

PROTECTIVE CLOTHING FOR PROFESSIONAL PESTICIDE USERS

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Abstract—The growing concern for health and safety of pesticide workers in the United States has generated standards and regulations as well as standard practices of worker hygiene and a recent increase in research in personal protective equipment (PPE). Personal protective equipment includes protective clothing and such gear as face masks, respirators, gloves, boots and other items, and the current U.S.A. federal regulations and standards are reviewed. All clothing is protective to some extent, yet protective clothing can act as an occlusive dressing, holding chemicals in contact with the skin, an organ of transpiration. The greatest health risk from pesticides comes through primary exposure, yet secondary exposure can happen through wearing contaminated clothing or through decontamination. By making persons exposed to pesticides more aware of dangers, how to avoid contamination, and how to deal with contaminated PPE, the potential for adverse effects may be reduced. Recent work in the area is summarized; however, given the 1,500 active ingredients, 35,000 formulations, and the hundreds of activities, sites and exposure patterns, more work of a predictive nature on successful decontamination refurbishment of personal protective equipment is needed.

INTRODUCTION

Pesticides are valuable pest management tools, and as with any tool, must be used carefully and responsibly. Minimizing exposure is an important first step toward reducing risk of pesticide poisoning. Depending on the relative toxicity of the pesticide, accidental exposure to, or misuse of, a pesticide can have serious consequences. An understanding of the toxicity of the product and potential for personal exposure helps workers develop good habits of personal hygiene as well as personal safety that can mediate the risk. Personal protective equipment (PPE) benefits the worker and is a visual expression of appropriate pesticide use.

Widespread concern has led to federal standards in the United States, along with increased emphasis a measure of added safety through personal hygiene. Mandatory standards are viewed as appropriate because decision making about PPE is complicated by the broad range of pesticide products, toxicities, formulations and application methods.

Pesticides “protect us from insects, weeds, disease and hunger, but exposure to some pose a risk of cancer, birth defects, genetic mutations, and sterility” (Boraiko, 1980). Exposure does not mean the same as toxicity, but exposure is a problem for workers who use pesticides. The risk formula is $\text{Risk} = \text{Toxicity} \times \text{Exposure}$. Toxicity may vary by species, route of intake, formulation of pesticide, the products' age or relative potency, and the sex, age, and nutritional status of recipient. Savage *et al.* (1980) established a relationship between acute organophosphate poisonings occurring at a point in time and subsequent neurological problems. There are indications of cause-and-effect relationships between pesticide use and human health, including cancer occurrences (Buesching & Wollstadt, 1984; Burmeister *et al.*, 1984; Cantor, 1982; Hoar *et al.*, 1986).

Pesticides can enter the body orally, be absorbed through the skin, or breathed in through the lungs. There are two basic approaches to estimating occupational exposure to pesticides. Passive dosimetry is used to estimate the amounts of chemical contacting the surface of the skin or the amount of chemical available for inhalation through the use of appropriate trapping devices. Biological monitoring is used to estimate the internal dose from either a measurement of body burden in selected tissues or fluids or from the amount of pesticide and its metabolites as eliminated from the body.

Pesticide dermal exposure has only recently received attention, perhaps because the older pesticides are more poorly absorbed through the skin (Matsumara & Madhukar, 1980). For outdoor foliage applications, dermal exposure is of greater concern than inhalation exposure. Dermal exposure accounts for about 90% of the total exposure load (Wolfe *et al.*, 1972; Gold & Holcslow, 1985; Maibach *et al.*, 1971), and less than 1% of exposure is via respiration (Wolfe *et al.*, 1976). By minimizing exposure, risk can be minimized. PPE can help minimize exposure. Kansas

farmers who did not use protective clothing and equipment when working with herbicides had a higher risk of cancer than those who did protect themselves (Hoar *et al.*, 1986).

All clothing is protective to some extent, yet clothing can act as an occlusive dressing, holding pesticides in contact with the skin, an organ of transpiration. Contaminated work clothing enhances dermal absorption of organophosphate insecticides (Wicker *et al.*, 1979). Individuals wearing obviously contaminated clothing showed greater levels of exposure than did other workers (Lavy *et al.*, 1983).

By making persons who work with pesticides more aware of dangers, and knowledgeable about how to avoid contamination, and how to deal with contaminated clothing, the potential for adverse effects may be reduced. However, given the 1,500 active ingredients, 35,000 formulations, and the hundreds of activities, sites and exposure patterns, education alone cannot provide the full measure of protection, thus pesticide labeling is mandatory in the U.S., and employers are responsible for worker adherence (40 CFR §156)

If exposure is high, pesticides have dangerous potentiality. Labels provide information about short term (acute) effects of the pesticides through signal words – *Danger* on highly toxic products, *Warning* on moderately toxic products, and *Caution* on slightly toxic products. These signal words represent the classifications established by LD₅₀ values for oral and dermal dosages. The long term health effects (chronic effects) can be evaluated by reviewing the Occupational Safety and Health Administration mandated *Material Safety Data Sheet (MSDS)*. These provide information about whether the pesticide has been shown to product birth defects, cancer, and/or reproductive impairments in laboratory animals. *MSDSs* also provide more detail about potential acute effects of pesticides.

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) enables the Office of Pesticide Programs of the Environmental Protection Agency (EPA) to register chemicals for use as pesticides, provided that, among other criteria, “when used in accordance with widespread and commonly recognized practice, [they] will not generally cause unreasonable adverse effects on the environment” (40 CFR §152). Product testing ensures that pesticides are effective against target pests with minimum risk to people and the environment before introduction for public use.

EPA has issued revised guidelines designed to aid pesticide registrants and others in monitoring pesticide exposure and determining label information (40 CFR §170). The Worker Protection Standard is “designed to reduce the risk of illness or injury resulting from workers’ and pesticide handlers’ occupational exposures to pesticides used in the production of agricultural plants on agricultural establishments.” Any data used for registration by the chemical company must adhere to the published guidelines and have been conducted under Good Laboratory Practices (40 CFR §160). “Each individual pesticide product label may list specific PPE requirements reflecting the formulation, anticipated exposure route and level, and all forms of toxicity of the product” (40 CFR §156). Label information about use of PPE is part of the required testing and is to be included on the label section titled *Hazards to Humans: “Directions for Use; It is a violation of the law to use this pesticide in a manner inconsistent with its labelling.”* This statement effectively assigns the legal responsibility for safety to users of pesticide products, including the requirement to use whatever PPE is specified in the “Precautionary Statements.”

Route of entry statements indicate to the user the outcome that can be expected from exposure. For example, under the Pesticide Labeling Requirements (40 CFR §156), a pesticide label might read: “Poisonous if swallowed, inhaled, or absorbed through the skin. Rapidly absorbed through the skin and eyes.” This tells the user that this pesticide is a potential hazard through all three routes of entry, and that skin and eye contact are particularly hazardous. The specific action statements normally follow the route of entry statements and indicate what must be done to prevent poisoning accidents. In the case just described, the label might contain a statement: “Do not get in eyes, on skin, or on clothing. Do not breathe spray mist.”

PPE can mediate exposure if used and maintained correctly, thus reducing risk. Level I or basic protection includes a washable hat or cap with a full brim, firmly woven launderable long-sleeved shirt, and trousers. Additional protection can be realized by adding waterproof headcovering, face shield, goggles or respirator, cotton overalls with a waterproof apron, gloves and boots (Level II) and Level III PPE includes specialized impermeable clothing. Pesticide workers should use route of entry and specific action statements from the label to determine the type and degree of protection

that is needed to handle a pesticide safely. The PPE label statement interpretations can be used as a generalized guide to appropriate PPE selection (Table 1).

There are two general classifications of PPE garments: single use and reusable. A single-use garment is used once and then discarded; a reusable garment is used, decontaminated, stored and used at a later date. Important to reusing a garment is the efficacy of decontamination. Contamination may be of two types: "surface" contamination and "matrix" contamination. Surface contamination is chemical on the surface of PPE. Matrix contamination is chemical that has permeated or penetrated into the fabric or fiber. This chemical may reside in the interstitial spaces of fabrics, in the pores of the rubber, leather, or film or in the internal structure of fibers such as the lumen of cotton. Matrix contamination is not readily removed by decontamination nor is it readily detected visually. Scanning electron micrographs and x-ray diffraction analysis showed that pesticide residue deposits in the lumen and crenulations of cotton, and in the capillary spaces between polyester fibres (Obendorf & Solbrig, 1986; Breen *et al.*, 1984; Webb & Obendorf, 1987; Weglinski & Obendorf, 1985; Obendorf, 1988; Obendorf *et al.*, 1983). With pesticide residues deep

Table 1. Interpreting Personal Protective Equipment (PPE) Labeling Statements

Labeling Statement	Acceptable Personal Protective Equipment
Protective Eyewear	eye protection; safety glasses with brow and side shield; or full face shield
Goggles	chemical resistant goggles or full face shield over safety glasses
Dust/mist filtering respirator	Respiratory with organic vapor removing cartridge and pesticide prefilter; Respirator with pesticide approved canister; Air-supplying respirator
Canister respirator (gas mask)	Respirator with pesticide approved canister; Air-supplying respirator
Air-supplying respirator or self-contained breathing apparatus	Air-supplying respirator or self-contained breathing apparatus
Long-sleeved shirt and long-legged pants	Long-sleeved shirt and long-legged pants; Any coverall; or Any rubber or plastic suit
Coverall worn over short-sleeved shirt and short pants	Coverall worn over short-sleeved shirt and short pants; Long-sleeved shirt and long-legged pants; Any coverall; Plastic- or other barrier-coated coverall; or Any rubber or plastic suit
Chemical resistant apron worn over coverall or long-sleeved shirt and long-legged pants	Chemical resistant apron worn over coverall or long-sleeved shirt and long-legged pants; Plastic- or other barrier-coated coverall; or Any rubber or plastic suit
Chemical resistant protective suit	Plastic- or other barrier-coated coverall; or Any rubber or plastic suit
Waterproof suit or Liquidproof suit	Plastic- or other barrier-coated coverall; or Any rubber or plastic suit
Waterproof gloves	Any rubber or plastic gloves able to remain intact throughout the task being performed
Chemical-resistant gloves	Barrier-laminate gloves or any Glove Chart or Guidance-Document Approved Gloves
Chemical-resistant gloves such as butyl or nitrile	Butyl or Nitrile gloves or Glove Chart or Guidance-Document Approved Gloves
Shoes	Any leather, canvas, fabric or chemical-resistant shoes, boots, or shoe coverings (booties)
Chemical-resistant footwear	Chemical-resistant shoes, boots, or shoe coverings (booties)
Chemical-resistant boots	Chemical-resistant boots
Chemical-resistant hood or wide-brimmed hat	Rubber- or plastic-coated safari-style hat; Rubber- or plastic-coated firefighter-style hat; Plastic- or other barrier-coated hood; or Full hood or helmet that is part of some respirators

within the fibre, aggressive treatment is needed to remove the residue. After clothing had been laundered, it is generally considered to be clean by most applicators and their family members. (Stone *et al.*, 1986). When the wearer is not aware of pesticide residues in fabrics, dermal exposure may continue from wearing inadequately decontaminated garments. Thus refurbishment is an essential and critical part of continued safety, and decontamination is essential if the garment is to be worn again.

A recent example is the multiple pesticide intoxication case attributed to residue in laundered apparel (Clifford & Nies, 1989). A worker in a pesticide-formulating plant became ill and required hospitalization. Within a two-week period, two other workers required hospitalization for similar symptoms. Reconstruction of the incident shows that the first worker accidentally spilled methyl parathion on his coveralls. He followed the required safety measures of an immediate shower, then placed the plant-issued uniform in a disposal bag to be burned. Instead, the plant laundered the first worker's uniform and reissued to him, leading to his second episode of illness and hospitalization. While he was hospitalized, the launderers washed the coveralls, then reissued the garment to a second worker, who subsequently also required hospitalization for acute pesticide poisoning. After yet another laundering, a third worker wore the coveralls, then required medical attention for pesticide intoxication. The plant launched a thorough investigation of plant practices that may have contributed to the incident *before* discovering that the often-laundered coveralls rather than manufacturing procedures were responsible (Clifford & Nies, 1989).

Southwick *et al.* (1974) reported the death of an adult male attributed in part to wearing laundered clothing that held residues of methyl parathion. Young boys in Fresno, CA suffered parathion intoxication as a result of wearing contaminated-then-laundered blue jeans (Warren *et al.*, 1963).

The preponderance of decontamination is done at home using family or commercial laundering equipment. Finley and co-workers (Finley & Rogillio, 1969; Finley *et al.*, 1974; Finley *et al.*, 1977; Finley *et al.*, 1979) established that residues remain after decontamination. A complete removal of pesticide residues from laundered fabric seldom has been achieved (Laughlin & Gold, 1988). A farmer's coveralls worn through four planting seasons had residues of Treflan, Lorsban, Counter, Dyfonate and Thimet from normal management of corn and soybean crops that were not removed completely by home laundering and remained in the fabric for an extended time (Stone & Stahr, 1989).

DECONTAMINATION OF PROTECTIVE APPAREL

The research on decontamination is based on theories of soiling and soil removal, including the goal of maintaining an optimum balance of chemical energies, thermal energies and mechanical energies in the laundering process (Laughlin & Gold, 1988). The extent of soil removal in the cleansing process is affected by the soil, fabric substrate, cleaning method and interactions among all three factors, complicated by the chemical nature of pesticides which present additional challenges in soil removal. For example, emulsifiable concentrates (EC) may contain xylene, toluene, methyl ethyl ketone, or ethylene dichloride, among others. Wettable powders (WP) may be made up in clay, chalk or talc.

Pesticides as Soil

We have studied the problem of pesticide residues or "invisible soil" remaining in protective apparel after laundering (Laughlin & Gold, 1988). From this research, laundering recommendations have been published (Laughlin & Gold, 1989b) for minimizing direct and indirect exposure to workers and family members through procedures that maximize residue removal. We classified factors affecting successful decontamination as pesticide chemical class, pesticide formulation and pesticide concentration.

Pesticide Chemical Class. Differences among insecticides from three chemical classes of organophosphates, organochlorines and carbamates in pesticide residue after decontamination have been

found (Keaschall *et al.*, 1986; Nelson *et al.*, 1992). The largest overall residues were reported for organochlorines and smallest for carbamates; and within classes, the greatest variability for organophosphates. As much as 37% of chlorpyrifos remained after one laundering.

Pesticide Formulation. The carrier materials, clay or talc in wettable powders, and oils in emulsifiable concentrates, affects residue removal. Parallels were noted between particulate soils and wettable powders, and oil soils and emulsifiable concentrates for methyl parathion (Easley *et al.*, 1982a; Laughlin *et al.*, 1985), azinphosmethyl and Captan (Easter, 1983), and two pyrethroids, cypermethrin and cyfluthrin (Laughlin *et al.*, 1991a). For carbaryl and clorothalonil, removal was greater for the technical material than the formulated product (Fleeker *et al.*, 1988). Methyl parathion was more completely removed when it alone soiled the fabric than when it was mixed with toxaphene and DDT (Finley *et al.*, 1974).

Pesticide Solubility. Decontamination efficiency was dependent on formulation type and solubility (in water) of the active ingredient (Laughlin *et al.*, 1985; Braun *et al.*, 1990). Water-soluble amine formulation of 2,4-D herbicide was more completely removed than the less soluble ester formulation (Easley *et al.*, 1983). Pesticide residue removal was not always a function of pesticide solubility (Nelson *et al.*, 1988), as formulation affected pesticide removal more than solubility. Paraquat removal was enhanced in a salt medium, such as that found in very hard water (Nelson *et al.*, 1989). This may occur with other cationic pesticides such as difenzoquat and diquat. 2,4-D ester (Easley *et al.*, 1983) and chlorpyrifos (Laughlin *et al.*, 1988) were tenacious to decontamination, yet pesticides of similar structures were readily decontaminated.

Pesticide Concentration. Doubling the concentration of the methyl parathion (0.25% A.I., 0.50% A.I. 1.0% A.I. and 2.0% A.I.) decreased residue removal (Easley *et al.*, 1982). Full strength (54% A.I.) was more difficult to remove than the diluted (1.25 A.I.) methyl parathion, with more than 80% of the concentrated product remaining after one laundering and over two-thirds of the residue remaining after ten complete laundering cycles. The residue was approximately the level in laundered clothing in the incident of repeated intoxication that contributed to the death of a man in Utah (Southwick *et al.*, 1974).

Pesticide can "self-concentrate" in fabrics worn during repeated applications without decontamination. Fabrics contaminated daily, then either laundered daily, or after five days of recontamination, showed cumulative build-up of methyl parathion (Goodman *et al.*, 1988). The residue levels were much higher in the daily-dosed fabrics without daily laundering than in the duplicate fabrics laundered daily.

Refurbishment Factors

The deterative process is a result of multiple factors: chemical energies, of water, detergent, laundry aids, and the like; mechanical energies of agitation as well as time or length of cycles; and thermal energies of temperature of water. Factors such as soil saturation and whether the soil is in liquid or particulate form, enhance or inhibit soil removal. If one of these chemical, thermal and mechanical energies is diminished, the laundering process might be maintained at optimal effectiveness by compensation from another energy. For example, even if the laundering temperature is lowered, acceptable level of cleaning might be maintained by increasing chemical energy by concentration of detergent or by increasing mechanical energy by added agitation.

Chemical Energies. Most published research on soil removal has used commercial detergents (mixtures), rather than homogeneous surfactants, because the isolated homogeneous surfactant is unavailable and because the detergent product is what is used in home and commercial laundering. Pesticide residue removal studies also use this model of assessing commercial products for effectiveness of decontamination.

1. *Detergent Type.* Statistical homogeneity was found among four detergents (nonionic heavy duty liquid, and anionics of phosphate, high phosphate and carbonate) for methyl parathion (Easley *et al.*, 1982a; Laughlin & Gold, 1989c), between nonionic heavy duty liquid detergent

and a granular phosphate detergent for atrazine and carbaryl (Raheel & Gitz, 1985), and among three detergents, granulated Tide[®], and heavy duty liquids All[®] and Wisk[®] for carbofuran and methomyl (Chiao-Cheng *et al.*, 1988).

Exception to “no detergent type” effect occurred when pesticide formulation was part of the experiments; particular pesticide residue removal was more effective when an anionic phosphate detergent was used and oily soil pesticide residue removal was enhanced when nonionic heavy duty liquid detergent was used, for a formulation-detergent interaction (Laughlin *et al.*, 1991a; Laughlin *et al.*, 1991b), due to the carrier: oils in emulsifiable concentrate formulations and particulates in wettable powder formulations.

Surfactants are constituents in application-strength pesticides. These surfactants, often cationics, are used to enhance attraction of the pesticide to the target foliar materials; yet residues of cationic surfactants (fabric softener) in the fabric before contamination or used in the laundering process after contamination (through 50 washing cycles) had no effect on methyl parathion absorption and retention (Laughlin & Gold, 1990c).

2. *Detergent Concentration.* When detergent concentration was reduced, pesticide residues increased. Twice as much residue was found in fabrics decontaminated with half the usual amount of detergent (Hild *et al.*, 1989). Residue removal increased as detergent concentration increased, up to a point. When detergent concentration was twice the recommended amount, a plateau was observed.
3. *Prewash Product.* A prewash product provides an additional dosage of surfactant. Improved efficiency of a pre-wash product plus detergent was observed for methyl parathion decontamination with detergent only (Keaschall *et al.*, 1986) and for deltamethrin, trifluralin and triallate (Nelson *et al.*, 1988; Rigakis *et al.*, 1987).
4. *Mineral Content of Water.* The presence of minerals in water may interfere with the cleaning effectiveness of detergent; the detergency of an anionic product being reduced more than that of a nonionic product. As level of water hardness increased above 600 p.p.m., the anionic phosphate detergent was less efficient in methyl parathion removal than the heavy duty liquid detergent; however a prewash product used before laundering with phosphate detergent resulted in residue levels similar to those produced with heavy duty liquid detergents (Laughlin & Gold, 1990a). Similar findings were reported when the contribution of thermal energy (temperature of washing) and chemical energy (detergent type, detergent concentration, use of a prewash product, and level of minerals in water) on methyl parathion residues after laundering was evaluated (Laughlin & Gold, 1991b). Nelson *et al.* (1989) observed the opposite effect for paraquat. Salts in water increased removal of paraquat. They reported little difference in decontamination of chlorothalonil and carbaryl between distilled water and hard water.
5. *Laundry Auxiliaries.* Laundry auxiliaries can shift the chemical energy available in the refurbishment process, to enhance or to diminish chemical energy, thereby affecting the efficiency of laundering. Laundering auxiliaries include: fabric softeners, bleaches, laundry boosters and starch, among others. Fabric softener, whether not used, used once, or used repeatedly with and without removal cycles, had no impact on residue remaining after decontamination (Laughlin *et al.*, 1988; Laughlin & Gold, 1990c). Starch at 4.0% add-on did inhibit penetration through the fabric and did affect absorption of the liquid pesticide, so that subsequent laundering of the fabric removed the starch and absorbed pesticide (Sagan & Obendorf, 1988). Laughlin *et al.* (1988) observed no contribution of 0.5% starch add-on to completeness of chlorpyrifos decontamination. Bleach in the washing process did not decrease contamination of diazinon, chlordane, chlorpyrifos, bromacil, azinphosmethyl and methyl parathion (Lillie *et al.*, 1982; Laughlin *et al.*, 1985).

Thermal Energies. Increased temperature of presoak or rinse cycles did not assist in residue removal, but temperature increase in the wash cycle does. The hotter the water for washing, the lower the residues (Laughlin & Gold, 1991b), especially when detergent was used without prewash product.

Mechanical Energies. Higher water temperatures, longer extractions time, and greater extraction volume increased the removal of carbaryl and chlorothalnil (Fleeker *et al.*, 1988a; Nelson *et al.*, 1989). Increasing the volume of water, thereby increasing the mechanical energy, improved the efficiency of paraquat removal in laundering (Olsen *et al.*, 1986). Decreasing the water volume to one-quarter increased MeP residue (Hild *et al.*, 1989). Water volume played a more significant role in decontamination than mechanical agitation, as there were no significant differences due to agitation.

Textile Characteristics

The refurbishment of protective apparel, and the deterative action in the laundering process, is the product of three systems, a solvent (usually water), surfactant (usually detergent and laundry aids) and a solid (soil or textiles). The chemical composition of textiles and textile finishes, and physical properties of fiber structure, yarn structure and fabric structure, impact or level of residue removal in refurbishment.

Fiber Content. Fiber content of fabric does not affect pesticide residue retention when the protective apparel fabrics are cotton or cotton/polyester blends in denims, chambrays and uniform-weight fabrics (Finley *et al.*, 1974; Easley *et al.*, 1982a; Laughlin *et al.*, 1985; Easley *et al.*, 1983; Easley *et al.*, 1982b; Kim *et al.*, 1982; Easley *et al.*, 1981; Laughlin *et al.*, 1986; Laughlin & Gold, 1989a; Laughlin & Gold, 1987a; Uyenco & Obendorf, 1984). These observations hold true for methyl parathion, 2,4-D ester and amine, chlorpyrifos, fonofos, alachlor, and malathion. Exceptions were from the work of Easter (1983) and Lillie *et al.* (1981, 1982). Easter compared five fabrics with a range of fiber contents and fabrications: cotton and polyester denim and chambray, along with the barrier fabrics of uncoated Tyvek[®] olefin, coated Tyvek[®] olefin and GoreTex[®] nylon/polytetrafluoroethylene/nylon. The wettable powder, Captan[®], was more difficult to remove from all-cotton fabrics than from the synthetics. Guthion emulsifiable concentrate was more difficult to remove from GoreTex[®] than from other fabrics. Easter and DeJonge (1985) concluded that fiber content/fabric type was the overriding factor in after-laundering residues. Fiber content determined both the extent of penetration and the distribution of malathion across yarns and fibers (Solbrig & Obendorf, 1985). Malathion moved into cotton fibers, locating in the lumen and crenulations as well as surrounding the fiber; but did not penetrate into polyester fiber, and methyl parathion was similar, but had higher concentrations on the yarn surfaces of cotton (Obendorf & Solbrig, 1986).

Yarn and Fabric Structure. The location of multicomponent (clay and oil) soil was in the crevices between the closely spaced fibers and laundering does remove large quantities of the soil from yarn surfaces (Obendorf, 1988). Within the yarn bundle, the more deeply the soil had penetrated, the more difficult it was to remove in laundering. Parallels were noted between particulate/oily soils and pesticides in removal through laundering. The final location of pesticide (DDT) with textile substrate was related to fiber content and morphology, fabric geometry and finish (Kim & Kim, 1988). Fiber irregularities served as deposit sinks for the pesticide. While pesticide will fill surface voids first, the more deeply it penetrates in to the fabric/yarn/fiber structure, the more difficult decontamination becomes.

Fabric Weight. Fabric weight affected residue retention, with less retention in lighter weight fabrics and more residue retention in a heavier weight fabric (Newburn *et al.*, 1994; Laughlin *et al.*, 1991a; Olsen *et al.*, 1986). These findings are consistent with differences in soiling propensities of an "oily" soil and a particulate soil, and the differences due to fabric weight in soil penetration, and the effectiveness of laundering in removing soil.

Fabric Finishes. Soil repellent finishes have been advocated to reduce absorption and penetration of pesticides through fabrics (Freed *et al.*, 1980; Orlando *et al.*, 1981). The most significant factor in pesticide contamination and removal by laundering was the soil repellent finish (Laughlin *et al.*, 1991b; Laughlin *et al.*, 1988; Laughlin & Gold, 1990b; Laughlin & Gold, 1990a; Laughlin *et al.*,

1986). The soil repellent finish inhibited absorption of pesticides on fabrics; however, any prior laundering diminished the effectiveness of consumer-applied soil repellent finish (Easter, 1983; Laughlin *et al.*, 1988; Ringenberg, 1988) and these finishes hindered pesticide removal in laundering (Laughlin *et al.*, 1986; Easter, 1983; Goodman *et al.*, 1988; Laughlin *et al.*, 1986). Although residue remaining in fabrics after laundering was similar across unfinished fabrics, durable press finished fabrics and soil repellent finished fabrics, the soil repellent finish limited pesticide pickup at contamination to 80 to 90% of what was absorbed on unfinished fabrics (Laughlin *et al.*, 1986) and residues, as a proportion of initial contamination, was greatest for the soil repellent finished fabrics (Easter, 1983; Laughlin *et al.*, 1986).

Barrier Fabrics. Fabrics such as spunbondeds and melt-blowns are designed as limited use or disposable items, but some packaging of protective coveralls states that they can be washed. Sontara fabrics offered resistance to methyl parathion absorption; but laundering was not planned for this spunlaced nonwoven and, in fact, it did not survive one laundering cycle (Laughlin & Gold, 1990d). Repellent finishes limited absorption; however, laundering before pesticide contamination decreased the effectiveness of the functional finish; however, there was no contribution to increased amounts of residue remaining on nonwoven fabrics as was observed for cotton and cotton blend fabrics.

Gore-tex[®], a multi-layer fabric including a PTFE membrane had a fairly high percent of malathion retention; surprisingly so, since malathion is highly water soluble (Branson & Rajadhyaksha, 1988). Following decontamination, small concentrations of malathion were present on the surface nylon fibers of the face and back fabric, but malathion was trapped in the PTFE membrane and was the most difficult layer to decontaminate.

Fabric History. Changes in fiber, yarn and fabric structure occur during wear or during refurbishment that enhance soil retention. Fabrics were altered by laundering and abrasion, such that they absorbed more methyl parathion and retained more residue (Laughlin & Gold, 1987a). Durable press cotton was particularly susceptible to abrasion and to pesticide residue retention, due to the fiber fractures and fissures that developed during use and laundering, and thus should not be selected for protective apparel.

Fabric that is used by pesticide workers may be soiled by body oils and by oily soils associated with equipment operation. Oily soils have significantly lower surface tensions and can penetrate fibers more readily than water based soils. As oily soiled fabrics ages, removal through laundering becomes increasingly difficult. Particulate soil does not appear to adhere to the cotton or polyester, but rather to an organic film that coats the fibers.

Oily soils (synthetic sebum and vegetable oil) applied onto fabric specimens and then laundered prior to contamination, contributed to pesticide absorption and retention (Laughlin & Gold, 1990b). Laundering removed significant quantities of pesticide; however, when the "history" of the specimen included oily soil followed by laundering, specimens absorbed less pesticide at contamination than did non-oily soiled specimens, while repellent finished specimens absorbed more methyl parathion. Oily soil, particularly on soil repellent fabrics, was a pre-disposer to increased pesticide contamination. When oily soil was applied over unlaundered contaminate, more residue was removed in subsequent laundering. But, if oily soil was present before contamination, methyl parathion removal during laundering was less complete. These observations were consistent between the two oily soils, synthetic sebum and vegetable oil.

The contribution of oily and particulate soil residue to pesticide residue removal was evaluated using artificially soiled 100% cotton and 65% polyester/35% cotton fabrics (Laughlin, 1992a). Initial contamination was not dependent on the soil level or fiber content of the fabric, but residues remaining after laundering were affected by soiling level. Pesticide residues were greater when the fabric had a heavy soil build-up, even though the initial contamination was lower. Based on these findings, protective apparel should be kept as clean as possible.

Leveling refers to the very slow and incomplete removal of soil in laundering. Indicative of this leveling phenomenon was the retention of pesticide residues after refurbishment regardless of decontamination temperatures, detergent type, laundry additives, pre-rinse or wash cycle, pre-wash treatment, fiber content of fabric, textile finish, yarn size or weave of fabric. Also occurring during the decontamination process was the disorption of soil from the fabric via the washing liquor and

re-deposition on the same fabric or deposition onto another fabric (Laughlin *et al.*, 1986). Pesticide soiling occurs not only when the textile was worn during application, but contamination also occurred during laundering (Laughlin & Gold, 1989, Laughlin *et al.*, 1986). Dispersion of pesticide from the original area of contamination to the entire fabric through soil redeposition has been reported (Olsen *et al.*, 1986, Laughlin & Gold, 1989, Laughlin, 1992b).

Dry Cleaning. As an alternative decontamination, dry cleaning was effective in removing carbaryl and chlorothalonil (Fleeker *et al.*, 1988b) and chlorpyfos (Ringenberg *et al.*, 1988); however, dry cleaning solvents can transfer pesticide from contaminated garments to those not contaminated, even after removal of the originally contaminated apparel item. Thus, dry cleaning is not recommended.

Volatilization. Storage before or after laundering assisted in minimizing the contaminate, through decomposition or volatilization of the chemical (Laughlin & Gold, 1987). Since only one-third of the concentrated (54% A1) methyl parathion was removed from fabrics through ten washings, storage for periods of time and/or at temperatures that maximized the loss of the chemical may be an alternative. Specimens that were contaminated, laundered, and then held for up to 4,032 hours showed lowest residues (Laughlin & Gold, 1989). Both conditions and time affected residues, with greatest residues in specimens held at 0°C, and the smallest residues after the longest time periods. Conditions of moving air and high humidity enhanced dissipation of methyl parathion, regardless of fiber content or finish. Wet cleaning plus holding in moving air significantly reduced the concentrated (54% A1) methyl parathion in fabrics.

Light and Heat. Exposure to sunlight, heat and humidity might be an effective means of decontaminating fabrics since pesticides breakdown in the natural environment. No difference attributable to ultra-violet light, heat or humidity was found for malathion on Goretex®, multicomponent fabric (Branson & Rajadhyaksha, 1988). Alachlor degrades to trace levels at 150°C for 60 minutes or 200°C for 15 minutes (Kim & Kim, 1988; Kim, 1989). Microwave intensities of high, medium, and low settings were inadequate to produce parallel degradation.

IMPLICATIONS

Providing adequate protection to all who work with pesticides will continue to be problematic. The greatest eminent health risk from pesticides comes through primary exposure. By making persons exposed to pesticides more aware of dangers, how to avoid contamination, and how to deal with contaminated clothing, the potential for adverse effects may be reduced. More work of a predictive nature (Laughlin, 1986) on successful decontamination is needed.

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