbs (1985) tested malathion penetration though 16 fabrics including spunbonded polypropylene with melt blown fibers (SMB) and spunbonded 100% olefin (SBO) fabrics of various weights. A commercially finished SMB allowed a penetration of 218.3 ug/cm^2, while 145.1 ug/cm^2 of the pesticide formulation penetrated a regular unfinished SMB of the same weight. The SBO allowed a penetration of 17.8 ug/cm^2. A Scotchguard® finish reduced the penetration of malathion through both fabrics, to 16.5 ug/cm^2 for the SMB and 5.1 ug/cm^2 for the SBO.

Leonas (1985) tested the penetration of 4 pesticides through twenty-three fabrics including Tyvek® and a polypropylene fabric with a sandwich of spunbonded/meltblown/spunbonded fiber layers (SMS), a construction similar to that of Kleenguard®. Both fabrics completely resisted the penetration of dicofol and ethion. The penetration of methyl parathion was similar for both fabrics, 9.5 ug/cm^2 for Tyvek® and 8.5 ug/cm^2 for the SMS. In contrast, approximately 8.3 times more captan penetrated through Tyvek® than the SMS fabric.

Both Hobbs and Leonas used fabrics similar to those used in this study; however, direct comparisons cannot be made because both presented their results only as the amount of pesticide that penetrated the fabrics and neither stated the total amount of pesticide that was initially applied to the upper fabric. For that reason, comparisons of the percentage of pesticide penetration cannot be made. Also, differences in the contamination techniques must be considered. Like Hobbs, Leonas used a spraying chamber to contaminate specimens. The pressure of the spray would affect penetration of the liquids. One observation can be made about the results of these studies. Unlike the results for tri-allate, Kleenguard-like fabrics did not always allow a lower pesticide penetration rate than Tyvek®.

Two studies did use a contamination procedure similar to the pipetting procedure used in this study. Laughlin et al. (1984) pipetted 0.2 mL of a dilution of methyl parathion onto Tyvek®. Of the pesticide applied, 0.10% penetrated to a 50/50 cotton/polyester poplin under layer, and another 0.10% penetrated through the poplin to a collector pad. The percentage penetration of methyl parathion (a total of 0.2%) was less than, but relatively similar to, the penetration of tri-allate through Tyvek® in this study (0.9266%).

Staiff et al. (1982) contaminated spunbonded, 100% olefin (SBO) specimens with 0.2 mL of concentrated parathion in the emulsifiable concentrate formulation. After 3 minutes, 33.14% of the pesticide penetrated the SBO. A maximum penetration of 50.3% occurred after 1 [illegible] In this study, the penetration of parathion was much higher than that observed for tri-allate or methyl parathion on similar fabric. The concentration of the pesticide formulation may be a factor in the higher penetration rate. Also, during the penetration test, Staiff et al. placed 50 mL beakers over the 0.2 mL "splash" to maintain constant surface area and surface contact. This procedure would enhance penetration.

In conclusion, there was a significant difference in the penetration of tri-allate through Kleenguard® EP and Tyvek® although penetration was less than 1% for both fabrics. Abrasion caused a significant increase in pesticide penetration through Kleenguard® EP, but it had no significant effect on the penetration through Tyvek®. At the most abraded level on Kleenguard® EP, however, the penetration of tri-allate was about 2.5 times less than the penetration of tri-allate through Tyvek®. And finally, fabric thickness correlated with pesticide penetration for all three levels of abrasion on the Tyvek® fabric, and for the unabraded Kleenguard® EP fabric, but after abrasion, there was no relationship between thickness and pesticide penetration on Kleenguard® EP. This study simulated levels of abrasion which might typically occur on disposable coveralls after approximately 12 hours of wear; if the coveralls were worn for a longer time period, both the levels of abrasion and the rate of pesticide penetration may significantly increase.

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

The purpose of this study was to examine the effect of abrasion on pesticide penetration through disposable coverall fabrics. Prior to the pesticide penetration study, testing was conducted in order to establish laboratory abrasion which simulated abrasion observed on Kleenguard® EP coveralls after they were worn in a field trial.

Of the two abrasion instruments tested, the Brush Pilling Tester produced abrasion on Kleenguard®-EP more similar to that observed on garments worn in the field trial than did the Taber Abraser, both in terms of residual tensile strength and the visual appearance as observed in scanning electron microscope photos. The abrasion on the Kleenguard® EP fabric, produced by the Taber Abraser, was similar only to the most severe level of field trial abrasion. Tyvek® was abraded by both instruments, but not significantly in terms of tensile strength, except at 300 cycles on the Taber Abraser. Saranex® was not abraded significantly by either instrument, and therefore, was not included in the pesticide penetration study. In SEM photos, the abrasion produced by the Taber Abraser differed from that produced in the field or by the Brush Pilling Tester in three ways: 1. the abrasive damage on the Kleenguard® EP fabric penetrated to the inner layer, where microfine fibers were drawn out to the surface; 2. the loosened fibers on both Kleenguard® EP and Tyvek® were spun into a "yarn" by the circular motion of the machine; and 3. the Taber Abraser caused the coating on Saranex® to begin to wear away while the Brush Pilling Tester caused only random scratches on the surface of the Saranex® fabric, even after 6 minutes of brushing time.

The mean percentage of the dilute tri-allate formulation which penetrated both coverall fabrics was less than 1%, even after abrasion. The penetration of tri-allate through Tyvek®, however, was about 2.5 times higher than the penetration through Kleenguard® EP at the most abraded level. For Kleenguard® EP, there was a significant increase in the penetration of tri-allate as the level of abrasion increased. For Tyvek®, there was no significant difference in pesticide penetration at all three levels of abrasion.

The percentage of pesticide which penetrated through unabraded Kleenguard® EP fabric increased significantly when the initial thickness of the specimen decreased. This correlation between thickness and penetration was not significant when the fabric was abraded at the two levels. At all three levels of abrasion on Tyvek®, pesticide penetration increased as the initial thickness of the specimen decreased. There was no significant correlation between the initial weight of the specimen and pesticide penetration for either fabric.

5.2 Conclusions

The levels of abrasion used in the penetration study were chosen to simulate moderate and very severe levels of abrasion typically found on Kleenguard® EP coveralls worn for approximately one day in a field trial. In the pesticide penetration study, both moderate and very severe abrasion caused a significant increase in the penetration of dilute tri-allate through Kleenguard®EP. At both levels of abrasion, there was no significant increase in the penetration of tri-allate through Tyvek®. In actual wear, therefore, a Tyvek® garment abraded at these levels should maintain the protection to spills and splashes of the original, unabraded garment if the conditions of contamination are similar to those simulated in this study. During a typical day's wear, Kleenguard® EP would begin to lose its original level of protection from spills and splashes as the coverall became abraded. Despite this, even at the most abraded level, Kleenguard® EP still provided greater protection than the unabraded Tyvek®. In the conditions of this study, the penetration of tri-allate was approximately 2.5 times higher through Tyvek® than Kleenguard® EP at the most abraded level. Yet, according to the results of this study, both fabrics are likely to provide a relatively high degree of protection from spills and splashes of tri-allate; penetration even at the most abraded level, was less than 1%. In other words, 99% of the dilute tri-allate did not penetrate the fabrics, but simply stayed on the fabric surface. During the contamination procedure, the droplets of pesticide tended to bead up and then dry on the surface of the Kleenguard® EP. In actual wear conditions, body movement would probably cause the droplets to roll off the fabric surface. In contrast, the droplets of pesticide readily spread out and wetted the surface of Tyvek®. The protection of either fabric to spray or a contamination source that is at a greater pressure than that used in this study cannot be determined from this study.

In light of these results, farmers should be educated to recognize the signs of abrasion (fuzzing, pills, cuts, holes, or thin spots) on their disposable coveralls. To ensure the highest protection and safety while wearing disposable coveralls, farmers should be warned to remove coveralls if they are noticeably abraded. Of the three fabrics tested in the abrasion study, Kleenguard® EP is the one most likely to suffer abrasion in field conditions. On the other hand, Saranex® would likely perform better, suffering less abrasion, than Kleenguard® EP or Tyvek® in the wear conditions of farmers spraying pesticides. This study examined durability and repellency, but factors such as comfort and economics also are important considerations when farmers select coveralls.

5.3 Recommendations

This research was conducted to study the relationship between abrasion and pesticide penetration. One of the key problems of the project was to find a laboratory method of abrasion which simulated, in range and type, the abrasion found on field trial nonwoven garments. Other aspects of the study, such as variations in the pesticide and the method of contamination, were held constant in order to control and simplify results in relation to the abrasion. Many other aspects of the research require further study in order to completely understand the factors of abrasion in the field, the simulation of that abrasion and the relationship between abrasion and pesticide penetration on disposable coveralls. Further research could include:

1. A duplication of the study, with other pesticides and other formulations of pesticides.

2. Penetration studies on abraded disposable fabrics in which the effects of pressure during spraying are simulated: both the pressure from the contamination procedure and the pressure from the body underneath the coveralls.

3. Penetration studies on abraded disposable fabrics in which the effects of temperature are examined.

4. Further testing of the abrasion produced in the laboratory. Specimens taken from coveralls worn in a field trial (where the conditions of spraying are maintained

without the use of actual pesticides) could be ranked in the same levels of abrasion used in this study. The penetration study could then be replicated on these specimens. Comparisons between the penetration of pesticide through field trial and laboratory abraded specimens could be made, to further determine the effectiveness of the laboratory simulation of field trial abrasion. 5. Observation of agricultural workers, preferably recorded on video tape, in the process of spraying pesticides to determine what factors cause abrasion on the coveralls. This information could be used to improve the laboratory simulation of field abrasion.

6. A replication of the experiment using other nonwoven fabrics.

7. Tyvek® and Saranex® could be included in a field trial to determine how abrasion affects the performance of the fabrics.

8. Another aspect of the durabilty of the coveralls could be examined by testing the rate of pesticide penetration through the seams on disposable coveralls.

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APPENDIX I

DISPOSABLE COVERALL SURVEY

May 6, 1987

Dear District Home Economist;

A joint research project is now being conducted by the Clothing ~~and~~ Textiles Department at the University of Alberta and Alberta Agriculture to test disposable coveralls and disposable gloves for their use by farmers when applying pesticides. As a part of this research, we are interested in determining what types of disposable coveralls and gloves are readily available to Alberta farmers, should they desire to purchase these products. You can assist us by determining what local stores in your district carry disposable coveralls and gloves. We require information about the fiber type, design features, cost and the size ranges available. We have included an information sheet about various disposable coverall fabrics to help you to evaluate the coveralls which you encounter. For your convenience, a survey is enclosed for you to record this information.

If you have any questions about this survey, please call:

Bertha Eggertson	427-2412
Sherri Martin-Scott	432-7216

Please return the survey by June 1, 1987. Thank-you for your assistance,

Sincerely,

Sherri Martin-Scott

DISPOSABLE COVERALL FABRICS

Kimberley Clark produces three 100% polypropylene disposable coveralls.

1. Grey Kleenguard
   - with blue stitching

2. White Kleenguard
   - with green stitching

3. White Extra Protection Kleenguard
   - with red stitching

These coveralls cost approximately $7.00 - $10.00

Tyvek is a registered trademark of E. I. Dupont for its 100% spunbonded olefin fabric. This fabric is made into coveralls by various companies; for example, Seam Enterprises, Durafab, Pro-Tec-Tion, etc.

There are at least three types of Tyvek coveralls which you may encounter:

1. Regular Tyvek
   - white
   - approximately $10.00

2. Polyethylene (PE) Coated Tyvek
   - yellow or grey
   - approximately $20.00 - $30.00

3. Saranex Laminated Tyvek
   - white
   - approximately $20.00 - $30.00

You may find disposable coveralls that are neither Kleenguard nor Tyvek, made by manufacturers other than those mentioned here. Indicate these coveralls on the survey under the heading "Other".

DISPOSABLE COVERALL SURVEY

1. WHICH LOCAL STORES CARRY DISPOSABLE COVERALLS AND/OR DISPOSABLE GLOVES?

2. WHAT BRANDS OF DISPOSABLE COVERALLS AND GLOVES ARE IN STOCK AT THESE STORES?

COVERALLS

Please check (√) fiber type in the appropriate column, indicate size ranges available and cost and designate design features with codes listed below.

CODES FOR DESIGN FEATURES

Hood = H
Sleeve: Raglan = R
Fitted = F
Boots = B
Type of closure: Zipper = Z
Snaps = S

MANUFACTURER	FABRIC TYPES	(√)	DESIGN	COST	SIZES
Kimberly Clark	Grey Kleenguard				
	White Kleenguard (green stitching)				
	White Extra-Protection Kleenguard (red stitching)				
Seam, Durafab, Pro-Tec-Tion	Tyvek Spunbonded Olefin (white)				
	Polyethylene Coated Tyvek (yellow or grey)				
	Saranex Laminated Tyvek (white)				
Other					

GLOVES - (disposable only; for example, surgical gloves)
Please provide as much information as posible.

MANUFACTURER	FABRIC CONTENT AND FINISHES OR COATINGS	COST	SIZES

3. IN YOUR ESTIMATION, WHICH COVERALL IS MOST COMMONLY AVAILABLE?

4. IN YOUR ESTIMATION, WHICH COVERALL IS MOST COMMONLY AVAILABLE?

APPENDIX II

RAW DATA

FABRIC: Tyvek REPLICATION: 1

* average of two

TREATMENT	Volume Std INJECTED	CONC STD g/mL	Volume SPEC. INJECTED	SPECIMEN DILUTION FACTOR	PEAK * HEIGHT STD (mm)	PEAK * HEIGHT SPEC (mm)	PENETRATION (mg)	(%)
0.5mL IN FLASK	7μL	1.0 x 10^{-5}	7μL	1000	173	199.0	11.50	-
	"	"	"	"	177.2	162.3	9.16	-
	"	"	"	"	169.8	163.5	10.49	-
	"	"	"	"	176.6	198.8	11.26	-
	"	"	"	"	177.8	174.4	9.81	-
	"	"	"	"	178.3	185.5	10.40	-
							ave.: 10.44 mg	
CONTROLS (no abrasion)	7μL	10^{-5}	7μL	10	80.0	60.4	7.55 x 10^{-2}	0.723
	"	10^{-6}	"	100	134.5	212.0	1.578 x 10^{-1}	1.511
	"	"	"	"	152.2	135.8	8.93 x 10^{-2}	0.855
	"	"	"	"	153.3	126.2	8.232 x 10^{-2}	0.7886
	"	"	"	"	153.0	207.8	1.358 x 10^{-1}	1.301
3 min abrasion	7μL	10^{-6}	7μL	1000	182.2	30.9	0.1696	1.624
	"	"	"	100	155.4	77.1	0.0496	0.475
	"	"	"	"	160.7	147.0	0.09148	0.876
	"	"	"	"	169.8	145.0	0.08540	0.818
	"	"	"	"	176.4	149.6	0.08481	0.812
6 min abrasion	7μL	10^{-6}	7μL	100	178.6	137.8	0.07116	0.685
	"	"	"	"	186.9	183.6	0.09823	0.941
	"	"	"	"	185.1	179.2	0.09681	0.927
	"	"	"	"	~~18~~ 184.4	135.3	0.07337	0.703
	"	"	"	"	178.8	119.9	0.06706	0.642

FABRIC: Tyvek REPLICATION: 2

* average of two

TREATMENT	Volume Std INJECTED	CONC STD g/mL	VOLUME SPEC. INJECTED	SPECIMEN DILUTION FACTOR	PEAK * HEIGHT STD (mm)	PEAK * HEIGHT SPEC (mm)	PENETRATION (mg)	(%)
0.5mL in FLASK	7μL	10^{-6}	7μL	10,000	100.4	108.1	10.767	-
	"	"	"	"	102.5	107.4	10.418	-
	"	"	"	"	104.3	116.4	11.160	-
	"	"	"	"	101.9	96.8	9.4995	-
	"	"	"	"	89.9	100.9	[illegible]	
							ave = 10.62 mg	
CONTROLS (no abrasion)	7μL	10^{-6}	7μL	100	104.0	121.9	0.11721	1.1037
	"	"	"	"	104.4	122.6	0.11743	1.1057
	"	"	"	"	102.0	120.2	0.11784	1.1096
	"	"	"	"	106.8	78.3	0.073315	0.6903
	"	"	"	"	113.0	90.0	0.079646	0.750
3 min abrasion	~~7μL~~	10^{-6}	7μL	100	104.6	110.8	0.10593	0.9977
	"	"	"	"	~~127.2~~ 111.6	127.2	0.11398	1.073
	"	"	"	"	111.4	124.4	0.11167	1.0515
	"	"	"	"	117.0	93.4	0.07985	0.7517
	"	"	"	"	115.7	93.4	0.07869	0.74096
6 min abrasion	7μL	10^{-6}	7μL	100	117.5	118.5	0.10051	0.946
	"	"	"	"	114.0	110.8	0.09719	0.914
	"	"	"	"	114.0	133.0	0.11667	1.10
	"	"	"	"	117.0	137.2	0.11726	1.10

FABRIC: Tyvek REPLICATION: 3 * average of two

TREATMENT	Volume Std INJECTED	CONC STD g/mL	Volume SPEC. INJECTED	SPECIMEN DILUTION FACTOR	PEAK HEIGHT STD (mm) *	PEAK HEIGHT SPEC (mm) *	PENETRATION (mg)	(%)
0.5mL in FLASK	7µL	1.0 x 10⁻⁶	7µL	10,000	157.1	167.5	10.662	—
	"	"	"	"	156.7	176.7	11.276	—
	"	"	"	"	150.7	165.5	10.982	—
	"	"	"	"	142.7	150.5	10.566	—
	"	"	"	"	151.3	170.2	11.249	—
							ave: 10.94 mg *	
CONTROLS (no abrasion)	7µL	1.0 x 10⁻⁶	7µL	100.	146.7	112.8	0.07689	0.7041
	"	"	"	"	150.4	123.4	0.08205	0.7514
	"	"	"	"	151.4	131.6	0.08692	0.796
	"	"	"	"	149.7	124.4	0.08310	0.782
3 min abrasion	7µL	10⁻⁶	7µL	100	153.3	159.3	0.10391	0.950
	"	"	"	"	155.6	143.4	0.09216	0.842
	"	"	"	"	160.4	194.3	0.12114	1.10
	"	"	"	"	161.2	121.7	0.07550	0.690
	"	"	"	"	164.5	184.2	0.11198	1.02
6 min abrasion	7µL	10⁻⁶	7µL	100	149.4	104.6	0.07013	0.6411
	"	"	"	"	151.6	80.2	0.0529	0.484
	"	"	"	"	155.0	247.5	0.15968	1.460
	"	"	"	"	151.2	108.8	0.07196	0.6578

FABRIC: Kleenguard EP REPLICATION: 1 * average of two

TREATMENT	Volume Std INJECTED	CONC STD g/mL	VOLUME SPEC. INJECTED	SPECIMEN DILUTION FACTOR	PEAK * HEIGHT STD (mm)	PEAK * HEIGHT SPEC (mm)	PENETRATION (mg)	(%)
0.5 mL in FLASK	Same as Tyvek						Ave: 10.44 mg	
CONTROLS (no abrasion)	5µL	1.0x10^-6	7µL	100	212.3	26.7	0.008983	0.0860
	"	"	"	10	211.3	# 122.6	0.00414	0.0396
	"	"	"	4	206.4	112.0	0.00388	0.0372
	"	"	"	100	206.0	31.2	0.01082	0.1036
	"	"	"	10	211.6	109.0	0.00368	0.0352
3 min abrasion	5µL	1.0x10^-6	7µL	100	212.8	99.8	0.01672	0.160
	"	"	"	"	206.2	36.2	0.01254	0.120
	"	"	"	"	204.4	54.1	0.01891	0.1811
	"	"	"	"	210.3	41.4	0.01406	0.1347
					216.0	65.5	0.02166	0.2075
6 min abrasion	5µL	1.0x10^-6	7µL	100	192.5	56.0	0.02078	0.1990
	"	"	"	"	209.0	101.4	0.03466	0.3320
	"	"	"	"	212.4	86.8	0.02919	0.2796
	"	"	"	"	218.0	86.0	0.02818	0.2699
	"	"	"	"	226.3	115.5	0.03646	0.3492

FABRIC: Kleenguard EP REPLICATION: 2

* average of two

TREATMENT	Volume Std INJECTED	CONC STD g/mL	VOLUME SPEC. INJECTED	SPECIMEN DILUTION FACTOR	PEAK HEIGHT STD (mm) *	PEAK HEIGHT SPEC (mm) *	PENETRATION (mg)	(%)
0.5mL IN FLASK		Same as Tyvek					Ave: 10.62mg	
CONTROLS (no abrasion)	7µL	1.0x10⁻⁶	7µL	10	130.4	43.2	0.003129	0.0312
	"	"	"	"	129.6	80.0	0.006173	0.0581
	"	"	"	"	106.8	72.4	0.006779	0.0638
	"	"	"	"	116.8	85.8	0.007365	0.0693
3 min abrasion	7µL	1.0x10⁻⁶	8µL	10	124.8	31.2	0.0250	0.235
	"	"	5µL	10	130.8	120.6	0.0922	0.8682
	"	"	7µL	10	[illegible]	145.8	0.01058	0.0996
	"	"	"	"	140.8	77.4	0.005497	0.05176
6 min abrasion	7µL	1.0x10⁻⁶	7µL	100	151.9	42.2	0.02778	0.2616
	"	"	8µL	"	147.3	74.2	0.04077	0.3839
	"	"	8µL	"	221.2	219.6	0.08687	0.8180
	"	"	7µL	"	213.6	207.6	0.09119	0.9152

FABRIC: Kleenguard EP REPLICATION: 3 * average of two

TREATMENT	Volume Std INJECTED	CONC STD g/mL	VOLUME SPEC. INJECTED	SPECIMEN DILUTION FACTOR	PEAK * HEIGHT STD (mm)	PEAK * HEIGHT SPEC (mm)	PENETRATION (mg)	(%)
0.5mL in FLASK		Same	as	Tyvek			Ave: 10.94 mg	
CONTROLS (no abrasion)	7uL	1.0x10⁻⁶	7uL	10	139.0	145.1	0.010439	0.0954
	4	"	"	"	142.7	193.1	0.01353	0.1237
	"	"	"	"	148.8	90.1	0.006055	0.0553
	"	"	"	"	150.0	145.2	0.00968	0.0855
3 min abrasion	7uL	1.0x10⁻⁶	7uL	100	143.6	61.2	0.04262	0.3900
	"	"	"	10	126.4	120.0	0.009494	0.0868
	"	"	"	"	136.3	171.6	0.01258	0.1151
	"	"	"	"	139.2	56.5	0.0040589	0.0371
	"	"	"	"	143.6	167.2	0.0163	0.149
6 min abrasion	7uL	1.0x10⁻⁶	7uL	100	140.6	45.1	0.03208	0.2932
	"	"	5uL	10	146.8	130.4	0.0125	0.1143
	"	"	7uL	100	145.6	156.0	0.10714	0.9793
	"	"	5uL	10	140.0	111.0	0.01110	0.1015
	"	"	4uL	10	239.8	139.6	0.03006	0.2748