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Guidance Manual for Selecting Protective Clothing for Agricultural Pesticides Operations

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Project Officer
Uwe Frank
Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Edison, New Jersey 08837-3679

Risk Reduction Engineering Laboratory
Office Of Research And Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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Foreword

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities.

Under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the EPA and, more specifically, its Office of Pesticides Programs (OPP) is mandated to protect the health and safety of agricultural pesticide handlers and agricultural workers who may be exposed to pesticides. In support of this mission, this manual consolidates and extends information on the performance, availability, and limitations of personnel protective equipment required for pesticide handlers. Based on this information, guidance is developed for the selection, use, and reuse of such equipment. This publication provides a vital communications link between the researcher and the user community.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

Abstract

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and its amendments provide for the protection of the health and safety of farmers and farm workers who may be exposed to pesticides. Reduced contact with the active ingredients and other components of pesticides is particularly important for people who mix, load, and apply pesticides. Personal protective equipment is one means by which contact with potentially harmful pesticides can be minimized.

The Guidance Manual summarized here consolidates and extends literature information on the barrier effectiveness of protective materials to pesticides, the effect of personal protective equipment (PPE) on the productivity of pesticide handlers, heat stress associated with the use of PPE, and methods for decontamination of PPE. The Guidance Manual contains extensive appendices describing commercially available products.

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Section 1

Introduction

1 Introduction

1.1 Pesticide Regulation

1.1.1 Current Role of the Environmental Protection Agency

The regulation of pesticides is mandated by Congress. Through its Office of Pesticides Programs (OPP), the Environmental Protection Agency (EPA) administers the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA).

FIFRA was enacted in 1947 and required that pesticide products be registered with the U.S. Department of Agriculture (USDA) prior to marketing in interstate commerce. In 1970, the EPA was established and the administration of FIFRA was transferred from the USDA to the EPA. In 1972, FIFRA was amended by the Federal Environmental Pesticide Control Act (FEPCA), which broadened Federal regulatory authority by making it "unlawful for any person to use any registered pesticide in a manner inconsistent with its labeling." The amendments required pesticide classification, revised registration procedures, and established certification. They also provided civil and criminal penalties for violations of the Act and authorized cooperative enforcement agreements between the EPA and the States.

1.1.2 Office of Pesticide Programs Mission

The 1972 Congressional deliberations emphasized that EPA should implement FIFRA to protect workers (farmers, farm workers, and others) who might be exposed to pesticides or their residues. EPA's clear authority to promulgate such requirements, including personal protective equipment (PPE) standards designed to limit workers' exposure to pesticides and pesticide residues, is well established in the legislative history and in the Courts.

1.1.3 Office of Pesticide Programs Involvement with Personal Protective Equipment

In fulfillment of its responsibilities mandated by FIFRA, the EPA's OPP is currently involved in:

- Developing a consistent policy for PPE that will be applicable to all aspects of the pesticide review process, including registrations of new pesticides, re-registrations of pesticides, and pesticide decisions related to human health concerns.

- Specifying PPE performance data that must be provided by potential pesticide registrants to support registration and re-registration applications.
- Reviewing PPE performance data submitted to the Agency.
- Resolving the status of new or continuing registration for pesticide products that threaten human health through the evaluation of PPE efficacy. This assessment is based on factors related to the PPE (design, performance, decontamination, cost), the pesticide (toxicity, formulation, route of entry) and the anticipated agricultural situation (task, duration, equipment, and environment).
- Developing product-specific PPE ensembles for inclusion on pesticide labels as required attire for persons handling the product.
- Developing a standard for PPE use and maintenance or agricultural pesticide handlers and restricted-entry workers.
- Developing guidance documents to support the Worker Protection Standard for Agricultural Workers, including information on decontamination of PPE; selection of gloves, footwear, body protection, respirators, and eye protection; and heat stress recognition, avoidance and alleviation.
- Providing guidance on the protection performance of available types and models of PPE.
- Defending the EPA's PPE decisions in a court of law, before Congress and/or to the scientific community, including the EPA Scientific Advisory Council.

1.1.4 Office of Research and Development's Personnel Protection Program

The EPA established in the mid-1980s a Personnel Protection Technology (PPT) Program within its Office of Research and Development (ORD). The goal of the PPT Program is to focus and optimize the technology-related aspects of the EPA's PPT research, development, testing, evaluation, technical support, and training efforts. The Program is managed within ORD's Risk Reduction Engineering Laboratory and has included internal projects as well as extramural cooperative agreements, interagency agreements, and contracts.

PPT is fundamental to the EPA's regulatory and operational missions. PPT includes gloves worn in the EPA's laboratories, robotic devices used at waste sites, methods for minimizing the exposure of agricultural workers and pesticides, and to mathematical models for predicting the chemical resistance of clothing materials.

The EPA must have state-of-the-art PPT information with which to develop, defend, and enforce its regulations. In particular, the Office of Pesticides and Toxic Substances (OPTS) must be able to assess petitions for the registration of new pesticides and premanufacture notifications (PMN) for new chemicals. Furthermore, OPP must be able to transfer information to the field in agricultural worker training programs. In some cases, the fundamental data upon which to base worker protection regulations have not been generated.

Under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA or Superfund) and the Superfund Amendments and Reauthorization Act of 1986 (SARA), EPA's Regions I through X and the Office of Solid Waste and Emergency Response either directly or through their contractors are major consumers of PPT. Cost-effective purchases of PPT require the EPA to know the range of products available. In order to optimize the selection and use of PPT, the EPA must understand the performance features and limitations of PPT. In those cases where it has unique needs, the EPA has the opportunity to develop or specify new products and procedures. To do so, however, requires insights into PPT science and engineering.

This Guidance Manual is one product of the PPT Program to address these needs and is specifically responsive to OPP's PPT needs as described in Section 1.1.3.

1.2 Purpose of Guidance Manual

The primary purpose of the *Guidance Manual for Selecting Protective Clothing for Agricultural Pesticides Operations* is to provide technical information and guidance to the OPP personnel who formulate PPE standards, decisions, and recommendations for persons who handle pesticides.

The secondary purpose of this Guidance Manual is as a source for technical information and guidance that will be transferred to persons who interpret the EPA's PPE standards, explaining or conveying the EPA's PPE decisions and advising agricultural pesticide handlers in the appropriate selection, use, and maintenance of PPE. These persons include:

- government and Cooperative Extension Service personnel in states, tribes, and territories;
- pesticide manufacturers, formulators, registrants, and dealers; and
- advisors and trainers of agricultural pesticide users.

1.3 Guidance Manual Content

The *Guidance Manual* has nine sections. The sections may be read sequentially if the reader wants a comprehensive understanding of current, pesticide-related PPE data or guidance on the interpretation of those data as it applies to agricultural situations involving pesticide mixers/loaders/applicators. Readers may also refer to one chart or subsection for immediate details about a particular topic or item of PPE. A single-page Section in Brief precedes the body of each section. These pages highlight and summarize the key information contained in the sections.

The nine sections are:

- Introduction. Section 1 explains the authority and administrative responsibilities of the EPA's OPP. It discusses the *Guidance Manual's* purpose and content.

- Handling Pesticides. Section 2 describes the range of handler activities, formulations options, exposure scenarios, environmental factors, and facility amenities as they relate to mixing, loading, and applying pesticides. Routine pesticide-handling tasks are dissected into procedural steps to help readers evaluate the risk of exposure, the need for protective equipment, and the potential effect of PPE on job performance.
- Chemical-Resistant PPE Products. Section 3 describes PPE types and emphasizes the importance of garment design and construction. Particular attention is given to hand protection and coveralls; aprons, head protection, and footwear are also included. This information is keyed to extensive appendices that describe types and brands of PPE and their sources.
- PPE Performance as a Barrier to Pesticides. Section 4 defines the terminology and procedures for evaluating glove and garment materials as barriers to pesticides. Recommendations for hand/arm and body protection relate the material properties to the formulation and ingredients of the pesticides.
- Eye and Face Protection. Section 5 reviews the characteristics of eye and face protectors that are suitable for the various forms of pesticides. The test is supplemented by an appendix that lists commercially available products.
- Effect of Personal Protective Equipment on Job Performance. Section 6 recognizes that protective equipment may reduce worker productivity or introduce additional safety problems. An approach is introduced for quantitatively assessing the magnitude of these effects pertinent to hand dexterity and tactility, mobility, vision, and speech intelligibility is assessed.
- Heat Stress. Section 7 addresses the role of protective equipment in heat-related illnesses. The problem is defined and sensible practices for avoiding or alleviating heat stress are outlined.
- PPE Selection and Use Process. Section 8 helps readers relate the information in earlier sections to actual pesticide situations and individual decision-making. A step-by-step process is given for PPE selection, use, and disposal.
- Decontamination/Laundering. Section 9 focuses on the decontamination of reusable protective equipment. It emphasizes the importance of proper maintenance and the risk of secondary exposure through pesticide transfer from contaminated clothing. Decontamination processes are discussed in terms of fabrics, detergents, temperature, water, timeliness, and fabric finishes.

Section 2

Handling Pesticides

2 The Section in Brief

In establishing personal protective equipment (PPE) requirements and work safety practices, regulators must strive for a balance between the goal of reducing risks to pesticide handlers and the reality of the limitations and complexities imposed by the agricultural workplace environment.

Establishing general personal protective equipment guidelines for handlers of agricultural pesticides is complicated by the vast range of activities encompassed by the term *agriculture*. Agriculture includes not only traditional row-crop farming, but also activities relating to livestock, poultry, pasture and rangeland, forests, nurseries, and greenhouses.

Even within these general categories of agriculture, there is wide variation in individual workplace environments. Nevertheless, there are several elements basic to every agricultural situation that affect PPE decisions:

- **Handling activities**—Users of agricultural pesticides, through mixing, loading, and application, perform many activities that involve direct exposure to the pesticides.

- **Formulation characteristics**—Appropriate PPE depends on pesticide form, toxicity, concentration, carrier solvents, and other inert ingredients.

- **Exposure scenarios**—The particular work situation affects not only the potential for exposure to pesticides, but also the potential for heat stress—an important factor to consider when managing the use of PPE. Pesticide handlers may be on foot, in a vehicle, or in an aircraft. They may have the benefit of engineering controls, or their risk may be increased because they are working in enclosed areas.

- **Environmental factors**—Weather conditions, including temperature, humidity, wind, and sunlight, can strongly influence the PPE selection process and the work regimen of pesticide handlers. If the work is particularly vigorous or the terrain is rough, the durability of the PPE may be more important than its chemical resistance.

- **Facility amenities**—Provisions for personal decontamination and cleaning of PPE vary widely. At some remote work sites, the only source of *clean* wash water is a nearby stream. Only large corporate agricultural establishments are likely to provide health monitoring for pesticide exposure and for heat stress symptoms.

2 Handling Pesticides

2.1 Introduction

The factors that influence selection decisions regarding personal protective equipment (PPE) and associated workplace safety practices for pesticide handlers are particularly complex in the agricultural setting. The range of handler activities, formulation options, exposure scenarios, environmental factors, and facility amenities is vast. The term "agriculture" often conjures the image of tractors with booms traversing fields of crops neatly planted in parallel rows. This is an unfortunate misconception. In addition to traditional row-crop farming, the generic term "agriculture" also typically includes activities relating to livestock, poultry, pasture and rangeland, forests, nurseries, and greenhouses. To guide or regulate the selection and use of PPE for the various circumstances of these diverse industries, a clear understanding of pesticide-handling tasks is needed.

2.2 Handling Activities

Users of agricultural pesticides perform many activities that involve direct exposure to these chemicals. Adequate PPE selection guidelines must address the range of pesticide-handling jobs and the associated exposure risks. To simplify and focus this discussion, the various pesticide activities will be described under three main operations: mixing, loading, and application.

2.2.1 Mixing pesticides

Activities associated with mixing pesticides include:

- transferring pesticide from original container to mixing or application tank or hopper and adding diluent
- conveying open pesticide containers to and from use site
- containing or cleaning up a pesticide spill
- washing contaminated equipment after use
- disposing of pesticide containers
- repairing contaminated mixing equipment such as leaking or broken hoses

2.2.2 Loading pesticides

Loading activities include:

- transferring pesticide from mixing apparatus to application equipment
- conveying open pesticide containers to and from use site
- containing or cleaning up a pesticide spill
- washing contaminated equipment after use
- repairing contaminated loading equipment

2.2.3 Applying pesticides

Applying pesticides may involve:

- On foot
  - using hand-held sprayers or shake cans
  - using backpack or knapsack sprayers or dusters
  - using portable, aerosol generators or foggers
  - pushing or pulling wheel-mounted sprayers
  - using high-pressure, handgun nozzles
  - using hand-held, fumigation equipment
  - using dipping vats or spray-dip machine
  - putting plants or seeds in pesticides
  - flagging for aircraft applications
  - repairing contaminated application equipment such as clogged nozzles, leaking or broken hoses, or other malfunctions that occur when the equipment is in use
  - adjusting contaminated application equipment such as adjusting boom height, adjusting nozzle pattern, or adjusting hopper openings
  - containing or cleaning up a pesticide spill
  - disposing of excess pesticide
  - washing contaminated equipment after use
- By vehicle
  - pulling or mounted with a low-pressure sprayer
  - pulling or mounted with a boom
  - pulling or mounted with a granular applicator
  - pulling or mounted with a high-pressure sprayer
  - pulling or mounted with injector or incorporator
  - pulling or mounted with a fumigation applicator
  - pulling or mounted with a power duster
  - pulling or mounted with an aerosol generator or fogger
  - pulling or mounted with an airblast sprayer
- By air
  - using aircraft with open cockpits
  - using aircraft with enclosed cockpits

2.3 Formulation Characteristics

The range of pesticide formulations routinely used in agricultural situations complicates the selection of appropriate PPE. Pesticide form, toxicity, concentration, and additives and inert ingredients are primary considerations in planning clothing strategies.

2.3.1 Form

Agricultural pesticides exist in a variety of forms: gases, liquids, emulsions, granules, powders, pellets, aerosols, encapsulates, and even impregnated materials such as wax bars and wiper wicks. Each type of formulation may require distinct strategies for protecting pesticide handlers with PPE.

Liquids may splash or slosh during mixing and loading, causing a potential exposure through ocular, dermal, and oral routes. Furthermore, until sprays have dried, such formulations have the potential to soak through non-chemical-resistant materials, creating dermal exposure. Due to perspiration, they may penetrate even after drying.

Dry formulations often cause clouds or puffs of powdery pesticide to waft upward during mixing and loading, causing potential exposure through ocular, dermal, and inhalation routes. Persons exposed to dry formulations may be unaware that pesticides have penetrated their clothing or equipment, because they do not sense "wetting through."

Gas formulations have obvious exposure potential through the inhalation route, but some also present an exposure risk through the dermal route. Exposure may occur if the gases become trapped in clothing made of fabrics or materials having low air permeability.

2.3.2 Toxicity

In general, the greater the pesticide toxicity, the greater the amount of protection needed by the worker. Toxicity categories (Table 1) are based on the LD_{50}, a statistical estimate of a chemical dose which, when administered, will kill 50 percent of the test animals within a stated period of observation.

Table 1. Toxicity categories

Category	Toxicity	Signal word
I	Highly toxic	Danger
II	Moderately toxic	Warning
III	Slightly toxic	Caution

Correlating PPE recommendations with the pesticide toxicity categories is helpful for the pesticide user accustomed to reading signal words on the product labels. One complication, however, is that a single pesticide may be ranked as Category I for oral toxicity and as Category II for dermal toxicity. A second complication is the duration of the exposure. Pesticide handlers may mistakenly believe they do not need protective equipment because they are using pesticides of low toxicity. In fact, longterm exposure to slightly toxic pesticides can sometimes be as dangerous as a brief exposure to a highly toxic pesticide.

2.3.3 Concentration

Agricultural pesticide handlers usually are exposed to highly concentrated pesticides during the mixing and loading process. Mixers/loaders of pesticides may be handling formulations with very high levels of active ingredients; 80 percent wettable powder formulations and 8-pounds-per-gallon emulsifiable concentrates are not unusual. Ultra-low volume concentrates and fumigant formulations may be close to 100 percent active ingredient and often have a high level of acute toxicity. Protecting handlers from exposure to these highly concentrated pesticides is clearly a priority when recommending PPE.

Many agricultural pesticides, however, are ready-to-use formulations with very low levels of active ingredients; 5 percent granular or dust formulations are common, and low-concentrate solutions containing 10 percent or less of active ingredient are typical for some livestock formulations. Basing PPE guidelines on mixing and loading activities may not be appropriate for those low concentrations.

2.3.4 Additives and inert ingredients

Another variation among formulations of agricultural pesticides is the plethora of additives and "inert" ingredients added to the active ingredients to create each formulation. These ingredients may contribute to the exposure risk and have an impact on the selection of appropriate PPE for agricultural pesticides.

Most emulsifiable concentrate formulations and some other agricultural formulations have petroleum-based solvents (often xylene), which are a potential hazard to humans orally, dermally, ocularly, and through inhalation. The PPE requirements must reflect the toxicity not only of the active ingredient, but also of the solvents. Other additives do not present direct hazards to humans, but do increase the hazard potential of the active ingredient. The properties of some additives may increase the potential for dermal penetration; others may enhance the adherence of the pesticide to surfaces, including PPE and skin. Still others may increase the potential of the active ingredient to "spread out," thereby potentially contaminating larger areas of skin or PPE.

2.4 Exposure Scenarios

One of the challenges in establishing PPE guidelines for agricultural pesticide operations is the extensive number of distinct exposure scenarios to be found in agriculture. These scenarios are important not only in ascertaining the degree of pesticide exposure, but also in assessing the level of effort required by the user—an important factor in determining heat-stress potential.

2.4.1 On foot

Persons handling pesticides while on foot are, in general, the most likely to receive direct exposure to the pesticide. They are necessarily in close proximity to the pesticide regardless of whether mixing, loading, applying,

flagging, cleaning, adjusting, or repairing contaminated equipment or entering treated areas to ventilate or to remove fumigation tarps. Even minor spray drift will contact the handler. The close proximity of applicator to equipment magnifies any equipment inadequacies or imperfections. A dripping or partially clogged nozzle, an unfastened cap, a leaky hose, or a loose connection are extremely likely to result in handler exposure.

In addition to direct contact with the pesticide, indirect exposure is also likely through such actions as brushing against plants, animals, or other items just treated with pesticides or from overhead fallout of pesticide, such as mists, drips, or dusts.

The potential for heat-induced illness is also likely to be highest for handlers on foot. Not only are they often exposed to direct, unshaded sunlight, they are also often carrying, pushing, pulling, or otherwise manipulating equipment or pesticide containers.

2.4.2 On a vehicle

Persons applying pesticides from a vehicle are, in general, separate from the immediate proximity of the pesticide being dispensed. Often they are located above and in front of the point of pesticide release. This factor, combined with the forward motion of the vehicle, reduces the probability that pesticide drift or runoff will contact them.

In standard practice, however, the vehicle-mounted applicator sometimes must exit the vehicle and walk to the rear of the application rig to repair, adjust, or monitor the equipment or the pesticide dispersal. When this occurs, the applicator often is climbing down from and back into a contaminated rig and walking through newly treated areas. Depending on the size and type of vegetation the applicator must traverse, the applicator may receive significant exposure to the pesticides, ranging from exposure to the feet and lower legs to whole-body exposure from overhead fallout. In addition, the applicator may receive further exposure due to the activity to be performed, such as unclogging nozzles or hoppers and adjusting boom height.

The heat-stress factors for pesticide users on vehicles is generally lower than that for users on foot. The obvious factor is that the equipment is replacing the energy-demanding activity of walking while simultaneously pushing, pulling, or carrying the application equipment and the pesticide. Two related factors also apply. The motion of the vehicle creates the effect of wind on the applicator with the concomitant cooling effect. Secondly, the vehicle is often equipped with a cab, awning, or other over-head shield that shades the applicator from the full force of the sun's intensity.

Airblast/mistblower applications, unless performed while in an enclosed cab, are likely to expose the pesticide applicator to large quantities of drifting "mist," often to the point of being completely drenched in the pesticide fallout. Such exposure cannot be avoided, even if the application is performed in conditions of little or no wind and care is taken to remain out of the direct path of the air blast.

2.4.3 By air

Agricultural pesticide users who apply pesticides from aircraft are also usually distanced from the pesticide being applied. The dispersal of the pesticide is from below the aircraft, and gravity and the speed of the aircraft carry the pesticide rapidly away from the cockpit.

Some possible exposure scenarios exist, however. When the pilot is also the mixer/loader of the pesticides, the pesticide exposure from that activity may be continued in the cockpit through contaminated PPE. The pilot also may be exposed to pesticides when climbing into or out of the cockpit of a contaminated aircraft. Finally, in some situations, a pilot making a sharp turn or flying in strong wind may fly through the pesticide swath just released from the aircraft. If the cockpit is not enclosed or if its air is not filtered, the resultant pesticide exposure could be significant.

2.4.4 Exposure scenarios deserving special consideration

2.4.4.1 Engineering Controls. Some equipment, such as enclosed cabs and enclosed cockpits, greatly reduces the risk of pesticide exposure. The need for PPE is also greatly reduced, but workers should have appropriate PPE available for situations that require them to leave the enclosed areas. Other equipment, such as closed mixing and loading systems, is also designed to reduce exposure. These systems may not warrant as great a reduction in PPE use because of the high risk of exposure in case of equipment failure.

2.4.4.2 Enclosed Areas. Agricultural pesticide handlers use some pesticides in enclosed areas such as greenhouses, silos, and barns. The use of pesticides in such areas increases the risk of inhalation exposure and may require the use of a respiratory protection device even if the identical application outdoors would not warrant such protection. The likelihood of increased potential for heat stress due to the enclosure is dependent on the effectiveness of the ventilation system.

All agricultural pesticides registered for use on crops that may be produced in greenhouses are automatically registered for use in greenhouses unless the registration and/or pesticide labeling specifically prohibits use in a greenhouse. Therefore, the increased inhalation hazard in an enclosed area should be considered when respiratory protection requirements are established for agricultural pesticides.

2.5 Environmental Factors

2.5.1 Weather

Weather conditions can strongly influence the PPE selection process and the work regimen of pesticide handlers. In general, agricultural pesticide use is performed under conditions where climate control or climate alteration is impossible or impractical. The advent of temperature-regulated cabs on pesticide application equipment is relatively new and not, as yet, widespread. Climate control in greenhouses consists mainly of manipulation of ventilating systems. The limited alteration in temperature that results is usually partially counteracted by the high humidity levels, which are inescapable

in the enclosed, constantly moist environment. Recommendations for PPE selection should be feasible under a wide range of temperature/humidity conditions without undue risk of heat-induced illness.

Except in these and a few other instances, such as aerial application, the use of agricultural pesticides occurs at ambient air temperatures and humidity—often at the height of the summer heat. Widespread areas of the United States routinely experience temperature/humidity conditions from June through September that make any outdoor activity extremely uncomfortable even without the added burden of personal protective equipment. These climatic conditions cause strong resistance to the use of plastic or rubberized clothing, respirators, goggles or face masks, nonwoven protective suits, or coveralls worn over another layer of clothing. Under some environmental conditions, workers resist the use of long-sleeved shirts.

The undesirable effects of high heat and humidity can be moderated by the cooling effect of the wind or of the air movement created by the vehicle's motion. Too much wind, however, can increase the possibility of exposure due to drift.

At the other extreme, agricultural pesticide use in the northern United States in the early spring may take place in temperatures at or barely above freezing. Pesticide handlers working in cold weather are amendable to the use of protective suits or coveralls over another set of clothing. In these conditions, however, some rubber or plastic garments may become stiff and brittle.

Pesticide handlers also may need protection against glare, sunburn, and the harmful ultraviolet rays of the sun.

2.5.2 Terrain

Most agricultural pesticide use in greenhouses, on nurseries, and on row crop farms is located in areas easily traversed either on foot or by vehicle. Chemical-resistant footwear is practical and often indicated in such situations. In some forestry, pasture, and rangeland areas, however, pesticide application must be undertaken on rough, ungraded terrain not accessible by vehicles. Under these conditions, the use of chemical-resistant footwear and leg coverings may be a lower priority than reducing exposure to physical risks such as abrasions and animal bites by wearing sturdy (such as leather) footwear and leg coverings.

2.6 Facility Amenities

2.6.1 Decontamination areas

Agricultural establishments range in complexity from the traditional one-family farm to large, complex corporations. Regardless of the size of the establishment, onsite running water for decontamination, private dressing rooms, hot showers, and professional laundry service are the exception rather than the rule. The majority of agricultural establishments do not have a controlled, "factory-like" setting. Many agricultural establishments do not have potable running water anywhere on the premises except at the "office"

which may be a personal residence. There is usually no specific indoor facility provided for handlers to change into or out of PPE or to wash themselves after handling pesticides. The "decontamination facility" at the facility headquarters will often consist of cold running water, a bar of soap, and a stack of paper towels. This facility is often located in an unprotected outdoor site.

Water sources for decontamination may be even more primitive for persons handling pesticides at sites removed from the headquarters facility. Handlers may be assigned duties that are many miles from the headquarters and far removed from any source of running water. Running water is often plentiful in greenhouses and on nurseries, but it may be pumped in from a nearby supply of surface water, which is contaminated. Irrigation water on farms and nurseries may not be suitable for even emergency decontamination because pesticides have been or are being applied in the irrigation water. In these remote outdoor locations, water for routine washing of the hands and face and for emergency decontamination may be supplied in a carboy with a push-button spigot. In some remote forestry situations, the only source of wash water is a nearby stream.

2.6.2 Health monitoring

The large corporate agricultural establishments may have an on-staff occupational safety officer. The officer conducts biological monitoring of individual handlers both for pesticide exposure and for heat stress symptoms. For many other agricultural establishments, however, monitoring individual handlers either for pesticide exposure or for heat-related illnesses is difficult. Many of the smaller establishments are unequipped and resistant to conducting intrusive monitoring such as blood or urine sampling of their employees. Even body weight, temperature, and blood pressure monitoring is infeasible at many of these facilities. Unlike a factory situation where employees work in close proximity to one another and to sanitation and medical facilities, pesticide handlers on agricultural establishments often work independently, totally isolated from supervisory personnel, and often miles from any modern sanitation or medical facilities. These handlers cannot rely on visual monitoring by supervisors or on biological monitoring to aid in diagnosis and intervention in the event of either a pesticide-related or heat-induced emergency. Even frequent work breaks to recover from the heat stress symptoms, may be inconvenient in some agricultural situations. There may be no nearby area that is suitably shady and pesticide-free to enable a handler to remove the PPE and wash before drinking the appropriate fluids and allowing the body temperature to return to near-normal.

2.7 Conclusion

Establishing selection guidelines for personal protective equipment and correlated work safety practices for the protection of handlers of agricultural pesticides is a challenge. A balance must be achieved between the goal of reducing the risks to the handlers and the reality of the limitations and complexities imposed by the agricultural workplace environment. Regulators must weigh the various factors and attempt to establish PPE requirements and work safety practices that are practical, sensible, and functional in the agricultural workplace and still provide the handler a significant degree of reduction in exposure to pesticides.

Section 3

Chemical–Resistant PPE Products

3 The Section in Brief

Chemical-resistant personal protective equipment (PPE) allows no measurable amount of pesticide to move through the material or item during the time the PPE is used. Most chemical-resistant PPE is made of some type of plastic or rubber. The chemical resistance of these materials is chemical specific.

While the chemical resistance of the PPE materials is important, the physical properties of the materials and the design and construction of the PPE item contribute significantly to the effectiveness of PPE:

- Puncture and tear resistance are often required.
- To increase the likelihood that the PPE will be worn, and that it will not introduce other safety hazards, the materials and PPE items should not interfere with dexterity or mobility.
- Seams must be sealed to prevent leakage (i.e., penetration). Items with few seams usually are preferable.
- Fabric linings can trap pesticides and may be virtually impossible to get clean. A fabric layer in any PPE item should be coated on both sides with the chemical-resistant material, and the edges should be sealed.

Hand Protection

Hands and forearms get the most pesticide exposure, so the choice of gloves and sleeves is important. Chemical-resistant gloves come in two main styles:

- Those made of two flat, hand-outline pieces fused together at the edges (fit either hand).
- Those made by dipping a three-dimensional mold into a liquid form of the glove material (often right- and left-handed).

In addition to the chemical resistance of the material, also consider other factors, such as:

- **Thickness**—For a given material, thicker gloves are more protective and durable than thinner ones, but allow less dexterity and tactility. Although barrier laminate gloves (such as Silver Shield and 4H) are thin, they are resistant to most pesticides; however, they have dexterity and comfort deficiencies.

- **Size**—Gloves that are too small or too large are uncomfortable and can reduce dexterity. Gloves of the same stated size made by different manufacturers can vary greatly in such dimensions as finger length.

- **Length**—Protective sleeves, or gloves that extend as far as the upper arm, may be needed for some jobs.

Foot Protection

In addition to the chemical resistance of boots and shoe covers, it is important to consider the thickness, height, and durability suitable for the job.

Head Protection

Wide-brimmed hats provide considerable protection for face and neck. Hoods that pull on over the head are preferred over those that use snaps, Velcro, or other closures.

Body Protection

Apron lengths range from slightly above the knee to the ankles. Some aprons are wide enough to cover only the front of the body; others wrap almost completely around the torso and legs. Some have a drip trough around the bottom to collect runoff, and some have a double layer of material in the waist area.

Chemical-resistant suits may be one-piece coveralls or overalls, or two-piece outfits—jacket/shirt and pants. The most effective and economical chemical-resistant suits are those made of nonwoven fabrics laminated to or coated with a plastic film. The film type must be selected for resistance to the specific pesticide being handled, and the supporting fabric must have a strength appropriate for the task. Clothing made of such fabrics has associated with it the potential for heat stress.

3 Chemical-Resistant PPE Products

3.1 Introduction

The EPA's Worker Protection Standards for Agricultural Pesticides provides the definitions for two terms that are used throughout this manual:

- Personal Protective Equipment (PPE)—devices and apparel worn to protect the body from contact with pesticides or pesticides residues.
- Chemical-resistant—a material or item that allows no measurable movement of the pesticide being used through the material or item during use.

PPE products that might be used to protect pesticide handlers from pesticides include:

- gloves and sleeves
- boots and shoe covers
- aprons
- hats and hoods
- jackets, pants, and coveralls

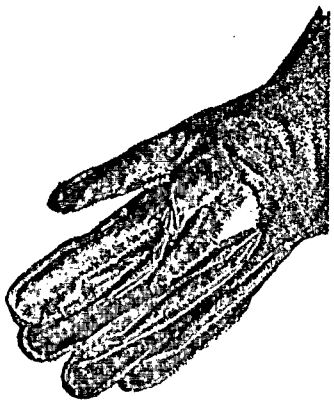
Within each product category, a wide range of product types and features are available. The purpose of this section is to describe the products as an aid to their proper selection, recommendation, specification, and regulation. Manufacturing methods, materials of construction, and construction types and styles are addressed. Extensive tabulations of commercially available products in each category are given in Appendices A through I. Appendix J is a directory of the telephone numbers and addresses of the PPE vendors listed in the previous appendices. Emphasis is placed on gloves since the hand and forearm have been identified as the parts of the body that comes into the most contact with pesticides in handling situations.

3.2 Hand and Forearm Protection (Gloves and Sleeves)

3.2.1 Glove manufacturing methods and materials

Gloves worn for hand and forearm protection from pesticides use polymeric materials as the primary barrier to liquids and vapors. The polymers historically used for chemical-resistant gloves include butyl, chloroprene, natural, nitrile, and fluorocarbon rubbers; and polyvinyl chloride, polyvinyl alcohol, and polyethylene plastics. More recently polyethylene vinyl alcohol, poly-

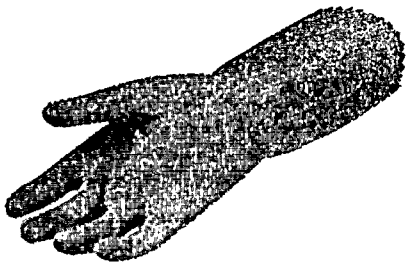
tetrafluoroethylene, and other highly chemically resistant polymers have been added to the latter group. All the mentioned rubbers and plastics are being used either individually or in combination with one another in commercially available gloves. Combinations include blends and layered systems.



Glove fabricated from hand silhouette

Chemical-resistant gloves are fabricated in two physical forms. One is that of the hand silhouette. This glove is made by die cutting a two-dimensional outline of a hand from a plastic film. Two of these flat hand forms are welded, usually by heat, around the edges to form a glove. This type of glove is typically loose fitting and, by its construction, ambidextrous. Disposable polyethylene gloves are probably the most common example of this type of construction. Recent advances in composite plastic film technology have yielded silhouette gloves, such as Silver Shield® by Siebe North Inc. and 4H® by Safety-4, Inc. with chemical-resistant properties that are significantly better than those of traditional glove materials. Workers often find silhouette gloves undesirable because of poor fit, loss of dexterity, and difficulty in keeping the gloves on the hand.

The second and more widely used fabrication method for chemical-resistant gloves is dip molding. In this process, a hand mold, made of porcelain or metal, is immersed into a polymer-containing liquid. Fabric lined (i.e., supported gloves) are made by placing a fabric glove on the hand mold prior to dipping. (See Section 3.2.1.4.) Depending on the polymer, the molds may be dipped into one of three types of polymer-containing liquid: latex, solvent, or plastisol. Immersion is followed by a slow withdrawal of the mold to allow a uniform runoff of the liquid. Excess liquid in the form of drops at the fingertips may be removed by electrostatics, bringing oppositely charged electrodes into proximity with the drops. The molds may be dipped several times to buildup glove thickness. The polymer is then cured or dried depending on the system. The glove is stripped from the mold and talc or chalk may be applied to prevent blocking (i.e., gloves adhering to themselves or each other). In mass production, a rack holds many such molds so that many gloves are produced simultaneously.



Glove fabricated by dip molding

Dipped gloves are right and left handed and are sized, enabling a better fit to be obtained. Properly fitting gloves are more comfortable and have less negative effect on dexterity. Dipped gloves are sometimes molded with curved fingers to provide improved comfort. Curved fingers more closely approximate the relaxed position of the hand.

As mentioned, there are three types of liquid solutions or suspensions into which the hand molds can be dipped. The name of the liquid system is often used in the descriptive name of the glove (e.g., Natural Rubber Latex Glove, Solvent-Dipped Nitrile Glove). Since the type of process used can affect the performance of the glove, latex, solvent, and plastisol dipping processes are described in the next paragraphs.

3.2.1.1 Latex System A rubber latex is defined as a colloidal, aqueous emulsion of a hydrocarbon rubber. Colloids are particles or fibers (in this case rubber) with one or more dimensions in the range between 1 millimicron (nanometer) and 1 micron. Such particles have a very high ratio of surface

area to volume and consequently do not settle out of the suspension due to gravity.

In addition to polymer and water, latices contain stabilizers, preservatives, thickeners, and antifoaming agents. These components are either water soluble or of the same particle size as the polymer to prevent settling. The temperature and the pH of the latex must be controlled to prevent precipitation. The solids content of a latex dipping emulsion can range from 35%-72%.

Before it is dipped into the latex, the hand mold is usually dipped in a coagulant solution. When the mold is subsequently dipped into the latex, the liquid immediately adjacent to the mold coagulates. The thickness of coagulated material depends on temperature, amount of coagulant, solids, and viscosity. If a second dip in the latex is required to buildup glove thickness, coagulant must be reapplied.

After dipping, the latex is dried and cured (vulcanized). Vulcanization is carried out at 200°-220°F. Some latices are formulated with reactants that allow curing at lower temperatures.

Some of the glove types which are formed from latices include natural, chloroprene, and nitrile rubber, and various blends of these materials.

3.2.1.2 Solvent-Based System. In a solvent-based system, dry rubber is first milled and compounded with various additives on a rubber mill. The milling (mastication) softens the rubber by breaking polymer chains. The compounded rubber is then dissolved in an appropriate solvent to form the dipping solution. Because the solvents are volatile, the solids content of the dipping solution is closely monitored and adjusted as necessary.

The hand mold is dipped into the solution and slowly withdrawn to form a polymer layer. Repeated dips are used to buildup glove thickness. The solvents are evaporated and the polymer cured in air-circulating ovens.

The chemical resistance of solvent dipped gloves is generally greater than that of latex gloves of the same polymer. It is believed that in a multi-dip process the imperfections of any one layer are covered by subsequent layers.

Some of the gloves which are formed from solvent-based systems include nitrile, fluoroelastomers (e.g., Viton®), butyl, and polyvinyl alcohol.

3.2.1.3 Plastisol System. Plastisol systems are chiefly used for polyvinyl chloride. In a plastisol system, colloidal polymer particles are dispersed in a plasticizer.

Plasticizers are organic compounds and can be described as high boiling, polymer solvents. However, solvation of the polymers only occur at high temperatures. At ordinary temperatures, the polymer/plasticizer mixture is a suspension. Between temperatures of 260°-350°F, the crystalline structure of the polymer is melted followed by solvation of the polymer.

Before dipping, the mold is preheated in an oven to 350°-400°F. When the mold is dipped into the plastisol, the liquid adjacent to it gels forming a coating. Upon withdrawal, the mold is heated to 400°F.

Permanence of a plasticizer is an important requirement for plasticized materials since the loss of plasticizer can reduce the physical and barrier properties of the final product. Some solvents used in the formulation of pesticides can extract plasticizer.

3.2.1.4 Lining. Chemical-resistant gloves can be manufactured with or without lining. Below are described the two types of lining used in gloves. The advantages and disadvantages of liners in gloves are discussed in Section 3.2.3.4.

One type of liner is a fabric liner. This type of liner increases the physical strength of the glove and improves wearer comfort. There are two general variables in fabric liners - material and weave. The materials currently being used include nylon, cotton, and polyester. The types of weaves are plain and knitted. Plain weave provides greater strength since it is constructed with tightly interlacing yarns. Knitted fabrics are used when moderate strength and considerable elongation are required.

In the manufacture of fabric supported gloves, woven or knitted fabric gloves are slipped over the hand molds before dipping. Several steps may then be required before dipping into the polymer-containing liquid including: scouring to remove surface impurities; heat setting to correct width and minimize shrinkage of the liner during dipping; and mildew treatments for high humidity applications.

The dipping is then done following the most appropriate procedure for the particular polymer system as described earlier. Viscosity of the dipping liquid and immersion time will determine to what degree the polymer penetrates the supporting fabric.

The second type of lining is a flocked lining. A flocked lining does not provide physical support to the glove as a fabric lining does, however, it does improve wearer comfort. Flocked linings are formed by turning a glove inside out and coating the inside surface with an adhesive. One- to two-millimeter long fibers of cotton, rayon, polyester, nylon, or blends thereof are then brought in contact with the adhesive by electrostatic attraction or by using a fluidized bed. The packing density of the fibers on the glove is controlled to achieve the desired fullness or feel.

3.2.2 Design features

As discussed in Section 2, pesticides handlers require differing degrees of hand/forearm protection and manipulative capabilities. Chemical-resistant gloves are available in a variety of materials, shapes, sizes, and surface textures. In selecting gloves, the goal is to balance and optimize safety, durability, tactility/dexterity, and cost considerations relative to the functional requirements. An extensive listing of the design features and the sources of more

than 400 commercially available chemical protective gloves is presented in Appendix A. In addition to material of construction, these features include:

- thickness
- size
- length
- lining material
- cuff style
- grip type

and are described in the following paragraphs.

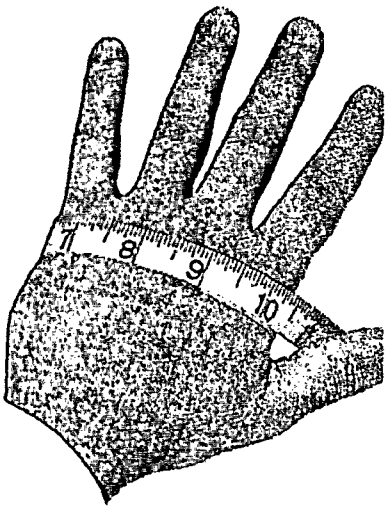
3.2.2.1 Thickness. Unsupported chemical-resistant gloves are produced over a range of thickness. Thickness is typically described in units of mils (1 mil = 0.001 inch = 0.0025 cm). Supported gloves are described qualitatively in terms of weight (e.g., light- or heavy-weight); consequently, no thickness values are given in Appendix A for supported gloves. In general, barrier effectiveness and resistance to tear, puncture, etc. increase with thickness and tactility and dexterity decrease. The effect of thickness on chemical barrier properties is described in Section 4.2.2.3.

Thickness is controlled in the manufacturing process by adjusting the temperature, solids content, and viscosity of the dipping liquid. Duration of immersion, rate of withdrawal, and number of immersions also affect thickness. In latices, variations in the coagulant are also used.

The thickness of commercially available gloves ranges from approximately 1 to 60 mils (0.002 to 0.152 cm). Silhouette gloves are the thinnest: 1.25 mils for polyethylene and 2.5 to 3 mils for the gloves (Silver Shield and 4H brands). So called "surgeon's gloves" (natural rubber latex), which have a good tactile response, typically range from 4 to 9 mils in thickness. The most commonly used chemical-resistant gloves typically range from 12 to 22 mils in thickness. By additional, partial immersions in the dipping liquid, areas such as the lower hand and fingers can be intentionally made thicker than the upper portion of the glove for additional strength or abrasion and chemical resistance.

Variations in thickness on an individual glove are common. Areas such as the crotch between the fingers can be up to 2 mils thinner than the rest of the glove. This is caused by uneven runoff during the dipping process. Compared to other areas of the glove, the finger crotches can have significantly shorter chemical breakthrough times.[1]

3.2.2.2 Glove Size. Optimization of glove fit is critical from both a comfort and a functional standpoint. Gloves that are too small provide less coverage, bind the hand, and cause rapid hand fatigue. Manipulation of small objects may also be impaired if the gloves are so tight that it is difficult to wrap the hand or fingers around an object. Gloves that are too large are also uncomfortable since the hand is continually shifting position inside. Dexterity can be impaired by the large, floppy fingers getting in the way when attempting to handle small objects.



Measurement of hand circumference for glove fitting

Gloves are sized either numerically or qualitatively. A numerical scale ranging from men's sizes 7-12 (7 being the smallest) is most often used. The size designation is the circumference (in inches) of the hand measured around the palm and below the metacarpal joints. Gloves are sized more qualitatively as "small, medium, large, X-large" or simply "men's size," "women's size," or "one size fits all" are also used.

Size, and therefore fit, depends on the particular set of molds used by each manufacturer. A size 7 from manufacturer "A" may not fit the same as a size 7 from manufacturer "B." Although their circumferences may be the same, the gloves may vary significantly in any number of other dimensions which are critical to fit; for example, finger length and circumference, and the distance between the thumb and the index finger.

3.2.2.3 Length. In many pesticide handling operations, direct contact with the pesticide is limited to the hands and fingers. Other operations may require protection of the wrist and forearm. Indirect exposure can occur at any time by accidental splashing, spilling, or drifting sprays. Because of these various situations, gloves of different lengths are required. As discussed in Section 3.2.4, chemical protective sleeves may be used with gloves for additional forearm and upper arm protection.

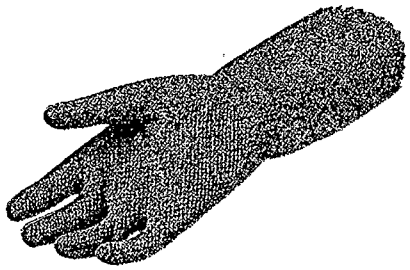
Gloves are manufactured in several lengths referred to in the industry as gauntlet lengths. The length is measured from the tip of the middle finger to the edge of the cuff. Lengths typically range from wrist length up to 18 inches, or just below the elbow. Longer gloves that extend to the upper arm are also available.

3.2.2.4 Liners. Fabric support in protective gloves provides several desirable characteristics and one significant disadvantage from the perspective of pesticides. Supporting materials provide additional strength to the glove to resist punctures and tears that could be caused by sharp objects. In addition, they absorb perspiration, thereby increasing comfort.

Liners, however, reduce the tactile response of gloves making it more difficult to "feel" something. In addition, if abrasion of the glove results in exposed lining fibers, these fibers could act as wicks and draw liquid into the glove. Most importantly, fabric liners are difficult to decontaminate. Supported gloves are not readily turned inside out for purposes of washing and the cloth may trap pesticides. For these latter reasons, lined gloves are not recommended for pesticides handling.

3.2.2.5 Cuff Style. Cuffs may be finished in one of several styles:

- Natural—the cuff is straight and results from dipping process, with no post cutting.
- Pinked—the cuff is either straight or jagged and is produced by cutting the glove gauntlet to the desired length.
- Rolled—a bead of polymer is formed around the circumference of the cuff. This feature is designed to reduce the likelihood for tears initiating at the cuff. The rolled cuff also inhibits liquids from running off the upper portion of the glove onto the user.



Glove with pinked cuff style

There is no significant difference in the tear strengths of the natural and the pinked cuffs. Some supported gloves are available with knitted wrists which help hold the glove on the hand.

3.2.2.6 Grip Type. Various finishes are often applied to the lower hand, fingers, or palm areas of gloves. These finishes are of a rough, uneven texture or a simple embossed pattern. They are designed to increase abrasion resistance and improve gripping ability.

Glove with rolled cuff style

3.2.3 Sleeves

Sleeves are flexible tubes of a fabric, plastic, or rubber material that are used to protect portions of the arm from contact with chemicals. Appendix B is a listing of commercially available sleeves, their characteristics, and their sources. Sleeves are available in three lengths: forearm (≈12-14 inches), elbow (≈16-22 inches), and shoulder (≈22-27 inches). The most common length is 18 inches. The typical sleeve has an elastic band around the opening at each end to hold the sleeve in place on the arm and seal off the arm from the external contamination. The elastic band may be enclosed in the sleeve material by several different seaming techniques or it may be exposed. In some cases, the elasticized closure is in the form of elasticized cloth much like the knitted wrist closures on gloves. This latter type of end finish is undesirable for use with pesticides since it is likely to trap pesticide and be difficult to decontaminate. Sleeves are also available with snap closures. Shoulder length sleeves are usually fitted with a strap or other form of tie for keeping the sleeve in place at the shoulder.

Sleeves are fabricated from many of the same materials as are aprons and garments. These materials include plastic films of polyethylene and polyvinyl chloride, nonwoven fabrics, and rubber-coated fabrics. These materials range in weight from 4-mil films to 18 oz/sq. yd. coated-fabrics. The coatings may be on one or both sides of the supporting fabric. For pesticide operations, fabrics coated on both sides and with the edges sealed are preferred. The support fabric of a material that is coated only on one side can potentially trap pesticide and increase the difficulty of decontamination.

Sleeves are seamed along their length. For chemical resistance, it is important that seam stitching be sealed against liquid penetration.

3.3 Foot Protection (Boots and Shoe Covers)

3.3.1 Introduction

For purposes of this document, boots are defined as rubber or plastic footwear that is worn directly over socks, fabric booties, or the foot without any other footwear. Shoe covers are footwear that is worn over other footwear, for example, rubber or plastic galoshes that are worn over leather work boots.

Chemical-resistant boots

3.3.2 Boots

Chemical-resistant boots are fabricated from rubber, plastics, or blends thereof. The principal materials are natural rubber, which is sometimes coated with polyurethane, polyvinylchloride, and blends of these materials. Within a single boot, the composition and the thickness of the materials may vary from location to location, e.g., the soles and the uppers may differ. In addition, boots are available with a range of:

- shaft opening sizes, i.e., the diameter of the opening into which the foot is placed
- heights, ranging from ankle (6 inches) to "halfs" (12 inches) to knee (16 inches) to over the knee
- closure types, e.g., strings and elastic straps
- sole patterns
- toe types, i.e., plain or steel
- shank types, i.e., steel, rigid plastic, or plain
- sizes; some boots are sized in lengths and widths others are available in small, medium, and large

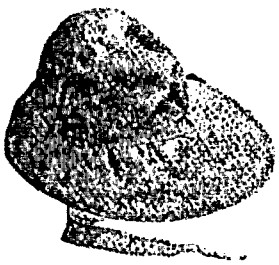
Appendix C describes a sampling of commercially available boots.

Typical rubber overshoes

3.3.3 Shoe covers

Shoe covers are footwear designed to be worn over shoes or boots that are not chemically resistant, for example leather or fabric shoes and boots. Shoe covers may be intended as single- or multi-use products. They may be described by many of the same characteristics as are boots, although they are generally less expensive. Appendix C contains a representative compilation of shoe cover products.

3.4 Head Protection (Hats and Hoods)



Sou'wester hat

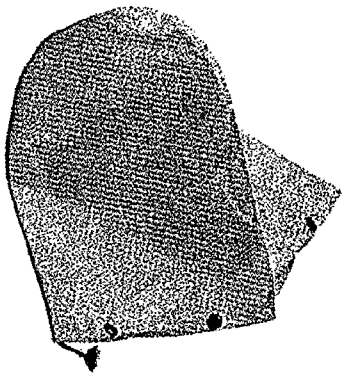
3.4.1 Hats

Hats are used to reduce pesticide contact with the top of the head, face, and neck areas. Appendix D is a listing of commercially available hats that may be suitable for agricultural applications. These hats are typically Sou'wester or Nor'easter in design. Basically, they have wide brims that reduce direct contact of the upper face and back of the neck with mists, droplets, powders, etc. from overhead. The wide brims also provide shade from the sun. Some are available with chin straps (to secure the hat in the wind). Nor'easters have pulldown earflaps that may be lined with cloth (e.g., flannel) for warmth.

To be effective against most pesticide formulations, hats must be fabricated from materials or fabrics that contain a continuous film of plastic or rubber, e.g., a coated fabric. Holes due to stitching must be sealed to prevent leakage from the outside onto the head. Similar to sleeves, the fabric should be coated on both sides to minimize pesticide entrapment and facilitate decontamination. Consequently, fabric-lined styles are less desirable.

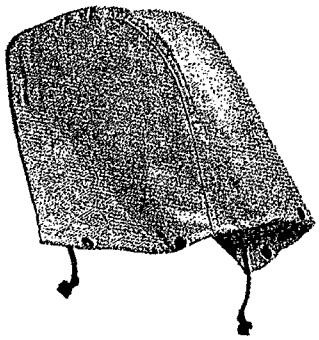
3.4.2 Hoods

Chemical-resistant hoods are available in a variety of styles, differentiated principally by the extent of head and upper body coverage. Some hoods cover only the head. These hoods are typically sold in combination with a jacket or coverall to which they can be attached and detached. Other hoods cover the head and neck. Still others cover the head, neck, and shoulders. Appendix E is a listing of representative hoods that may be suitable for agricultural applications.



Two piece hood

Hoods are fabricated from many of the same fabrics that are used for garments. Hoods are fabricated from two or more pieces of fabric. In general the more pieces that are used, the better the hood follows the contours of the head, neck, and shoulder. The trade-off for better fit, however, is more seams. Similar to sleeves and garments, the seams must not provide a route of entry for the chemical. Seams should be stitched and sealed, thermally welded, or otherwise effected. The edges of coated fabrics must be sealed at the edges to prevent wicking of liquids into the supporting fabric. Also similar to sleeves and hats, only coated-fabrics that are coated on both sides are desirable for use by pesticide handlers.



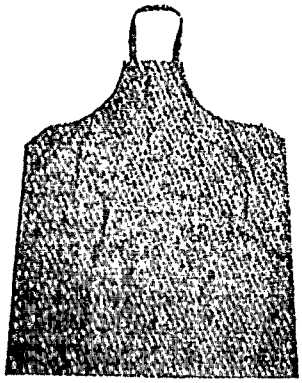
Three piece hood

Hoods may be open around the face or contain a transparent face piece. (Only those with an open face are addressed herein.) Those with open face and which are detachable typically employ a drawstring for closure around the face. Other hoods are elasticized around the face opening.

Some hoods are donned over the top of the head. Other hoods have snap, Velcro®, or other closures in the front and donned by opening the closure and wrapping the hood over and around the head. For chemical protection, hoods without a front opening are preferred.

3.5 Frontal Protection (Aprons)

Aprons provide frontal protection from splash and other types of chemical contact. Aprons are available in four general styles. Bib type aprons cover the body from the chest to the knees or lower. Waist type aprons cover the stomach and upper legs. Split-leg aprons are divided at the crotch and fastened around each leg. Sleeved aprons (sometimes referred to as smocks or frocks) provide coverage of the upper chest, shoulders, and arms, as well as the legs to the knees or below. Appendices F and G contain descriptions of and sources for representative, commercially available aprons.



Bib type apron

Sleeved apron

Within each of the four general styles, aprons differ in:

- materials of construction—aprons are fabricated from virtually all the fabrics from which jackets, pants, or coveralls are produced.
- type and location of ties—all aprons have a tie around the waist. Bib-type aprons also have neck ties. Some neck ties are fixed in length and others are adjustable. Some ties are fitted with safety releases such that if, the apron becomes caught in moving equipment, the apron will pull away from the person.
- length and width—aprons are available in a virtually unlimited combination of lengths and widths. Lengths range from slightly above the knee to the ankles; widths range from only frontal coverage to almost complete circumference of the torso and legs.
- edge finish—edges of aprons may be unfinished (usually the case for those aprons of films of PVC and PE) or stitched or stitched and sealed (usually the case for aprons of fabric-supported materials).

Some apron designs include a gutter (drip trough) around the bottom to collect runoff from the upper portion. Others incorporate a second, reinforcing layer of fabric in the waist area, referred to as belly patches.

Similar to other types of protective clothing available for protection from pesticides, aprons that are fabricated from plastic films or fabrics that are coated on both sides are preferred to fabric-supported aprons that are coated only on one side, leaving the fabric side open for pesticide contamination that may be difficult to remove. The edges of any fabric-supported material should be sealed against pesticide wicking and absorption.

3.6 Body Protection

3.6.1 Woven cotton and cotton/polyester

Clothing based on woven cotton and cotton/polyester fabrics is used broadly throughout agriculture, including by pesticide handlers. The fabrics vary in:

- type of weave, e.g., plain versus twill
- weight, i.e., weight per unit area
- finish, e.g., soil repellent, durable press, etc.

The clothing varies in:

- style
- type and location of closures
- location of pockets

The permutations on the above characteristics are virtually limitless and will not be discussed here. Information on cotton and cotton/polyester fabrics and clothing can be found in general texts on textiles.[2]

3.6.2 Nonwoven fabrics and fabrics containing microporous PTFE

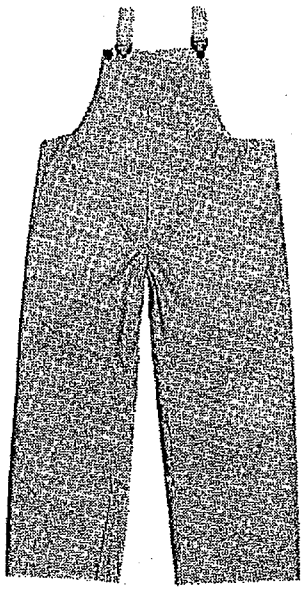
3.6.2.1 Nonwoven Fabrics. Nonwoven fabrics are made by laying down and bonding together or entangling fibers of natural or synthetic materials. Paper, for example, is a nonwoven material. Various fabric producers have

developed proprietary processes for producing nonwoven fabrics. The most common, nonwoven fabrics used in protective clothing are:

- Tyvek® 1422, a spunbonded high density polyethylene product of The DuPont Company
- SMS®, a product of Kimberly-Clark, Inc., in which a layer of melt-blown polypropylene is laminated between layers of spunbonded polypropylene
- Sontara®, a blend of wood pulp and polyester produced by the DuPont Company and converted into clothing by many manufacturers
- nonwoven polypropylene from a variety of converters

In some cases, these fabrics are converted to garments by their manufacturer; in other cases, the fabric is sold as roll goods to an independent converter for processing into clothing. Regardless, a myriad of garment types and styles having an extensive range of features are commercially available. Features and design elements that vary among the garments include:

Pieces—Both one- and two-piece garments are available. The two-piece garments comprise a jacket and pants. Many jackets are designed to accept a detachable hood or have a permanently attached hood. The pants may be of standard design or bib-type (also known as an overall). Single-piece coveralls may incorporate a permanent hood or provisions for a detachable hood. Some coveralls are available with permanently attached booties, intended to be worn inside shoes or boots. The built-in booties reduce the problem of maintaining a secure, chemical barrier at the pant/boot interface.



Bib type pants (overalls)

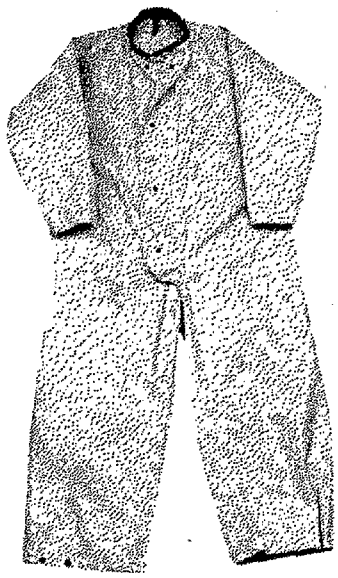
Closures—Some garments have front zippers, which may be either metal or plastic. Other garments have snaps. Still others have the closure in the back or on the side, taking the closure out of the most likely path of a liquid splash. Some single-piece garments are like sacks into which the persons stands and pulls up around his body. These sack-style garments are closed with a single drawstring closure at the neck.

Hoods—Garments are available with and without hoods. Some are elasticized around the face; others have a drawstring. Still other garments have a built-in, transparent facepiece.

Seams—may be stitched, solvent-welded, taped, adhesively-bonded, or heat-welded. Several types of stitching are used, including lock stitch, chain stitch, and serged stitch. Other types of stitched seams are felled and bound. Regardless of the seam type, the seam should be as strong or stronger than the fabric itself. Stitching should be of a quality that does not compromise the barrier effectiveness of the garment.

Sleeve style—Garments are available with yoke, raglan, and straight style sleeves. The raglan style generally gives a wider range of motion to the wearer.

Sleeve endings—Sleeves end at the wrist in either one of two finishes: plain or elasticized.



Coverall

Pant endings—Pants end at the ankle in several finishes: plain, elasticized, or with an attached bootie.

In Appendix H, commercially available garments are characterized using the above features as descriptors. A preliminary assessment of the features and the quality of construction of some of these products has been completed.[3]

Critical to the performance and acceptance of these garments is their fit. Other than for men's unhooded coveralls, there is no standard for sizing or any other feature of the garments. The men's coverall sizing standard is ANSI/ISEA 101-1985.[4] Despite this standard, workers at hazardous waste sites frequently complain of garment failure due to tearing.[5] Efforts are underway by ISEA (Industrial Safety Equipment Association) and ASTM to develop better sizing standards. The goal is a sizing system that is keyed to the dimensions of the worker and that accommodates various underclothing worn by field workers. Underclothing may range from shorts and a T-shirt in hot environments to bulky, winter clothing in cold environments.

3.6.2.2 Fabrics Containing Microporous PTFE. Polytetrafluoroethylene (PTFE) is the chemical name for the trademarked name, Teflon®. By highly-controlled processing procedures, microporous films of PTFE are produced. Due to the small size of the pores and the poor wetting of PTFE by water, these films allow the passage of water vapor but not liquid water. Because water vapor and other gases can pass through the pores, the films are called "breathable." By combining the film with fabrics (principally nylon), composite fabrics result that are strong and "breathable." Gore-Tex®, a trademark belonging to W. L. Gore and Associates, is the most commonly known brand of such fabrics.

Clothing based on Gore-Tex is claimed to be suitable for protection from splashes and particles by W.L. Gore. Because it is porous, however, the clothing is not recommended for protection from gases or from liquids other than from the immediate splash. While it is a barrier to liquid water, it is not a barrier to those liquids, including many organic liquids found in pesticide formulation, that wet PTFE to a greater degree than does water. Gore-Tex clothing, because it breathes, is claimed to be more comfortable than clothing from other fabrics which provide comparable levels of protection.

3.6.3 Plastic or rubber film/sheet, film-coated or -laminated woven or nonwoven fabrics

A virtually limitless variety of types, styles, and quality of clothing is produced from fabrics that contain a continuous film of a plastic or rubber for protection from potentially hazardous chemicals. These garments range from limited-use coveralls costing less than $5 to encapsulating ensembles based on state-of-the-art materials and costing several thousands of dollars.

It would seem that the economic realities of agriculture dictate that only the lower priced garments will be used. Included in this grouping are:

- coveralls of nonwoven fabrics (as described above) to which films of polyethylene, Saranex®, or other plastic films have been laminated

- one- or two-piece ensembles (often referred to as rainsuits) fabricated from films or coated-fabrics of polyvinyl chloride (PVC), neoprene rubber, nitrile rubber, or polyurethane

Appendix I is a listing of the features of commercially available garments representative of those that are readily available to those responsible for pesticide handlers. The product lines are extensive in their permutations of garment features. The range of the variations can only be appreciated by obtaining and reviewing the converters catalogues. Some general comments follow.

A distinction should be made between rainwear and chemical-resistant splash suits. While in many cases the materials of construction are similar, converters of chemical-resistant clothing generally give more attention to the details of seam and closure integrity, finish, and location. Within any given fabric category, there can be significant differences in the weight (oz./sq. yd.) of the fabric. Fabrics of higher weight are generally stronger, although they may also place more of a burden on the wearer.

Some garments have integral hoods and booties, others a detachable hood and no boots, and still others neither. Plain pant and bibbed pant (also known as overalls) may be expected to provide different levels of frontal protection from pesticides. Other garment options include pockets and elastic across the lower back to improve fit.

3.7 Physical Characteristics

The physical characteristics of PPE are as important as its chemical-resistant properties. If the PPE lacks physical strength and is easily punctured or torn, there is the potential for chemical leakage that could far overshadow the amount of contact due to permeation through the material. If the PPE material is excessively thick or stiff, then dexterity, tactility, and mobility could be comprised.

There are literally hundreds of methods for testing the physical properties of the materials of construction of PPE. Standard methods have been developed by organizations such as:

- ASTM—American Society for Testing and Materials
- Federal Government and Agencies within it, e.g., Department of Defense
- AATCC—American Association of Textile Chemists and Colorists
- NFPA—National Fire Protection Association
- INDA—International Nonwovens and Disposables Association

The selection of the most appropriate methods is dependent on the application of the PPE. If sharp objects are to be handled on a regular basis, then resistance to cut and puncture may be more important than abrasion. Even within one category of tests, the selection will be dependent on the application and the PPE material. There are, for example, at least five standard abrasion tests applicable to fabrics.

There seems to be no consensus as to the "best" test methods for chemical protective clothing. In fact the best methods are those that are found to be applicable to the particular situation at hand. Unfortunately there seems to have been very few studies aimed at defining and characterizing the physical property requirements for and performance of PPE.

As one step toward filling the information gap, the EPA and U.S. Coast Guard jointly sponsored a study aimed at the identification of a battery of tests that would be generally useful for characterizing the physical properties of PPE.[6] In the study, various test methods were analyzed and applied to PPE materials representative of the various groups of materials described above, except woven fabrics. The result of the study is the battery of recommended tests listed in Table 2. To this group, one might add a test for flexibility, such as ASTM D1053.

Regardless of which test is selected, persons using the results must bear in mind that tests on pieces of fabric under laboratory conditions may or may not represent the performance of the item of clothing in the field. For the test to be predictive, it must accurately represent and anticipate the failure mechanism(s) of the clothing item. One would do well to heed the warning found in the scope section of one of the abrasion tests (ASTM D1630):

No relation between this test and service performance is given or implied . . . The significance to be attached to the results can only be determined by each laboratory for its particular problem.

Table 3 summarizes, in a general way, the physical characteristics of unsupported gloves. The table was developed by compiling the property ratings of several glove manufacturers. The ratings are intended only as a guide.

Table 2. Recommended physical property test methods for PPE

Property	Standard test method
Garment, glove, boot, hat, and hood materials	
Puncture	NFPA 1973 – Paragraph 3–2.7
Puncture-propagation tear	ASTM D2582
Abrasion	ASTM D3884 coupled with ASTM F739 and ASTM D751 as endpoint tests
Burst	ASTM D751
Aging	ASTM G26 coupled with ASTM F739 and ASTM D751 as endpoint tests
Electrostatic charge	NASA MMA – 1985–79
Visor Materials	
Line of sight	ASTM D881
Haze-abrasion	ASTM D1044
Impact	ASTM D3029

Table 3. Physical characteristics of glove materials*

Glove resistance	Abrasion resistance	Cut resistance	Flexibility*	Puncture resistance*	Tear resistance*	Cost
Butyl Rubber (butyl)	F	G	G	G	G	High
Natural Rubber	E	E	E	E	E	Medium
Neoprene	G	E	G	G	G	Medium
Nitrile Rubber (nitrile)	E	E	E	E	G	Medium
Polyethylene	F	F	G	P	F	Low
Polyvinyl Alcohol (PVA)	F	F	P	F	G	High
Polyvinyl Chloride (PVC)	G	P	F	F	G	Low
Viton	G	G	G	G	G	High

*Ratings are subject to variation depending on formulation, thickness, and whether the material is supported by fabric.

E = Excellent
G = Good
F = Fair
P = Poor

References

[1] Berardinelli, S.P. and R. Hall. Site-Specific Whole Glove Chemical Permeation, Am. Ind. Hyg. Assoc. J., *46*, pp. 60–64, 1985.

[2] Hollen, N., J. Saddler, A.L. Langford, and S.J. Kadolph. *Textiles*. 6th Ed., MacMillan Publishing Company, N.Y., N.Y., 1988.

[3] Schwope, A.D. Preliminary Assessment of Life-Cycle Costs of Protective Clothing. Final Report. U.S. Environmental Protection Agency, Office of Research and Development, Contract No. 68–03–3293. Work Assignment 1–06–5.1, Cincinnati, OH, 1989.

[4] American National Standards Institute. ANSI 101–1985—Men's Limited-Use and Disposable Protective Coveralls—Size and Labelling Requirements. American National Standards Institute, 1430 Broadway, New York, NY, 10018, 1985.

[5] Sawicki, J.C., C. Mond, A.D. Schwope, and S. Watkins. Limited Use Chemical Protective Clothing for EPA Superfund Activities. Draft Final Report. U.S. Environmental Protection Agency, Office of Research and Development, Contract No. 68–03–3293, Work Assignment 3–60.1, Cincinnati, OH, 1989.

[6] Carroll, T.C. and A.D. Schwope. The Selection and Measurement of Physical Properties for Characterization of Chemical Protective Clothing. Final Report. U.S. Environmental Protection Agency. Office of Research and Development. Contract No. 68–03–3293. Work Assignment 3–140. Cincinnati, OH, 1989.

Section 4

PPE Performance as a Barrier to Pesticides

4 The Section in Brief

No one PPE material is resistant to all chemicals or in all situations. A material's effectiveness as a barrier to a pesticide depends on many factors, including the composition and structure of the material, the composition and form of the pesticide, the duration of the contact period, and the temperature.

Even when the best **material** has been selected for a given situation, the effectiveness of the PPE item also depends on the design and construction of the item and whether it is used and maintained correctly.

Pesticides can move through PPE in two ways:

- They may **penetrate** through spaces between fibers and through other openings such as seams and closures.
- They may chemically **permeate** the material itself, even when there are no holes or openings.

Researchers have found that, in general:

- A material that is a barrier to one liquid may not be equally effective against other liquids.
- The effectiveness of the barrier increases with the thickness of the material.
- The less penetrable a material is by air, the more effective is the barrier.
- Comfort decreases as the effectiveness of the barrier increases.
- Worker acceptance of PPE decreases as comfort decreases.

Arm/Hand Protection

Some chemicals severely attack one glove material, but have no effect on others; some chemicals have severe effects on **all** commonly available glove materials.

For protection against solid pesticide formulations, such as granules and dusts: Most materials having a continuous polymeric film work well; protection depends more on such factors as fit; coverage; seam, closure and interface integrity; and durability.

For protection against water-based formulations containing no organic solvents: Most common rubber or plastic gloves, except polyvinyl chloride and natural rubber gloves less than 0.2 mm thick and those of polyvinyl alcohol, should provide sufficient protection.

For protection against formulations containing organic solvents: Use materials recommended on pesticide labels and in charts such as the ones in this section. These recommendations are based on breakthrough times for the solvents only (rather than the active ingredients). In EPA testing, solvent breakthrough time was equal to or less than active ingredient breakthrough in 76 percent of the tests, making this a **conservative** estimate of glove performance.

Most glove selection charts are based only on chemical resistance factors. Fit, comfort, durability, and cost are also important considerations.

Body Protection

- Long-sleeved shirts and long pants are better than short sleeves and short pants.
- Heavier woven fabrics are better barriers than lighter ones.
- For fabrics of equal type and weight, greater cotton content provides a more effective barrier.
- Woven fabrics appear to be better than knits, and twills are preferable to plain weaves.
- Synthetic nonwoven and microporous PTFE fabrics with low air penetrability are often better barriers than woven fabrics.
- Fluorocarbon treatments generally improve the resistance of porous fabrics, both woven and nonwoven, to penetration by liquid pesticides.
- A fabric with a coating or lamination of a continuous film of plastic or rubber provides the most effective barrier.

Even clothing made from a highly effective barrier material, however, may not be protective if it fits poorly or is designed with closures that gap or other openings that allow the pesticide to penetrate.

Multiple layers of clothing contribute to protection. Two layers of a light fabric provide a better barrier than a single layer having the same total thickness.

4 PPE Performance as a Barrier to Pesticides

4.1 Overview

As discussed in previous sections, pesticides may be encountered in the form of solids, liquids, or gases. When engineering controls or work practices do not prevent the contact of the pesticide with the skin, PPE may be required. For PPE to be a barrier to a potentially harmful chemical, it must be properly designed, selected, used and maintained. The materials of construction of the PPE are key determinants of its barrier effectiveness and, therefore, in its selection. PPE materials available to pesticides handlers include:

- woven fabrics, principally cotton and cotton/polyester blends
- nonwoven fabrics, principally of polyethylene or polypropylene
- fabrics incorporating a microporous membrane
- fabrics coated or laminated with continuous films of plastic or rubber
- free-standing films, sheets, or shaped forms of plastic or rubber

The effectiveness of each of these types of materials as a barrier to a pesticide is dependent on a wide range of factors, including:

- chemical composition of the material
- material thickness
- material weight per unit area
- fabric treatments (finishes)
- fabric air permeability or porosity
- chemical composition of the pesticide formulation
- form of the pesticide, e.g., mist, spray, bulk liquid, dust, granules, vapor
- amount of the pesticide
- duration of the contact period
- force of contact
- temperature
- moisture presence, e.g., humidity, rain, perspiration

The movement of pesticides through clothing fabrics may occur by one or both of two processes: penetration and permeation. Penetration encompasses movement through openings between fibers and yarns, stitching, seams, closures, or flaws by mechanisms such as wicking, wetting, pressure gradients, bulk flow, and so forth. For penetration to occur there must be a hole. Permeation involves absorption, diffusion, and desorption of the chemical within a film, coating, or an individual fiber. Permeation occurs

due to a concentration gradient across a continuous (i.e., nonporous) layer of material. Standard and customized tests exist for measuring penetration and permeation. Insight into the likely resistance of a PPE material to penetration or permeation can often be obtained by degradation testing.

With regard to chemical transit through PPE and PPE materials, it is generally true that:

- no one PPE material is resistant to all chemicals.
- one cannot predict with certainty the barrier effectiveness of a PPE material to one liquid on the basis of its performance against another liquid. Predicting chemical resistance to multi-component liquids, which many pesticides are, is particularly problematic.
- barrier effectiveness increases with the thickness of the material.
- barrier effectiveness increases with decreases in air permeability.
- comfort decreases with increased barrier effectiveness.
- worker acceptance of PPE decreases as comfort decreases.

The purpose of this section is to consolidate technical information on the performance of PPE items and materials as barriers to pesticide formulations and the components thereof. The section begins with a review of test methods, proceeds to the performance information, and provides selection guidance. The later information is organized under two general headings: Hand/Arm Protection and Body Protection.

4.2 Measures of Chemical Resistance

4.2.1 Penetration

As defined above, penetration is the movement of a chemical through holes in the material or fabricated component of PPE. Standard penetration tests exist and are described below. In general, these tests have been found either not applicable or are not practiced by the research community involved in studies pertinent to protection from pesticides. Consequently, this research community, which is relatively small and generally contained within the nation's Land Grant universities, has used other methods.

These other methods typically involve placing a sorbent pad behind the material to be tested, exposing the material to pesticide, and measuring the amount of pesticide that reaches the pad. Resistance is reported as the amount of pesticide found on the pads either relative to that found on the pads behind other fabrics or relative to the amount of pesticide applied. Such a test can be performed in the laboratory or in the field.

The penetration literature reviewed for and cited in this document was generated by less than a dozen research groups. Since there is no standard penetration test, each group has followed its own variation of the above generalized procedure. The procedures vary in:

- the amount of pesticide applied,
- mode of application, e.g., spray, droplets, or pool of liquid,
- type of nozzle and application pattern,
- application time,

- distance of the application source from the PPE material
- vertical or horizontal orientation of the PPE material
- amount of time the material/collector assembly might be aerated following the exposure

Furthermore, the pesticide solutions used by different researchers are rarely the same and, in most cases, not described in sufficient detail as to source and chemical composition. This situation makes comparison of published results very difficult. For example, it is not unusual for two researchers to obtain diametrically opposed data regarding the effect of fabric finishes or fabric weight on penetration resistance.

4.2.1.1 ASTM F903—Resistance of protective clothing materials to penetration by liquids[1]. In this procedure, pressure is applied to a liquid test chemical that is in contact with the PPE material specimen on its normal outside. The other side of the specimen is visually observed for the appearance of the chemical. Various time/pressure regimens are suggested, depending on the application for the PPE. The test cell and gasket are designed to accommodate seams and closures.

4.2.1.2 ISO 6530—Clothing for limited protection against dangerous liquid chemicals—resistance to penetration—marking[2]. A specimen of the clothing fabric is formed to fit an approximately 12-inch long gutter. The gutter is inclined to the horizontal at a 45° angle. Liquid chemical is poured onto the fabric at the upper end and collected as runoff at the lower end. Penetration resistance is assessed on the basis of the amount of chemical collected compared to the amount of chemical poured onto the fabric.

4.2.1.3 AATCC 22-1985—Water Repellency: Spray Test[3]. A specified volume of water is sprayed from directly above onto a fabric specimen which is held tautly at a 45° angle to horizontal. A wetted pattern forms; its size and shape dependent on the water repellency of the fabric. Evaluation is accomplished by comparing the pattern to standard patterns.

4.2.2 Permeation

4.2.2.1 Theory. Permeation is a three-step process in which:

- the chemical is sorbed at the surface of the PPE material.
- the chemical diffuses through the material.
- the chemical desorbs from the material at the surface opposite that where sorption occurred.

The permeation process occurs on a molecular level and is differentiated from penetration, which is the bulk movement of the challenge through holes in the material. Permeation may occur with no visible or degrading effect on the clothing material.

The permeation rate is proportional to the difference between the chemical concentrations on the outside surface (i.e., the surface in contact with the chemical) and on the inside surface (i.e., that in contact with skin or underclothing). Rate is inversely proportional to thickness. The constant of proportionality is called the diffusion coefficient. Mathematically,

Permeation Rate = Diffusion Coefficient x Concentration Gradient.

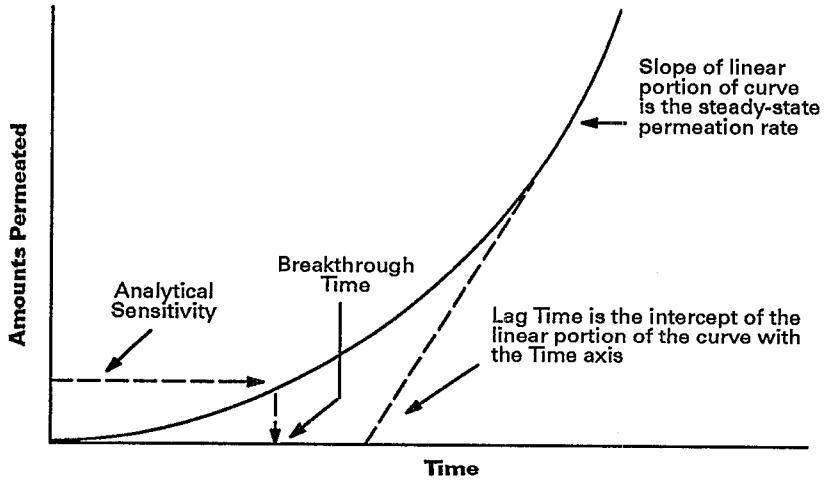
The diffusion coefficient is a property of the chemical/material pair and may be constant or a function of the concentration of the chemical in the material.

Generally, the concentration gradient is a function of the solubility of the chemical in the material and the diffusion coefficient is a measure of the ease with which the chemical moves through the polymer network of the material. An increase in either the concentration gradient or the diffusion coefficient will increase the permeation rate. Both the solubility and the diffusion coefficient increase with temperature; consequently, so does the permeation rate.

In addition to the rate of permeation, the elapsed time between when the chemical first contacts the outer surface of the material and its appearance at the inside surface is of interest. This is known as the breakthrough time. Breakthrough time is more a function of the ease with which the chemical moves through the polymer (i.e., the diffusion coefficient) than the solubility of the chemical in the polymer. Measured breakthrough times are heavily influenced by the apparatus, procedures, and analytical sensitivity of the permeation test.

The permeation process is described mathematically by Fick's laws. An idealization of a Fickian permeation process is shown in Figure 1 in terms of the cumulative amount of chemical that permeates the material as a function of time under the conditions of continuous contact of the material with chemical. For some time after the contact is begun, the permeation rate is slow and will go undetected, depending on the sensitivity of analytical procedures. Breakthrough time is when the chemical is first detected at the unexposed surface or in a collection medium contacting it. After breakthrough, the permeation rate increases until a steady-state rate is achieved.

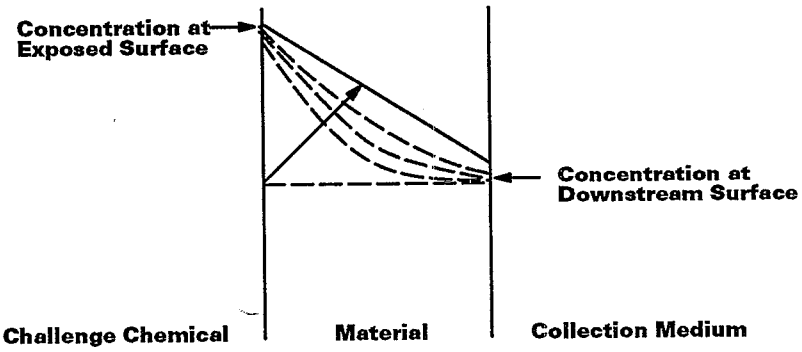
Figure 1. Idealization of Fickian Permeation



One other parameter associated with the theoretical consideration of the permeation process is the lag time. The lag time is the x-axis intercept of the back extrapolation of the slope of the steady-state (linear) portion of the permeation curve.

In Figure 2, the concentration gradient across the glove material is also shown as a function of time from initiation of the contact.

Figure 2. Concentration gradient across material as a function of time. Arrow in material indicates direction of concentration profile change as a function of time. Solid diagonal line is gradient at steady-state.



4.2.2.2 Permeation Test Methods.

4.2.2.2.1 Overview—Permeation testing is straightforward in concept:

- the test cell has two chambers, with the PPE material acting as the partition between the chambers
- the normally outside (as worn) surface of the PPE material is exposed to the test chemical
- the non-exposed surface or the downstream chamber is monitored for the test chemical.

Although simple in concept, the test can produce results that vary significantly from laboratory to laboratory. The reason is that considerable latitude is given to the tester for selection of the means of collecting and analyzing for permeant.[4]

The collection medium and the analytical techniques by necessity vary from chemical to chemical and are dependent on the precision with which the permeation process is characterized. The ideal collection medium will have a high capacity for the permeant(s), be well-mixed, be readily analyzed, and have no effect on the clothing material. High capacity means that any chemical that permeates the clothing material will be readily assimilated by the collection medium. Often times this requires that the collection medium be agitated. Any hindrance to the rapid uptake of permeant by the collection medium will lead to underestimates for the permeation rate and overestimates for the breakthrough time.

Air, nitrogen, helium, and water are the preferred collection media. These substances generally have no effect on the clothing material and do not complicate the analytical chemistry. However, these preferred media do not have sufficient capacities for permeants having very low vapor pressures and low aqueous solubilities. Unfortunately, this group of permeants includes many of the active ingredients of pesticide formulations. Research supported by the EPA's Offices of Research and Development (ORD) and Pesticides Programs (OPP) has investigated alternative collection media for these compounds.[5,6] A solid sorbent held in intimate contact with the downstream surface of the PPE material and periodically removed and analyzed was found most effective. Also, as described below, British researchers have investigated adding to (i.e., spiking) the challenge solution with a tracer chemical that reacts colorimetrically upon reaching the collection medium. Presumably, the permeation of the tracer is correlated with that of the active ingredient. Results of testing with pesticide solutions using a tracer are presented later.

Permeation testing is typically performed in one of two modes: continuous or intermittent contact of the PPE material with the challenge chemical. Continuous contact is the "worst case" condition since the PPE material is contacted with the challenge chemical for the entire duration of the test. Since many field scenarios involve splashes or droplets, test protocols have been developed to be representative of these types of contacts. In the following paragraphs, several existing or draft standard test methods are discussed.

4.2.2.2.2 ***Continuous exposure***—ASTM F739—*Resistance of Protective Clothing Materials to Permeation by Liquids or Gases*[7]—ASTM F739 was promulgated in 1981 and defines a test cell, procedure, and reporting method for measuring the resistance of PPE materials to permeation by single and multicomponent challenge liquids and gases. The method is applicable to PPE materials that incorporate a continuous polymer layer intended to act as a barrier to chemicals. In the test, a two-inch diameter swatch of the PPE material is mounted vertically in the test cell and is continuously exposed to the challenge chemical(s). Provision is made for testing at ambient and non-ambient temperatures. The duration of the test is set by the tester. It may be until breakthrough is detected, steady-state permeation established, or a specified time. The collection medium and analytical technique are also at the discretion of the tester.

The test may run in either an open-loop or closed-loop mode. In the open-loop mode, fresh collecting medium is continuously passed over the downstream surface of the clothing material and then to an analytical instrument (e.g., gas chromatograph). In the closed-loop system, the volume of collection medium remains constant throughout the test. Samples are taken with replacement or are so small in volume so as not to significantly change the collection volume.

The thickness (cm) of the material, the fabric weight (g/m^2), the breakthrough time (min), the permeation rate (micrograms/cm^2/min), the analytical sensitivity, and collection medium must be reported. In addition, a plot of the permeation rate versus time is required. Methods for calculating permeation

rates are given for open- and closed-loop test procedures. A more generalized format for reporting the results of permeation testing is given by ASTM Standard F1194.[8]

As described above, ASTM F739 is applicable to permeants that are either volatile or soluble in water. Many chemicals, including the active ingredients of many pesticide formulations, lack both the necessary volatility and water solubility to be collected by air, nitrogen, or water. Consequently, ASTM Committee F23, which is responsible for F739, is expanding the method to include a means for collecting non-volatile, non-aqueous permeants. The modified procedure is described in Section 4.2.2.2.1.

For certain cases involving highly toxic challenge chemicals or for increasing analytical sensitivity, smaller test cells are advantageous. It is the responsibility of the tester to demonstrate equivalency of alternative test cells to the ASTM F739 cell. Higher sensitivities can be achieved by increasing the ratio of the clothing material area to the collection medium volume (closed-loop system) or decreasing the flowrate (open-loop systems).

Draft Revision of BS 4724—Method of Test for the Resistance of Clothing Materials to Permeation by Harmful Liquids. Part 1: Method for the Assessment of Breakthrough Time (Air Impermeable Materials)[9]—In this draft British Standard, a 1 cm diameter piece of a PPE material is exposed to the challenge chemical and its breakthrough time determined by a color change of an indicator in a distilled water collection medium. This is only a test for breakthrough time; the quantity permeated is not measured. The test apparatus is oriented such that PPE material is horizontal and the collection medium is below but not touching the PPE material. The suggested indicators are chlorophenol red and bromothymol blue. In some cases, the test chemical will itself cause a color change upon permeating. In other cases, breakthrough is determined by means of a tracer in the challenge solution. The suggested tracers are piperidine and propionic acid. These tracers are sufficiently volatile to pass through the air gap between the underside of the clothing material and the indicator-containing collection medium.

This method has been used extensively by G. A. Lloyd of Harpenden Laboratory (England) in the testing of PPE materials upon exposure to neat (undiluted) and multicomponent solutions, including pesticides.[10] Some of his group's findings are presented later in this section.

Draft Revision of BS 4724—Methods of Test for the Resistance of Clothing Materials to Permeation by Liquids. Part 2: Method for the Assessment of Rate of Permeation (Air Impermeable Materials)[11]—In this draft British Standard, a 4.9 cm^2 diameter piece of PPE material is exposed in a horizontal orientation to the challenge chemical; the chemical is placed on the material. A gas or liquid collection medium stream is passed under the material and to the analytical instrument. The test is run only in an open-loop mode. The cumulative amount of chemical permeating the swatch is determined and plotted as a function of time.

In the March 1986 draft that was reviewed in the preparation of this manual, there is a discrepancy between the definition of breakthrough time and the reporting requirement for breakthrough. In the definitions section, breakthrough is defined as above, that is the elapsed time to the first detection of permeant (similar to ASTM Method F739). However, in the reporting section of the draft, breakthrough time is defined as the lag time. Lag time can be before or after the first detection of permeant, depending on the sensitivity of the analytical method.

In contradiction of the title of the method, permeation rate is not one of the reported results. Rather, the method specifies the reporting of the total mass permeated 30 and 60 minutes after breakthrough (i.e., lag time). There may be some advantages to reporting amount permeated two times rather than permeation rate. Committee F23 of the American Society for Testing and Materials (ASTM) is presently considering modifying its reporting requirements.

In addition to these quantitative results, the method also directs the tester to report any changes in the appearance of the swatch evident at the end of the test.

ISO Draft—A Standard Test Method for the Determination of the Permeation of Liquid Chemicals through Protective Clothing[12]—This draft standard of the International Standards Organization is essentially the same as the above British Standard involving the use of tracers. There are some differences in the reporting requirements and options.

4.2.2.2.3 Intermittent exposure. U.S. Army—Vapor Penetration Method[13]—This procedure is used by the U.S. Army in evaluating the resistance of glove, tent, packaging, and other barrier materials to permeation by chemical warfare agents. In the method, a 10 cm^2 rectangular piece of the test material is exposed to droplets of the chemical. The droplets are specified in terms of number and diameter and are placed on the horizontally-held material and the test chamber closed. Air is passed under the material and analyzed for the test chemical. Air at a measured flowrate may also be passed over the droplets to effect their evaporation. On a predetermined schedule, additional droplets are placed on the test material.

ASTM Draft Splash Test[14]—Based on a method developed by the EPA's Offices of Research and Development and Toxic Substances (OTS), ASTM Committee F23 is presently working toward the development of a standard splash test.[15] In its present form, the method utilizes the permeation test cell of ASTM F739. Starting with the cell rotated 45° in the direction of the challenge chemical chamber vertical orientation, a small amount of liquid (5 cm^3) challenge chemical is charged to the cell and the cell rotated 135° until the PPE material is horizontal and covered by the liquid. This position is maintained for a predetermined time and then the chemical is poured from the cell and air blown through the challenge chamber. After another predetermined period of time, the material is recontacted with the liquid and the cycle repeated. The collection medium is selected and monitored as in

ASTM F739. Interlaboratory testing of this method has been completed with reproducible results.

4.2.2.3 Factors affecting permeation test results. Permeation rates and breakthrough times are a function of temperature, the thickness and composition of the test material, and the nature of the chemical challenge. Each are discussed below.

Temperature—The solubility of a chemical in a polymer and the ease with which the chemical moves through the polymer network both increase with temperature. Consequently, permeation rates increase and breakthrough times decrease as temperature is increased. Most published permeation data were obtained at 20-25° C. Since worker exposures to pesticides may occur at higher temperatures, temperature effects must be considered when assessing the effectiveness of clothing. Breakthrough times for benzene in neoprene were 40 minutes at 7° C, 24 minutes at 22° C, and 16 minutes at 37° C.[16] Over this same range the permeation rates increased by 74%. British researchers have demonstrated decreases in breakthrough times ranging from 3% to 29%, dependent on the chemical/material pair, as the temperature was increased from 23°C to 30°C.[10]

Without permeation data for at least two temperatures, it is not possible to predict the magnitude of the temperature effect for any given chemical/material pair. Tests must be performed at the maximum (worst case) temperature and/or over the temperature range of the anticipated application of the clothing.

Thickness—Permeation rate is inversely proportional to the thickness of the test material. The rate decreases as the thickness increases, theoretically in a linear manner. Examples are shown in Table 4. Breakthrough times increase as the thickness increases. The breakthrough time relationship is not linear. Although there is no theoretical basis for it, some researchers have correlated breakthrough time with the square of the clothing material thickness. Accordingly, doubling the thickness increases the breakthrough time by a factor of four. The factor, however, may exceed four by as much as 50%.[4] Others have found lesser increase in breakthrough time as thickness is increased. In attempting to determine such correlations, it is critical that all experimental conditions are maintained consistent for each test over the thickness range. This includes the formulation of the clothing material. As shown in the next paragraphs, specimens of the same thickness from gloves of the same generic material but from different manufacturers exhibited differences as large as an order of magnitude in breakthrough times.

Composition of Clothing Materials—As discussed in Section 3, PPE is fabricated from a wide variety of polymeric materials by many processes. Glove materials, for example, are multicomponent formulations containing one or more polymers and copolymers, processing aids, stabilizers, fillers and so forth. Gloves are typically sold under the generic name of the principal polymer in the formulation (e.g., nitrile, butyl, etc.). However, the formulations for the products sold under one generic name will vary from manufacturer to manufacturer and, in some cases, within one manufacturer.

Table 4. Effect of thickness on the permeation of benzene through neoprene rubber at 22°C[16]

Thickness, cm	Breakthrough time, min	Permeation rate, μg/cm²/min
0.041	6	500
0.076	24.5	230
0.16	60	80

Since the barrier effectiveness of a polymeric material is determined by the specific interactions between the chemical and the material, a variety of performances may be expected for clothing sold under the same generic name. Indeed, this effect has been measured.[17,18] See Table 5. For nitrile glove materials of approximately the same thickness from eight manufacturers, the breakthrough times exhibited differences of a factor of ten for perchloroethylene, a factor of six for p-xylene, and a factor of four for butyl acetate. For neoprene glove materials from five manufacturers (Note: There is a greater thickness variation among the neoprene gloves than with the nitrile gloves), the breakthrough times differed by factors of eight for ethanol, five for n-hexane, and two for butyl acetate. As will be discussed later, each of the above chemicals has been identified as one that may appear in a pesticide formulation. In particular, xylenes are widely used as an ingredient in emulsifiable concentrates of Toxicity Category I and II pesticides.

Chemical Composition—Published permeation data are predominantly from tests in which the challenge chemical is neat. Considerably less testing has been performed with multicomponent chemical solutions. That which has been reported represents a broad spectrum of results. In some cases, the permeation of any one component occurs at a slower rate than when the chemical was tested in neat form. In other cases, the permeation is at a greater rate, and in others there seems to be little effect. Examples of each are shown in Table 6.[19] At present, there are no means for predicting the behavior of multicomponent solutions.

This situation represents a particular problem with regard to pesticides which are virtually all multicomponent formulations. Research, much of it sponsored by the EPA, is ongoing in an attempt to better understand the role of the carrier solvents, surfactants, and other components in the permeation of the active ingredients.[20,21,22] Data from these studies are presented in detail later in this section.

Table 5. Breakthrough times (minutes)* for perchloroethylene, p-Xylene, n-Butyl acetate, ethanol, and n-Hexane through nitrile and neoprene gloves from several manufacturers[18]

Manufacturer	Thickness (mm)	Perchloro-ethylene	p-Xylene	n-Butyl acetate	Ethanol	n-Hexane
Nitrile						
Ansell	0.36	30	11	15		
Best	0.28	135	27	28		
Edmont	0.32	215	33	44		
Granet	0.32	90	24	32		
Intermarket	0.36	125	28	39		
LRC	0.28	295	54	38		
North	0.32	145	33	38		
Pioneer	0.32	295	60	56		
Neoprene						
Ansell	0.38			14	500	106
Best	0.64			13	110	21
Edmont	0.46			20	480	82
Granet	0.55			13	80	23
Pioneer	0.55			33	690	72

*Mean of six measurements.

Table 6. Permeation of three two-component mixtures through two glove materials[19]

Composition (A/B)/Vol %	Glove material (thickness, cm)	Breakthrough time (min)		Permeation rate ($mg/m^2/sec$)	
		A	B	A	B
Methanol/ n-butyl Acetate	Nitrile (0.38)				
0/100			60		91
10/90		38	39	26	91
25/75		24	28	50	71
50/50		34	38	63	32
75/25		53	>150	26	<1
90/10		103	>150	10	<1
100/0		108		4	
Methyl Ethyl Ketone/Hexane	Viton (0.23)				
0/100			>200		
5/95			150		
10/90		39	33	<25	<25
25/75		6	6	55	25
50/50		3	3	330	86
75/25		3	3	670	135
90/10		3	3	1140	63
100/0		3		1100	
p-Xylene/Toluene	Nitrile (0.38)				
0/100			32		26
25/75		28	25	6	18
50/50		34	32	20	18
75/25		54	54	19	5
100/0		53		27	

4.2.3 Degradation

Degradation is any undesirable change in a physical property or the appearance of the PPE material. Examples include swelling, shrinkage, loss of puncture and tear resistance, and an increase in stiffness due to exposure to pesticides. The degradation effects of a pesticide on PPE materials can be assessed in the laboratory or in the field.

In a typical degradation test, a specimen from the PPE or, in some cases (e.g., a glove), the entire item is immersed in the pesticide for some period of time. At predetermined intervals, the specimen is removed, tested, and observed. In the laboratory, strength, puncture, and tear properties are commonly measured using a machine with which the specimen is stretched and the force required to stretch the specimen recorded. Significant increases or decreases (±20%) in any of the properties would be indicative of poor resistance to the pesticide formulation. Losses in these properties would generally result from the sorption of one or more components of the pesticide formulation by the glove material.

Increases in properties are often associated with the extraction of components from the glove material by the pesticide formulation. The stiffening of polyvinyl chloride (PVC) gloves due to extraction of plasticizer is an example.

Care must be taken when testing clothing materials that derive their physical properties from a supporting fabric but their barrier properties from the coating. The supporting fabric may not be affected but the barrier coating may be degraded by the chemical.

Sorption or extraction may also be evidenced by changes in the weight and/or dimensions of the test specimen. Measurement of such effects are relatively easy to perform in either the laboratory or the field. For this reason, until recently most chemical resistance charts published by suppliers of polymeric materials and polymer-based PPE were based on weight change or swelling measurements. Again, weight or dimensional changes of ±20% for rubber materials or ±3% for plastic materials should be considered significant and indicative of poor resistance to the pesticide formulation.

ASTM standard tests exist for measuring the chemical resistance or degradation of rubber and plastic materials; examples include:

- ASTM D471—Rubber Property--Effects of Liquids
- ASTM D543—Resistance of Plastics to Chemical Reagents
- ASTM D751—Testing of Coated Fabrics
- ASTM D412—Rubber Properties in Tension
- ASTM D1388—Stiffness of Fabrics, Cantilever Test Method

In addition, Committee F23 of ASTM is presently developing a method specifically for chemical-resistant materials. The intent is a relatively simple test that can be performed in the field or in a minimally equipped laboratory with the objective of rapidly identifying only those material/chemical combinations that warrant additional testing by more stringent (and perhaps, expensive) methods (e.g., ASTM F739).

4.3 Arm/Hand Protection

4.3.1 Introduction

As discussed in Section 3, there are scores of polymeric materials from which gloves are fabricated. All of these materials are subject to some degree of chemical attack by pesticide formulations. The degree to which the pesticide formulation will attack any given polymeric material is dependent on the duration of the exposure, the temperature, the condition of the material, and the specific interactions between the polymer and the particular components of the pesticide formulation. A possible consequence of chemical attack is that the glove will no longer protect the worker's hands and lower arms from the pesticide.

Tests for measuring the chemical resistance and barrier effectiveness of glove materials to chemicals were discussed above. Many decades of such testing have shown that:

- no one glove material is a barrier to all chemicals
- any given chemical may severely attack one glove material and not affect another material
- certain chemicals or combinations thereof have severe effects on all commonly available glove materials

The effectiveness of gloves as chemical barriers is the subject of the remainder of this subsection. However, before beginning the discussion, it is important to note that chemical resistance is also fundamental to the issue of decontamination. (See Section 9.) Clothing materials that are not resistant to a chemical will absorb the chemical, making decontamination more difficult. Decontamination will then require removal of absorbed as well as surface chemical.

4.3.2 Pesticide formulation types

Pesticide formulations are designed to optimize the cost, handling, application, and effectiveness of the active ingredient. Some fumigants are used in undiluted form (commonly referred to as "neat"), whereas some herbicide formulations may have 15 to 20 ingredients in addition to the active ingredient. The other ingredients include diluents, surfactants, stabilizers, thickeners, solid substrates, solvents, and tackifiers. The resulting formulations are typically characterized as one of the following types:

- Aqueous solutions and concentrates
- Emulsifiable concentrates
- Wettable powders
- Dry flowables (water dispersible granules)
- Granules
- Others--including controlled release, dusts, and aerosols

From the perspective of protective clothing selection and chemical resistance, the pesticide formulation types may be more generally categorized as:

- Solids
- Solutions and dispersions that contain an organic solvent
- Aqueous solutions and dispersions, which contain no organic solvents

PPE materials having a continuous polymeric film are likely to resist permeation and penetration by all solid formulations and thus act as a barrier to solids contact with the skin. For solids, glove features such as fit, gauntlet length, durability, etc. as discussed in Section 3 are the key issues for glove selection decisions.

Chemical resistance factors are more important for aqueous solution formulations and most important for the formulations that contain an organic solvent. Most common glove materials, with the exceptions of polyvinyl alcohol and very thin (<0.2 mm) natural rubber gloves, are highly resistant to water and would be expected to provide good barriers to permeation by formulations that contain no organic solvents.

The solutions that contain an organic solvent usually in the form of emulsifiable concentrates and field application dilutions of such concentrates, represent the greatest potential challenge to the barrier effectiveness of polymeric gloves. Many of the solvents can severely degrade or permeate the glove materials when in neat form.

Because most pesticide formulations are proprietary and because until recently their components other than the active ingredient were not considered important from a health perspective, there is little published information available on the types and concentrations of organic solvents in pesticide formulations. However, information from the literature and discussions with persons knowledgeable on pesticide formulations provides some insight into the identity of the solvents. Categorized according to functional group type, solvents that are representative of those used in pesticide formulations are listed in Table 7.

In the remainder of this section, we describe the results of permeation tests performed using such carrier solvents in neat form and using commercially available, pesticide formulations containing these types of solvents. The results indicate that the permeation of various pesticide formulation components through common glove materials is often controlled by the type and amount of the solvent. Thus, the relative permeation of the pesticide active ingredient and other components can often be predicted based on information regarding the permeation of the carrier solvent in neat form. This finding can greatly simplify protective glove selection decisions because permeation tests using the solvents alone or focussed on the solvent are less complex to perform than those using actual formulations. Also a large database of information is now available for the types of organic liquids used as solvents in neat form.

4.3.3 Solvent permeation

Since the early 1980's, the EPA has supported the preparation of a guidance manual entitled *Guidelines for the Selection of Chemical Protective Clothing* targetted toward hazardous waste site and emergency spill response personnel.[23] As part of the *Guidelines* document, permeation data from clothing manufacturers, journal articles, and technical reports were compiled into a

database. Permeation data for several of the solvent liquids listed in Table 7 are available for common glove materials from this database. Appendix K of this manual provides a summary of the permeation data extracted from the *Guidelines* database for 12 common materials from which PPE is fabricated.

Table 7. Organic liquids used as carrier solvents in non-aqueous solution pesticide formulations

Functional group classification	Organic carrier solvent
Acetates	Amyl Acetate Butyl Acetate
Alcohols	Diacetone Alcohol Diethanol Amine Ethanol Hexylene Glycol Isopropanol Methanol Propylene Glycol Tetrahydrofurfuryl Alcohol
Halogenated Hydrocarbons	Methylene Chloride
Ketones	Acetone Cyclohexanone Isophorone Methyl Isobutyl Ketone
Petroleum Distillates, Aliphatic	Diesel Fuel (paraffins up to 600°F b.p.) Gasoline (C_4–C_{12} paraffins) Kerosene (paraffins up to 500°F b.p.) Mineral Oil Mineral Spirits Naphtha Petroleum Oil
Petroleum Distillates, Aromatic	Xylenes Xylene Range Solvents

These data were reviewed and a qualitative rating was assigned to each chemical/material pair for which data were available according to the criteria listed in Table 8. It is important to note that only the reported "breakthrough" times were used to assign the ratings and that, in some cases, the data range covers more than one category. In general, the lower resistance ratings within a range are associated with the thinner glove specimens for the generic material type. Table 9 provides a qualitative summary of the data in Appendix K in terms of the four ratings categories.

Table 8. Ratings categories for qualitative summary of neat carrier solvent permeation data

Rating category		Breakthrough time range (hr)
○	Best	> 4.0
◉		> 1.5–4.0
◐		> 0.5–1.5
●	Worst	< 0.5

General observations from Table 9 are:

- The longest breakthrough times are often found for the butyl rubber, nitrile rubber, polyvinyl alcohol, Silver Shield, and Viton materials.
- Long breakthrough times are also commonly found for the Neoprene and the nitrile rubber+PVC blend material, however, these materials also exhibited short breakthrough times for several of the chemical classifications of interest.
- Intermediate to short breakthrough times are often found for the polyvinyl chloride and polyethylene materials.
- Short breakthrough times are typically found for the natural rubber and natural rubber containing glove materials, the Neoprene/natural rubber laminate, and the Neoprene+natural rubber blend material.
- Many of the twelve glove materials exhibit good permeation resistance to chemicals from the alcohol and aliphatic petroleum distillate chemical classes.
- Few materials exhibit good permeation resistance to chemicals from the acetate, halogenated hydrocarbon, ketone, and aromatic petroleum distillate classifications.

The above observations are for *neat* chemicals representative of those used in pesticide formulations. Most solvent-containing pesticide formulations, of course, are multicomponent in composition and contain varying amounts and combinations of the organic liquids, water, active ingredient, and other unspecified constituents.

Permeation data for pesticide formulations are limited in the literature. In the next subsections, two pesticide formulation permeation studies are discussed. While these two studies provide useful information and insights, it is still difficult to broadly generalize the effects of active ingredient, solvent, surfactants, etc. upon the permeation behavior and to extrapolate the results of *neat* solvent permeation tests to predict protective glove resistance to multicomponent pesticide formulations.

Table 9. Qualitative ratings for glove materials based on neat carrier solvent breakthrough time data+

Carrier Solvent	Butyl rubber	Natural rubber	Neo-prene	Neoprene/ natural rubber	Neoprene + natural rubber	Nitrile rubber	Nitrile rubber + polyvinyl chloride	Poly-ethylene	Polyvinyl alcohol	Polyvinyl chloride	Silver Shield	Viton Fluoro-elastomer
Acetates												
Amyl Acetate	—	●	●	—	—	◉	◉	—	○	●	—	—
Butyl Acetate	◉◎	●	●◉	●	●	●◉	◉	●	○	●	○	●
Alcohols												
Diacetone Alcohol	—	—	—	—	—	—	—	—	—	—	—	—
Diethanol Amine	—	—	—	—	—	—	—	—	—	—	—	—
Ethanol	○	●◉	◎○	◉	●	◉◎	○	◉	◎	●◉◎	○	—
Hexylene Glycol	—	—	—	—	—	—	—	—	—	—	—	—
Isopropanol	—	●◉◎	◎○	●	●◉	○	○	◎	—	◎	—	—
Methanol	—	●○	◎○	—	—	○	○	—	—	◎	—	○
Propylene Glycol	—	◎	—	◎	—	—	—	◎	—	—	—	—
Tetrahydrofurfuryl Alcohol	—	—	—	—	—	—	—	—	—	—	—	—
Halogenated Hydrocarbons												
Dichloromethane	●	●	●	●	●	●	●	●	●○	●	◎	◉
Ketones												
Acetone	○	●	●◉	●	●	●	●	●◎	○	●	○	●
Cyclohexanone	○	—	—	—	●	●	—	—	○	—	○	●
Isophorone	—	—	—	—	—	—	—	—	—	—	—	—
Methyl Isobutyl Ketone	◉◎○	●	●◉	—	—	●◉	●	●	○	●	—	●○

+ Breakthrough Time Range (Hours): ● = < 0.5 ◉ = 0.5–1.5 ◎ = 1.5–4 ○ = > 4

Table 9 (continued). Qualitative ratings for glove materials based on neat carrier solvent breakthrough time data+

Carrier Solvent	Butyl rubber	Natural rubber	Neo-prene	Neoprene/ natural rubber	Neoprene + natural rubber	Nitrile rubber	Nitrile rubber + polyvinyl chloride	Poly-ethylene	Polyvinyl alcohol	Polyvinyl chloride	Silver Shield	Viton Fluoro-elastomer
Petroleum Distillates, Aliphatic												
Diesel Fuel	◉	—	○	—	—	○	—	—	○	○	—	○
Gasoline (C_4–C_{12})	—	—	◉	—	●	○	—	—	○	◉	—	○
Light Fuel Oil	—	—	—	—	—	○	—	—	○	○	—	○
Kerosene	—	●	○	—	◐	○	—	—	○	◉○	—	○
Mineral Spirits	—	—	◐○	—	●	○	—	—	○	◉	—	—
Naphtha	—	—	●○	—	●	○	—	—	○	◉	—	—
Petroleum Distillates, Aromatic												
Xylene	—	◐	●◐	●	●	●◐◉	●◐	●	○	●	○	○
m-Xylene	●◐	—	●	—	—	●◐◉	—	—	○	—	—	○
o-Xylene	◐	—	—	—	—	●	—	—	○	—	—	○
p-Xylene	●	—	—	—	—	●◐	—	—	○	●	—	○

+ Breakthrough Time Range (Hours): ● = < 0.5 ◐ = 0.5–1.5 ◉ = 1.5–4 ○ = > 4

In order to increase confidence in and extend the generalizations which follow, additional testing is required and must be conducted according to test procedures that produce results not confounded by the complex nature of the formulation.

4.3.4 Pesticide formulation permeation

Permeation testing with commercially-available, non-aqueous pesticide concentrates and application-strength formulations was initiated in the mid-1980s by the EPA's Office of Research and Development in support of the Office of Pesticide Programs (OPP). To date, data have been generated for twenty pesticide formulations and seven common glove types. Because the specific identities and compositions of the pesticide formulations are confidential business information, the results of these studies have been published only in OPP confidential technical reports and "sanitized," less-comprehensive technical papers. In this section, we will present and discuss the results in non-confidential terms but so that important trends and generalizations can be demonstrated and used.

Only one other similarly extensive study of pesticide permeation of glove materials was found during the preparation of this manual. In this study by Lloyd, however, the specific formulation compositions and active ingredients were not reported and the findings are similarly presented in terms of general trends and observations. Until the data and detailed information from both (and other) sources become more available and publishable, decisions regarding glove selection and regulation must be based on extrapolation and conservative judgments.

4.3.4.1 EPA pesticide permeation study. Because limited data are available in the public domain to identify appropriate protective clothing for use in agricultural pesticide operations, the EPA sponsored a multiyear effort to generate, assemble, and correlate data on the resistance of protective glove materials to permeation by components of solvent-containing pesticide concentrates and application-strength formulations. Through 1990, the effort had involved:

- the development of a rapid-screening degradation test method to quickly assess the compatibility of pesticide formulations with glove materials,
- the modification of the standard ASTM F739-85 permeation test method to allow for the efficient collection and analysis of volatile and non-volatile, low aqueous solubility active ingredients in pesticide formulations,
- the measurement of breakthrough times and cumulative masses permeated for both the active ingredient and carrier solvents for a matrix of approximately twenty pesticide formulations and seven common glove materials, and
- the statistical analysis, correlation, and reporting of the test results in a series of OPP confidential reports[20,21,22] and sanitized technical papers.[5,6]

The first technical report presents information regarding the degradation test and permeation test method development as well as permeation test results for seven pesticide formulations and seven glove material types.[20] The second report presents the results of additional permeation tests using 11 different pesticide formulations and six glove material types.[21] The third

report focuses on two pesticide formulations and three to five glove materials, and specifically investigated the effects of concentrated versus application strength formulations.[22] Within each of these reports, rigorous statistical analyses of the data are presented and used as the basis for correlations and conclusions. In this subsection, the permeation data sets from these three reports are combined and reported as a single data set.

Because of the confidential nature of the pesticide formulation identity information, the results and conclusions of the EPA study are presented here in general terms and without identifying specific formulations tested. The discussion will focus only on the types and amounts of solvent present to correlate the results and to generalize the relative performance of the various gloves tested.

Materials and Procedures—Permeation tests were performed using a modified ASTM Method F739 permeation test cell and method with a silicone rubber sheeting material as the collection medium. Use of such a medium for collection of low volatility, low aqueous solubility compounds was summarized earlier in Section 4.2.2.2.2 and is reported in detail elsewhere.[5,10]

Permeation tests were performed for a matrix of approximately twenty pesticide formulations, generally solvent based concentrates, and seven glove material types. In total, over 115 permeation tests were performed in triplicate. Although the specific compositions of the formulations tested can not be revealed, Table 10 summarizes the range of active ingredients and carrier solvents contained in the various formulations. Frequently, mixtures of solvents and solvent types were present in a single formulation. The seven glove material types evaluated in this study are identified in Table 11. Note that, in some cases, more than one commercial brand of a generic glove material was tested.

The permeation tests were conducted for an eight hour duration with sampling at 15 minutes, 30 minutes, 1, 2, 3, 4, 6, and 8 hours. Permeations of both the active ingredient and carrier solvent were monitored. In some cases, the permeations of two carrier solvents were monitored in addition to the active ingredient. The results are reported in the technical reports in terms of:

(1) the breakthrough detection time for the active ingredient (AI),
(2) the breakthrough detection time for the carrier solvent(s) (CS),
(3) the cumulative amount of AI permeated at each sampling interval ($\mu g/cm^2$), and
(4) the cumulative amount of CS permeated at each sampling interval ($\mu g/cm^2$).

Table 10. Range of active ingredients and carrier solvents used in EPA permeation study

Component	Types of compounds
Active ingredients	Dicrotophos Endosulfan Ethion Ethyl Parathion Methyl Parathion Mevinphos Monocrotophos Naled Oxydemeton Phosalone
Carrier Solvents	
Alcohols	Isopropanol Hexylene Glycol
Ketones	Acetone Cyclohexanone Methyl Isobutyl Ketone
Petroleum Distillates, Aliphatic	Kerosene Mineral Oil Petroleum Oil
Petroleum Distillates, Aromatic	Xylenes Xylene range solvents

Table 11. Glove materials used in EPA permeation study

Generic material type	Manufacturer	Model	Average thickness (cm)
Butyl rubber	North	Butyl B174	0.05
	Mine Safety	#38553	0.04
Natural rubber	Granet	541	0.05
	Pioneer	Ivory White	0.06
Neoprene	Edmont	Neoprene 29-870	0.05
	Ansell	Neoprene	0.05
Nitrile rubber	Edmont	Sol-Vex 37-155	0.04
	Pioneer	Stansolv A-15	0.04
	Ansell	Challenger 613	0.04
	Best	Nitrile #727	0.04
Polyethylene	Fisher	Polyethylene	0.01
Polyvinyl chloride	Pioneer	Stan-flex	0.05
Silver Shield	North	Silver Shield	0.01

In this discussion, we focus on the breakthrough detection times for the AI and CS and the cumulative amounts of AI and CS permeated at eight hours for comparison of the performance of the various gloves. Similar to the approach used to rate the data for neat carrier solvent permeation in Section 4.3.3, the result for each formulation/material pair tested in the EPA study was assigned one of four qualitative ratings. Individual qualitative ratings were first assigned for each of the test measurements: AI breakthrough time, CS breakthrough time, AI cumulative amount at 8 hours, and CS cumulative amount at 8 hours, using the criteria defined in Table 12. These four individual ratings were then compared and reduced to a single rating, generally on the basis of the CS breakthrough time as described below.

Table 12. Individual ratings categories for qualitative summary of EPA permeation data

Rating category	Breakthrough time range (hr)	Rating category	Cumulative amount permeated at 8 hour range ($\mu g/cm^2$)
○ Best	> 4.0	○	< 10
◉	> 1.5–4.0	◉	> 10–100
◐	> 0.5–1.5	◐	> 100–1000
● Worst	< 0.5	●	> 1000

The discussion below begins with some general observations regarding the permeation of the active ingredient versus the carrier solvent within any given formulation and briefly summarizes the effects of the active ingredient and carrier solvent types. The subsection concludes with a discussion of the relative performance of the various glove materials tested.

Active Ingredient versus Carrier Solvent Permeation

One of the most important findings of the EPA study is that the permeation of the carrier solvent is generally a *conservative* indicator of glove performance relative to both AI and CS permeation.

In 100 of the approximately 115 permeation tests performed, the permeation of both the AI and CS was monitored over the test duration. The findings relative to a comparison of AI versus CS behavior were as follows. For breakthrough times:

- In 23% of the tests, the qualitative rating based on the breakthrough time for the CS was lower (i.e., shorter breakthrough time) than that for the AI.
- In 53% of the tests, the qualitative rating based on the breakthrough time for the CS was equal to that for the AI.

- In 24% of the tests, the qualitative rating based on the breakthrough time for the CS was higher (i.e., longer breakthrough times detected) than that for the AI. The majority of these cases were for butyl rubber, nitrile rubber, and Silver Shield materials in which the cumulative amounts of the AI that permeated over the eight hour duration were quite low (<100 $\mu g/cm^2$) and much less than the cumulative amount of the CS.

For cumulative amounts permeated at 8 hours:

- In 67% of the tests, the qualitative rating assigned based on cumulative amount of CS was lower (i.e., higher cumulative amounts permeated) than that for the AI. In most of these cases, the cumulative amount of AI was *much* lower than that for the CS.
- In 33% of the tests, the qualitative rating assigned based on cumulative amount of CS was equal to that for the AI.

On the basis of the above analysis, the breakthrough time of the CS can be used as a conservative basis for comparing glove performance both within this study and with the neat carrier solvent data (Section 4.3.3) and the Harpenden tracer study (described later in Section 4.3.4.2) for which only breakthrough time data are available.

Thus, each pesticide formulation/glove material tested in the EPA study is assigned a qualitative rating on the basis of the CS breakthrough time as shown in Table 13. Those cases in which the AI breakthrough time was detected before the CS breakthrough time are marked with an asterisk. Also, for those cases in which the permeation of the carrier solvent was not monitored, the breakthrough time of the AI was used to assign the qualitative rating.

Similar to the neat carrier solvent data summarized in Table 9, the table is organized by carrier solvent type. Each row represents a different pesticide formulation, which is identified only by the carrier solvent present and its concentration in the formulation. In cases where the formulation involved a mixture of carrier solvents, the results are reported under each carrier solvent present and the other carrier solvents are identified. Ten different active ingredients are represented.

Effect of Active Ingredient Type

In preparing and organizing Table 13, the results from the EPA study were first compared as a function of active ingredient type to elucidate their effect on glove material performance. Some differences were observed among the active ingredients when compared with other formulations containing the same carrier solvent at approximately the same concentration. However, such comparisons were limited because there are few cases in which different active ingredients were tested in formulations containing the same type and amount of carrier solvent. More importantly, though, the effect of the active ingredient type was quite small relative to the changes observed when the carrier solvent type and concentration are changed as described below.

Table 13. Qualitative Ratings for Glove Materials Based on Carrier Solvent Breakthrough Time Data (EPA Study)+

Carrier Solvent (and Concentration in Formulation)	Butyl rubber	Natural rubber	Neo-prene	Nitrile rubber	Poly-ethylene	Polyvinyl chloride	Silver Shield
Alcohols							
Isopropanol (<1%)	—	◉	○	○	—	—	—
Isopropanol (4%)	—	◐	○	○	—	—	—
Isopropanol (10%)	—	●	◉	○	—	—	—
Isopropanol (10%)	○	●	◉	○	●	◉	
Isopropanol (2%) and Petroleum Oil (94%)	—	○	○	○	—	—	—
Isopropanol (6%) and Hexylene Glycol (5%)	—	●	—	●	—	●	●
Ketones							
Acetone (26%)	◉ *	●	●	◐◉ *	●	●	○ *
Cyclohexanone (23%) and Xylenes (35%)	◉	●	◐	◉	●	●	—
Methyl Isobutyl Ketone (51%) and Xylenes (14%)	—	●	●	●	—	—	○
Petroleum Distillates, Aliphatic							
Kerosene (99%)	◐ *	●	○ *	○ *	●	◐ *	—
Petroleum Oil (94%) and Isopropanol (2%)	—	○	○	○	—	—	—
Mineral Oil (10%) and Xylenes (32%)	◉ *	●	●	○ *	●	●	—
Petroleum Oil (15%) and Xylenes (40%)	—	●	●	◉ *	—	—	—
Petroleum Oil (57%) and Xylenes (41%)	—	●	●	◉	—	—	—

+ Breakthrough Time Range (Hours): ● = < 0.5 ◐ = 0.5–1.5 ◉ = 1.5–4 ○ = > 4

* Rating based on carrier solvent breakthrough time although permeation of low amount of active ingredient was detected earlier.

Table 13 (continued). Qualitative Ratings for Glove Materials Based on Carrier Solvent Breakthrough Time Data (EPA Study)+

Carrier Solvent (and Concentration in Formulation)	Butyl rubber	Natural rubber	Neo-prene	Nitrile rubber	Poly-ethylene	Polyvinyl chloride	Silver Shield
Petroleum Distillates, Aromatic							
Xylenes (1%)	—	◉	○	○	—	—	—
Xylenes (10%)	—	●	◉	○	—	—	—
Xylenes (11%)	○	●	◉ *	○	●	◐ *	○ *
Xylenes (38%)	◉ *	●	●	●◉	●	●	○
Xylenes (48%)	—	●	◐	●	—	—	—
Xylenes (48%)	◐	●	●	●	●	●	—
Xylenes (48%)	◐	●	◐ *	●◐◉	—	—	—
Xylenes (57%)	●	●	●	◐	●	●	○ *
Xylenes (35%) and Cyclohexanone (23%)	⊖ *	◒	◒	⊖	◒	◒	—
Xylenes (14%) and Methyl Isobutyl Ketone (51%)	—	●	●	●	—	—	○
Xylenes (35%) and Mineral Oil (10%)	◉ *	●	●	○ *	●	●	—
Xylenes (40%) and Petroleum Oil (15%)	—	●	●	◉ *	—	—	—
Xylenes (41%) and Petroleum Oil (57%)	—	●	●	◉	—	—	—

+ Breakthrough Time Range (Hours): ● = < 0.5 ◐ = 0.5–1.5 ◉ = 1.5–4 ○ = > 4

* Rating based on carrier solvent breakthrough time although permeation of low amount of active ingredient was detected earlier.

Effect of Carrier Solvent Type and Concentration

The results of the EPA study indicate that the type and concentration of the carrier solvent are the most important variables in understanding and correlating the permeation of solvent-containing pesticide formulations through the various glove materials. This observation is readily apparent from a review of Table 13.

General observations follow regarding glove material permeation resistance organized by carrier solvent functional group classification. Note, however, that as reported in Table 13, not all glove materials were tested against all formulations.

Formulations Containing Alcohols

- For formulations containing only isopropanol, the longest breakthrough times, 4 to 8 hours, were measured for the butyl rubber, Neoprene, and nitrile rubber materials. Very short breakthrough time, <0.5 to 1 hour, were typically measured for the natural rubber and polyethylene materials.
- For the one formulation in which isopropanol was mixed with hexylene glycol, breakthrough times of <0.5 hours were measured for all materials tested.

Formulations Containing Ketones

- For the formulation containing only acetone, the longest breakthrough times were measured for butyl rubber, nitrile rubber, and the Silver Shield material. The four other materials tested had very short breakthrough times.
- Similar results were found for the mixtures of cyclohexanone and methyl isobutyl ketone with xylene, an aromatic petroleum distillate.

Formulations Containing Aliphatic Petroleum Distillates

- For the two formulations containing >94% of an aliphatic petroleum distillate, the longest breakthrough times were measured for the Neoprene and the nitrile rubber materials. (Note that the Silver Shield material was not tested). Short or conflicting breakthrough times were measured for the other materials.
- For the formulations also containing xylenes as a second carrier solvent, the longest breakthrough times were measured for the butyl and nitrile rubber materials. For these formulations, the Neoprene material was found to have a breakthrough time of <0.5 hour--much lower than for the formulations containing only the aliphatic distillates. As described below, Neoprene is a poor barrier to permeation by formulations with high concentrations of aromatic petroleum distillates.

Formulations Containing Aromatic Petroleum Distillates

- With the exception of the Silver Shield material, the relative resistance of the various glove materials is highly dependent upon the concentration of the xylenes in the formulation.
- At xylene concentrations <15%, the Silver Shield, nitrile rubber, butyl rubber, and Neoprene materials were all found to exhibit breakthrough times greater than 3 to 4 hours.

- At xylene concentrations >38%, only the Silver Shield and, in some cases, the nitrile rubber materials were found to exhibit breakthrough times greater than 3 to 4 hours.

Comparisons Within Glove Material Type
Tests were also conducted with different manufacturers' samples within a generic glove material type. As reported in Table 11, samples of different manufacturers' gloves were tested for butyl rubber, natural rubber, Neoprene, and nitrile rubber and several of the pesticide formulations. For nitrile rubber and one formulation type (48% xylenes), four different manufacturers' gloves were tested.

Although the specific results of these tests are not reported here, the conclusions based upon a statistical analysis of the data, as reported in the EPA technical reports[20,21,22] were:

- no statistically significant difference was observed between the permeation resistances of the two butyl rubber materials (one formulation tested only),
- statistically significant differences were sometimes observed between the various natural rubber, Neoprene, and nitrile rubber materials. For the natural rubber and Neoprene materials, these differences were small and did not span the ratings categories as assigned in Table 13. For the nitrile rubber materials, the differences sometimes did span several ratings categories and these are noted in Table 13.

4.3.4.2 Harpenden tracer study. Lloyd and his coworkers at Harpenden performed an extensive series of tests with pesticide formulations.[24] They used the tracer technique (BS4724) described in Section 4.3.2.2. Recall that in this technique breakthrough time is the time at which there is a color change in the collection medium due to the permeation of a tracer chemical added to the challenge solution. Presumably, this occurs simultaneously with the permeation of the chemical of interest. (Data generated for a small number of neat chemicals by Lloyd seem to support this presumption.) Use of this technique with multicomponent solutions raises additional questions because the identity of the permeant(s) (if there is one other than the tracer) is not discernible. ***Tracer breakthrough does not necessarily mean pesticide breakthrough.***

In spite of these reservations, a review of the Harpenden data provides further insight into the performance of gloves upon *continuous* exposure to pesticide formulations, as measured by the tracer technique. A summary of the breakthrough time data reported by Lloyd for the five glove materials tested are provided in Appendix L. Again, a qualitative summary of the data is presented in Table 14 again using the ratings categories previously defined in Table 8. The left column of Table 14 characterizes the carrier solvent composition of the different pesticide formulations; for proprietary reasons the active ingredient was not given in the original reference. Also note that not all glove materials were tested against each pesticide formulation.

Observations on the data follow:

Formulations Containing Alcohols

- For formulations with only an alcohol listed as a carrier solvent, tracer breakthrough times were typically greater than six hours for butyl, natural rubber, neoprene, and polyvinyl chloride. However, the alcohols investigated were multi-functional and relatively large in molecular weight in comparison to those (i.e., methanol, ethanol, and isopropanol) that have been tested in neat form.
- The tracer from methanol blends with dichloromethane and xylene exhibited much shorter breakthrough times; less than one hour for nitrile and polyvinyl chloride, and from 1 to 3 hours for neoprene.

Formulations Containing Halogenated Hydrocarbons

- The tracer in the "chlorinated hydrocarbon" formulation broke through the natural rubber, neoprene, and polyvinyl chloride in less than 1 hour. Breakthrough of the butyl occurred at approximately 3 hours.
- As described above, the tracer breakthrough times for the dichloromethane blend with methanol were generally short.

Formulations Containing Ketones

- With cyclohexanone and isophorone as singular carrier solvents in a formulation, tracer breakthrough occurred after 3 or more hours for neoprene, nitrile, and polyvinyl chloride.
- Upon blending cyclohexanone or isophorone with xylene, tracer breakthrough times for neoprene, nitrile, and polyvinyl chloride were much shorter. However, except at the highest xylene concentration, tracer breakthrough for neoprene remained in the range of 1 to 2 hours. The tracer breakthrough times for nitrile and polyvinyl chloride were greater than 1 hour only at xylene concentrations less than 20%. In the one case where butyl was tested, tracer breakthrough at the highest xylene concentration was 1 hour. (Additional discussion on xylenes is given below.)

Formulations Containing Aliphatic Petroleum Distillates

- Tracer breakthrough times were typically greater than 2 hours and often 6 hours for butyl, neoprene, and polyvinyl chloride. Times for natural rubber were shorter, usually in the range of 0.5 to 1.5 hours.

Formulations Containing Aromatic Petroleum Distillates

- For the aromatic petroleum distillates, tracer breakthrough times of less than 1 hour were measured for neoprene, nitrile, and polyvinyl chloride when the xylene concentration was above 60%. As the xylene concentration decreased, breakthrough times increased, and butyl and neoprene were the better barriers.

Table 14. Qualitative Ratings for Glove Materials Based on Tracer Breakthrough Time Data (Harpenden Study[24])+

Carrier Solvent (and Concentration in Formulation)	Butyl rubber	Natural rubber	Neoprene	Nitrile rubber	Polyethylene
Alcohols					
Diacetone Alcohol (16%)	○	◉	◉	—	○
Diethanol Amine (31%)	○	○	○	—	○
Tetrahydrofurfuryl Alcohol (41%)	○	○	○	—	○
Methanol (15%) and Dichioromethane (65%)	—	—	⊙	●	●
Methanol (30%) and Xylene (25%)	—	—	◉	⊙	⊙
Methanol (39%) and Xylene (35%)	—	—	◉	⊙	●
Halogenated Hydrocarbons					
Chlorinated Hydrocarbons	◉	●	●	—	●
Dichloromethane (65%) and Methanol (15%)	—	—	⊙	●	●
Ketones					
Cyclohexanone (19%)	—	—	○	○	○
Isophorone (80%)	—	—	○	◉	◉
Cyclohexanone (20%) and Oil (75%)	◉	⊙	○	—	◉
Cyclohexanone (10%) and Xylene (60%)	—	—	◉	⊙	⊙
Cyclohexanone (10%) and Xylene (70%)	⊙	●	●	—	●
Cyclohexanone (12%) and Xylene (37%)	—	—	⊙	⊙	⊙
Cyclohexanone (15%) and Xylene (20%)	—	—	◉	◉	⊙
Cyclohexanone (15%) and Xylene (20%)	—	—	◉	◉	⊙
Cyclohexanone (20%) and Xylene (50%)	—	—	◉	⊙	●

+ Breakthrough Time Range (Hours): ● = < 0.5 ⊙ = 0.5–1.5 ◉ = 1.5–4 ○ = > 4

Table 14 (continued). Qualitative Ratings for Glove Materials Based on Tracer Breakthrough Time Data (Harpenden Study)+

Carrier Solvent (and Concentration in Formulation)	Butyl rubber	Natural rubber	Neoprene	Nitrile rubber	Polyethylene
Halogenated Hydrocarbons (continued)					
Cyclohexanone (24%) and Xylene (43%)	—	—	◉	◉	◉
Cyclohexanone (30%) and Xylene (37%)	—	—	◉	●	◉
Cyclohexanone (30%) and Xylene (37%)	—	—	◉	●	◉
Isophorone (30%) and Xylene (40%)	—	—	⊙	◉	●
Petroleum Distillates, Aliphatic					
Parafin Oil (27%)	—	—	○	○	○
Parafin Oil (34%)	—	—	—	○	○
Parafin Oil (68%)	○	◉	⊙	—	○
Parafin Oil (70%)	○	◉	○	—	○
Parafin Oil (70%)	⊙	◉	○	—	○
Parafin Oil (70%)	○	◉	○	—	⊙
Parafin Oil (80%)	—	◉	○	—	⊙
Naphtha (42%)	○	◉	○	—	○
Naphtha (50%)	⊙	◉	○	—	⊙
Naphtha (54%)	○	⊙	○	—	○
Naphtha (35%) and Xylene (35%)	○	◉	○	—	○

+ Breakthrough Time Range (Hours): ● = < 0.5 ◉ = 0.5–1.5 ⊙ = 1.5–4 ○ = > 4

Table 14 (continued). Qualitative Ratings for Glove Materials Based on Tracer Breakthrough Time Data (Harpenden Study[24])+

Carrier Solvent (and Concentration in Formulation)	Butyl rubber	Natural rubber	Neoprene	Nitrile rubber	Polyethylene
Petroleum Distillates, Aromatic					
Xylene (22%)	○	◉	○	—	◐
Xylene (23%)	—	—	◉	◉	◉
Xylene (23%)	—	—	◉	◉	◉
Xylene (27%)	○	◉	○	—	○
Xylene (28%)	—	—	◉	◉	◐
Xylene (28%)	—	—	◉	◉	◐
Xylene (33%)	◉	◐	○	—	◉
Xylene (35%)	—	—	○	◉	◐
Xylene (39%)	○	◐	◐	—	◉
Xylene (45%)	◐	●	●	—	◐
Xylene (60%)	—	—	◐	◐	◐
Xylene (70%)	—	—	●	●	●
Xylene (70%)	—	—	●	●	●
Xylene (70%)	—	—	●	●	●
Xylene (80%)	—	—	◐	●	●

+ Breakthrough Time Range (Hours): ● = < 0.5 ◐ = 0.5–1.5 ◉ = 1.5–4 ○ = > 4

Table 14 (continued). Qualitative Ratings for Glove Materials Based on Tracer Breakthrough Time Data (Harpenden Study[24])+

Carrier Solvent (and Concentration in Formulation)	Butyl rubber	Natural rubber	Neoprene	Nitrile rubber	Polyethylene
Petroleum Distillates, Aromatic (continued)					
Xylene (20%) and Cyclohexanone (15%)	—	—	◉	◉	◐
Xylene (20%) and Cyclohexanone (15%)	—	—	◉	◉	◐
Xylene (37%) and Cyclohexanone (12%)	—	—	◐	◐	◐
Xylene (37%) and Cyclohexanone (30%)	—	—	◐	●	◐
Xylene (37%) and Cyclohexanone (30%)	—	—	◐	●	◐
Xylene (43%) and Cyclohexanone (24%)	—	—	◐	◐	◐
Xylene (50%) and Cyclohexanone (20%)	—	—	◉	◐	●
Xylene (60%) and Cyclohexanone (10%)	—	—	◉	◐	◐
Xylene (70%) and Cyclohexanone (10%)	◐	●	●	—	●
Xylene (40%) and Isophorone (30%)	—	—	◉	◐	●
Xylene (25%) and Methanol (30%)	—	—	◉	◐	◐
Xylene (35%) and Methanol (39%)	—	—	◉	◐	●
Xylene (25%) and Naptha (35%)	○	◐	○	—	○

+ Breakthrough Time Range (Hours): ● = < 0.5 ◐ = 0.5–1.5 ◉ = 1.5–4 ○ = > 4

The trends in Table 14 follow approximately those that would have been expected on the basis of the breakthrough times for the carrier solvents in neat form as reported in Table 9. Longer breakthrough times were generally associated with butyl, neoprene, and nitrile, and shorter times with PVC and natural rubber. In a few cases, the material that would have been expected to yield the longest breakthrough times was not tested; for example, butyl with the cyclic ketones and nitrile with the aliphatic petroleum distillates.

4.3.5 General recommendations for glove selection

The results presented in Tables 9, 13, and 14 are summarized in Table 15, again organized by carrier solvent type. When possible, the qualitative ratings based on the carrier solvent permeation data were grouped with those for the same carrier solvent in a pesticide formulation. Table 15 shows that there is, in general, good agreement among the breakthrough time trends from testing with neat chemicals and for pesticide formulations as reported by the EPA and Harpenden studies. In cases where direct comparisons are possible, the qualitative rating assigned using the results of neat carrier solvent permeation tests were usually the same as or lower than the rating from the relevant pesticide formulation test. Such agreement demonstrates the general accuracy and conservatism of this approach for making protective glove selection decisions.

In spite of some apparent discrepancies, the fact that all glove materials have not been tested, that all carrier solvents are probably not included, and the uncertainties of the tracer technique, Table 15 can be used as a starting point in the selection of clothing materials until more specific data from permeation testing with pesticide formulations become available. The information in the table could also be considered as a guide for the selection of candidate materials for further testing.

Based on the data and conclusions presented in Sections 4.3.3 and 4.3.4 and summarized in Table 15, Table 16 is provided as a final aid for protective glove selection decisions. Table 16 identifies the preferred glove types as well as those *not recommended* for use with pesticide formulations containing various carrier solvent types. The glove types identified as preferred are those that consistently provide the best permeation resistance to pesticide formulations and neat carrier solvents within each chemical classification identified. The glove types identified as not recommended are those that consistently provide very poor permeation resistance. Note that in many cases glove types included in Table 15 are not listed in Table 16. Gloves were not included in Table 16 when there were either too few data to categorize the material or the data were inconsistent or demonstrated intermediate performance. Also note that the recommendations in Table 16 are based solely on chemical resistance considerations. Other factors such as glove sizing, comfort, durability, and cost must also be considered as discussed elsewhere in this document. And finally, the *proper use* of chemical protective gloves is as important as their proper selection for limiting worker exposures to agricultural pesticide formulations.

Table 15. Comparison of qualitative ratings from neat carrier solvent permeation data and pesticide formulation permeation data (EPA and Harpenden studies)+

Carrier Solvent	Butyl rubber	Natural rubber	Neo-prene	Neoprene/ natural rubber	Neoprene + natural rubber	Nitrile rubber	Nitrile rubber + polyvinyl chloride	Poly-ethylene	Polyvinyl alcohol	Polyvinyl chloride	Silver Shield	Viton Fluoro-elastomer
Acetates												
Amyl Acetate (100%)	—	●	●	—	—	◉	◉	—	○	●	—	—
Butyl Acetate (100%)	◉◉	●	●◉	●	●	●◉	◉	●	○	●	○	●
Alcohols												
Diacetone Alcohol (16%)	○	⊙	⊙	—	—	—	—	—	—	○	—	—
Diethanol Amine (31%)	○	○	○	—	—	—	—	—	—	○	—	—
Ethanol (100%)	○	●●	⊙○	◉	●	⊙○	○	◉	⊙	●◉⊙	○	—
Isopropanol (100%)	—	●◉⊙	⊙○	●	●◉	○	○	⊙	—	⊙	—	—
Isopropanol (<5%)	—	◉⊙	○	—	—	○	—	—	—	—	—	—
Isopropanol (5–10%)	○	●	⊙	—	—	○	—	●	—	—	—	—
Isopropanol (6%) and Hexylene Glycol (5%)	—	●	—	—	—	●	—	—	—	●	●	—
Methanol (100%)	—	●○	⊙○	—	—	○	○	—	—	⊙	—	○
Methanol (15%) and Dichloromethane (65%)	—	—	◉	—	—	●	—	—	—	●	—	—
Methanol (30–39%) and Xylene (25–35%)	—	—	⊙	—	—	◉	—	—	—	●◉	—	—
Propylene Glycol (100%)	—	⊙	—	⊙	—	—	—	⊙	—	—	—	—
Tetrahydrofurfuryl Alcohol (41%)	○	○	○	—	—	—	—	—	—	○	—	—

+ Breakthrough Time Range (Hours): ● = < 0.5 ◉ = 0.5–1.5 ⊙ = 1.5–4 ○ = > 4

Table 15 (continued). Comparison of qualitative ratings from neat carrier solvent permeation data and pesticide formulation permeation data (EPA and Harpenden studies)+

Carrier Solvent	Butyl rubber	Natural rubber	Neo-prene	Neoprene/ natural rubber	Neoprene + natural rubber	Nitrile rubber	Nitrile rubber + polyvinyl chloride	Poly-ethylene	Polyvinyl alcohol	Polyvinyl chloride	Silver Shield	Viton Fluoro-elastomer
Halogenated Hydrocarbons												
"Chlorinated" Hydrocarbons	⊙	●	●	—	—	—	—	—	—	●	—	—
Dichloromethane (100%)	●	●	●	●	●	●	●	●	●○	●	⊙	◉
Dichloromethane (65%) and Methanol (15%)	—	—	◉	—	—	●	—	—	—	●	—	—
Ketones												
Acetone (100%)	○	●	●◉	●	●	●	●	●⊙	○	●	○	●
Acetone (26%)	⊙	●	●	—	—	◉⊙	—	●	—	●	○	—
Cyclohexanone (100%)	○	—	—	—	●	●	—	—	○	—	○	●
Cyclohexanone (19%)	—	—	●	—	—	●	—	—	—	●	—	—
Cyclohexanone (20%) and Oil (75%)	⊙	◉	○	—	—	○	—	—	—	⊙	—	—
Cyclohexanone (15%) and Xylene (20%)	—	—	⊙	—	—	⊙	—	—	—	◉	—	—
Cyclohexanone (10–30%) and Xylene (37–60%)	—	—	◉⊙	—	—	●◉	—	—	—	●◉	—	—
Cyclohexanone (10%) and Xylene (70%)	◉	●	●	—	—	—	—	—	—	●	—	—
Cyclohexanone (23%) and Xylenes (35%)	⊙	●	◉	—	—	⊙	—	●	—	●	—	—
Isophorone (80%)	—	—	○	—	—	⊙	—	—	—	⊙	—	—
Isophorone (30%) and Xylene (40%)	—	—	⊙	—	—	◉	—	—	—	●	—	—
Methyl Isobutyl Ketone (100%)	◉⊙○	●	●◉	—	—	●◉	●	●	○	●	—	●○
Methyl Isobutyl Ketone (51%) and Xylenes (14%)	—	●	●	—	—	●	—	—	—	—	○	—

+ Breakthrough Time Range (Hours): ● = < 0.5 ◉ = 0.5–1.5 ⊙ = 1.5–4 ○ = > 4

Table 15 (continued). Comparison of qualitative ratings from neat carrier solvent permeation data and pesticide formulation permeation data (EPA and Harpenden studies)+

Carrier Solvent	Butyl rubber	Natural rubber	Neo-prene	Neoprene/ natural rubber	Neoprene + natural rubber	Nitrile rubber	Nitrile rubber + polyvinyl chloride	Poly-ethylene	Polyvinyl alcohol	Polyvinyl chloride	Silver Shield	Viton Fluoro-elastomer
Petroleum Distillates, Aliphatic												
Diesel Fuel (100%)	◉	—	○	—	—	○	—	—	○	○	—	○
Gasoline (C_4–C_{12}) (100%)	⊙	—	◉	—	●	○	—	—	○	◉	—	○
Light Fuel Oil (100%)	—	—	—	—	—	○	—	—	○	○	—	○
Kerosene (100%)	—	●	○	—	⊙	○	—	—	○	◉○	—	○
Kerosene (99%)	⊙	●	○	—	—	○	—	●	—	⊙	—	—
Mineral Spirits (100%)	—	—	⊙○	—	●	○	—	—	○	◉	—	—
Naphtha (100%)	—	—	●○	—	●	○	—	—	○	◉	—	—
Naphtha (42–54%)	◉○	⊙◉	○	—	—	—	—	—	—	◉○	—	—
Naphtha (35%) and Xylene (35%)	○	⊙	○	—	—	—	—	—	—	○	—	—
Paraffin Oil (27–80%)	◉○	⊙	◉○	—	—	○	—	—	—	◉○	—	—
Petroleum Oil (94%)	—	○	○	—	—	○	—	—	—	—	—	—
Petroleum Oil (10–60%) and Xylenes (30–45%)	◉	●	●	—	—	◉○	—	●	—	●	—	—

+ Breakthrough Time Range (Hours): ● = < 0.5 ⊙ = 0.5–1.5 ◉ = 1.5–4 ○ = > 4

Table 15 (continued). Comparison of qualitative ratings from neat carrier solvent permeation data and pesticide formulation permeation data (EPA and Harpenden studies)+

Carrier Solvent	Butyl rubber	Natural rubber	Neo-prene	Neoprene/ natural rubber	Neoprene + natural rubber	Nitrile rubber	Nitrile rubber + polyvinyl chloride	Poly-ethylene	Polyvinyl alcohol	Polyvinyl chloride	Silver Shield	Viton Fluoro-elastomer
Petroleum Distillates, Aromatic												
Xylene (100%)	●◉	●	●	●	●	●◉⊙	◉	●	○	●	○	○
Xylenes (<30%)	○	⊙	⊙○	—	—	⊙	—	—	—	◉⊙	—	—
Xylenes (30–40%)	⊙○	◉	◉○	—	—	⊙	—	—	—	◉⊙	—	—
Xylenes (45–60%)	◉	●	●◉	—	—	◉	—	—	—	◉	—	—
Xylenes (70–80%)	—	—	●◉	—	—	●	—	—	—	●	—	—
Xylenes (<15%)	○	◉⊙	⊙○	—	—	○	—	●	—	◉	○	—
Xylenes (38%)	⊙	●	●	—	—	⊙	—	●	—	●	○	—
Xylenes (48%)	◉	●	●◉	—	—	●◉⊙	—	●	—	●	—	—
Xylenes (57%)	●	●	●	—	—	◉	—	●	—	●	○	—
Xylenes (20%) and Cyclohexanone (15%)	—	—	⊙	—	—	⊙	—	—	—	◉	—	—
Xylenes (37–60%) and Cyclohexanone (10–30%)	—	—	◉⊙	—	—	●◉	—	—	—	●◉	—	—
Xylenes (70%) and Cyclohexanone (10%)	◉	●	●	—	—	—	—	—	—	●	—	—
Xylenes (35%) and Cyclohexanone (23%)	⊙	●	◉	—	—	⊙	—	●	—	●	—	—

+ Breakthrough Time Range (Hours): ● = < 0.5 ◉ = 0.5–1.5 ⊙ = 1.5–4 ○ = > 4

Table 15 (continued). Comparison of qualitative ratings from neat carrier solvent permeation data and pesticide formulation permeation data (EPA and Harpenden studies)+

Carrier Solvent	Butyl rubber	Natural rubber	Neo-prene	Neoprene/ natural rubber	Neoprene + natural rubber	Nitrile rubber	Nitrile rubber + polyvinyl chloride	Poly-ethylene	Polyvinyl alcohol	Polyvinyl chloride	Silver Shield	Viton Fluoro-elastomer
Petroleum Distillates, Aromatic (continued)												
Xylenes (40%) and Isophorone (30%)	—	—	◉	—	—	⊙	—	—	—	●	—	—
Xylenes (25–35%) and Methanol (30–39%)	—	—	◉	—	—	⊙	—	—	—	●⊙	—	—
Xylenes (14%) and Methyl Isobutyl Ketone (51%)	—	●	●	—	—	●	—	—	—	—	○	—
Xylenes (35%) and Naphtha (35%)	○	⊙	○	—	—	—	—	—	—	—	○	—
Xylenes (30–45%) and Petrolum Oil (10–60%)	◉	●	●	—	—	◉○	—	●	—	●	—	—

+ Breakthrough Time Range (Hours): ● = < 0.5 ⊙ = 0.5–1.5 ◉ = 1.5–4 ○ = > 4

Table 16. Handwear selection guidance for protection for pesticide formulations that contain organic solvents

Carrier solvent type	Glove recommendations+	
	Preferred	**Not recommended**
Acetates	Butyl rubber* Polyvinyl alcohol Silver Shield	Natural rubber Polyvinyl chloride
Alcohols	Butyl rubber Neoprene Nitrile rubber Nitrile + PVC blend	Neoprene + natural blend
Alcohol mixtures with:		
Halogenated hydrocarbons	Neoprene*	Nitrile rubber Polyvinyl chloride
Aromatic pet. distillates	Neoprene	Nitrile rubber Polyvinyl chloride
Halogenated hydrocarbons	Silver Shield	Natural rubber Nitrile rubber Polyvinyl chloride
Ketones	Butyl rubber Polyvinyl alcohol Silver Shield	Natural rubber Neoprene + natural blend Nitrile + PVC blend Polyethylene Viton
Ketone mixtures with:		
Aromatic pet. distillates	Butyl rubber* Neoprene* Nitrile rubber* Silver Shield	Natural rubber Polyvinyl chloride
Petroleum distillates, aliphatic mixtures with:		
Aromatic pet. distillates	Butyl rubber Nitrile rubber	Natural rubber Polyvinyl chloride
Petroleum distillates, aromatic		
Xylenes (<40%)	Butyl rubber Nitrile rubber Polyvinyl alcohol Silver Shield Viton	Natural rubber Polyethylene
Xylenes (>40%)	Nitrile rubber* Polyvinyl alcohol Silver Shield Viton	Natural rubber Neoprene Polyethylene Polyvinyl chloride

+ Recommendations include only preferred and not recommended materials based on Table 15. Other materials were not categorized because of intermediate performance, inconsistent data, or because no data were available.

* Categorized as preferred glove but permeation resistance may be lower than other preferred gloves.

4.4 Body Protection

4.4.1 Introduction

Body protection includes shirts, pants, coveralls, aprons, hats, and the like. As mentioned earlier, these items are fabricated from three general groups of materials:

- Woven cotton and cotton/polyester fabrics
- Nonwoven fabrics, predominantly polyolefins, but including microporous polytetrafluoroethylene (PTFE)
- Woven or nonwoven fabrics to which a continuous film of plastic or rubber has been laminated or coated

These fabrics exhibit levels of barrier effectiveness that span many orders of magnitude. As discussed in Section 4.2.1, definitive comparison of the fabrics is difficult because the agricultural clothing research community has no standard test for measuring barrier effectiveness. Furthermore, the difficulty of this situation is compounded by varied practices among the researchers for describing the fabrics that they tested. Examples include:

- not reporting properties such as thickness, weight, and air permeability
- not identifying trademarked fabrics, referring to them rather by generic descriptions. Since no two researchers use the same generic description, persons attempting to use the literature cannot ascertain whether, in fact, the same material was or was not tested by two researchers. For example, the same fabric might be referred to as "synthetic nonwoven," "nonwoven polyolefin," "nonwoven polyethylene," and "Tyvek®."
- not identifying trademarked fabric treatments/finishes, referring to them rather by generic descriptions. For example, the descriptions of the same treatment may range from "soil repellent finish" to "fluorocarbon" to "a 3M fluorocarbon" to "Scotchgard®."

With these caveats in mind, the performance of the various materials from which body protection is fabricated is discussed in the following paragraphs under headings suggested by the three fabrics types defined above. Overall guidance derived from the information is presented in Table 17.

4.4.2 Woven cotton and cotton/polyester fabrics

4.4.2.1 Effect of pesticide amount. For woven and nonwoven fabrics, penetration increased with the amount of pesticide applied in the form of droplets (as distinct from spray).[25] Twenty-five, 50 and 75 µL of 0.3% solutions of four pesticides were applied to four different fabrics. The amount of penetration was not linear with applied volume, rather the percent penetration increased with the amount applied.

A fabric that provided relatively high penetration resistance at one volume did not necessarily provide a relatively high resistance at a different volume. There seems to be an absorbency capacity threshold beyond which the penetration resistance of some fabrics drops off dramatically. This behavior must be borne in mind when reviewing penetration data in which different volumes are applied. The capacity threshold may account for apparent discrepancies in data reported from different researchers.

Table 17. Body protection guidance

1.	Long-sleeved shirts and long-legged pants are preferred to short sleeves and short pants.
2.	For woven fabrics, heavier fabrics are better barriers than lighter fabrics. 250 g/m² has been suggested as a minimum.[27]
3.	For fabrics of the same type and weight, higher resistance to penetration was generally correlated with higher cotton content. The performance of 100% polyester is usually significantly below even 35/65 cotton/polyester blends. Although supporting data are not extensive, it seems that woven fabrics should be preferred to knits and, within the wovens, twills to plain weave.
4.	In general, low air permeability, synthetic nonwovens and microporous PTFE are better barriers than woven fabrics.
5.	Fluorocarbon treatment generally improves the penetration resistance of porous fabrics, both woven and nonwoven, to liquids and particles. The fluorocarbon reduces the differences between the resistances of 100% cotton and various cotton/polyester blends. Durable press finishes reduce penetration resistance to liquids. Studies of soil releasing treatments are inconclusive. Laundering reduces the effectiveness of finishes; they must be renewed periodically.
6.	The highest levels of protection can only be achieved through the use of a fabric that contains a coating or lamination of a continuous film of plastic or rubber.
7.	Any item of clothing, to be effective, must be properly designed, constructed, fitted, worn, and maintained.

4.4.2.2 Effect of fabric type. In laboratory testing, the penetration resistance to a spray of methyl parathion EC diluted to 0.12% (wt) with water was approximately three times greater for 100% cotton and 50/50 cotton/polyester than for 100% polyester.[26] All fabrics were 118 g/m².

There was no detectable penetration of denim (274 g/m²) or twill (235 g/m²) by 0.12% (wt) sprays of dicofol, ethion, or methyl parathion.[27] In the same study, chambray (116.3 g/m²) was penetrated by considerable amounts of the three pesticides and a similar solution of captan. On the basis of these results, 250 g/m² was suggested as a minimum weight for woven fabrics used for protection from pesticide sprays. Furthermore the authors speculated that twill might be preferred to plain weave construction. It was also found that dicofol EC diluted to 0.12% with water, penetrated 50/50 cotton/polyester (106 g/m²) by factors of 60 to 100 times more than it did 100% cotton (250 g/m²).

Upon challenge with droplets of parathion, guthion, paraquat, and dinoseb, chambray (shirt weight) was generally the least effective fabric.[25] Intermediate in effectiveness were coated poplin (193 g/m²), denim (500 g/m²), and spunbonded polyolefin. By Duncan's Multiple Range test, however, the spunbonded polyolefin was similar in performance to Gore-Tex (nylon-PTFE-nylon). The authors concluded that chambray and denim "are not effective barriers against the pesticides tested."

In general the penetrations of chlorpyrifos, chlorpropham, 2,4,5-T isooctyl ester, and pentachlorophenol from EC sprays and droplets were less for 100% cotton denim (weight not reported) than for 35/65 cotton/polyester denim (weight not reported).[28]

The penetration resistance of seven fabrics upon spray and droplet contacts with four forms of parathion and four other pesticides was investigated.[29] Although there was some problem with the experimental procedure as evidenced by the authors statement "It was difficult to draw any general conclusions about the protective quality of any particular garment material from the presented . . .," they did list the fabrics in the following order of resistance to penetration by sprays:

- rubberized cotton > spunbonded polyolefin (SBO) > white polyethylene coated SBO > cellulosic > 10-oz cotton drill > yellow polyethylene coated SBO > perforated SBO

In the same study and in permeation tests involving continuous contact with parathion EC, the permeation of the SBO, perforated SBO, and cellulosic was immediate. "Only garments constructed from polyethylene-coated SBO and rubberized cotton would provide acceptable protection against exposure to EC parathion splashed onto a worker."

The penetration of contaminated dust through knitted fabrics was significantly greater than through woven fabrics of approximately the same weight (120–150 g/m^2).[30] The dust particles were similar in size distribution to foliar residues. Knitted fabrics allowed 87 to 96% penetration whereas the woven fabrics allowed only 0.3 to 5.8% penetration. Furthermore, the addition of fluorocarbon soil repellent reduced the penetration of the woven fabrics by an additional 60 to 80%. The soil repellent also reduced the air permeability of the woven fabrics by 14 to 24%. There did not appear to be a difference between the penetrations of the 100% cotton and the 50/50 cotton/polyester fabrics within each fabric type. In the same tests, a non-woven allowed < 0.5% penetration.

4.4.2.3 Effect of fabric finish. In laboratory testing with methyl parathion EC diluted to 0.12% with water, fluorocarbon and acrylic acid-based finishes reduced penetration by approximately 50% or more.[26] The effect was greater for 100% cotton than for either 50/50 cotton/polyester or 100% polyester. All fabrics were 119 g/m^2. The durable press finish, dimethyl dihydroxyethylene urea, either had no effect or reduced penetration resistance. On performing a statistical analysis of their data, the authors reported "no significant differences were found in finishes." Nevertheless, they believe the data evidenced the trends reported above.

There was no consistent trend in the effect of a fluorocarbon treatment on the penetration resistance of chambray, denim, and twill to 0.12% (wt) spray of captan, dicofol, ethion, or methyl parathion.[27] Different solutions and fabrics exhibited increased, decreased, and the same performances due to the treatment. In a second series of tests in the same study, the authors found no effect of finish, but speculate that the result may be due to the procedure.

In laboratory testing with guthion (2-SC) diluted to 3.5 mL/750 mL with water, a fluorocarbon treated (Scotchgard) chambray was 1.2 times more resistant to penetration than untreated chambray.[31]

Several fluoroaliphatic finishes were applied to 100% cotton and 35/65 cotton/polyester from water- and solvent-based solutions and the penetration compared with that which occurred through fabrics treated with Scotchgard.[28] In general, fabrics treated with the water-based finishes exhibited higher penetration, but only one was more resistant than Scotchgard. Penetrations through 100% cotton and 35/65 cotton/polyester, which were treated with Scotchgard, were similar.

Several fabrics were challenged with methylene blue (0.1% and as an indicator of penetration) spiked water, water/surfactant (48:1), and cotton seed oil/surfactant (48:1).[32] Nonwovens treated with Scotchgard or other proprietary finishes allowed no penetration, similar to the polyethylene-coated spunbonded nonwoven. These same fabrics allowed the least penetration of malathion from both water and cotton seed oil solutions. The performance of all the finished nonwovens was significantly better than the untreated nonwovens. Scotchgard and Quarpel® fluorocarbon finishes on woven 100% cotton and 35/65 cotton/polyester prevented the penetration of the methylene blue from the aqueous but not the oily challenge. Unfinished wovens (denim) and a spunlaced polyester failed all solutions. In a second study, the comfort attributes of the fabrics were investigated and it was concluded that the spunlace polyester, which allowed no methylene blue penetration and was in the group allowing the least malathion penetration, had air and water permeabilities similar to shirt-weight cotton. This result suggested to the authors that the finished spunlace material may be a strong candidate for use in the field.

The drop absorbency and wicking of several fabrics (some with durable press finish) was measured upon contact with wettable powders and emulsifiable concentrates.[33] The findings were:

- with regard to absorbency: cotton > 50/50 > 65/35 > acrylic > nylon > PET > 50/50DP >65/35DP. Since DP reduces absorbency, it might reduce exposure.
- with regard to wicking: acrylic > nylon > polyester >100% > 50/50 > 65/35 > 50/50DP > 65/35DP. Since DP reduces wicking, it might reduce exposure.

In a follow-up study, the same author subjected thirteen fabrics to spray penetration testing.[34] His expectations on the basis of the absorbency and wicking test that the DP finish would reduce penetration were not realized. In fact there was no significant difference between the penetrations of DP-treated and untreated fabrics. On the other hand, fabrics treated with a fluorocarbon soil repellent (not identified) provided better penetration resistance than the untreated fabric. With both the carbaryl and atrazine flowable liquids, there was no statistical difference between the penetration resistance of 100% spunbonded olefin (Tyvek) and three fabrics treated with soil repellent: 100% cotton, 50/50 cotton/polyester, and 35/65 cotton/

polyester. Consistent with the results of the wicking study, 100% nylon, acrylic, and polyester provided the least resistance to penetration.

4.4.2.4 Effect of laundering. With a spray of methyl parathion EC diluted to 0.12% (wt) with water as the challenge, there was no effect of up to 50 launderings on the penetration resistance of 100% cotton or 50/50 cotton/polyester.[26] Laundering, however, did reduce the effectiveness of fluorocarbon and soil release finishes for 100% cotton and 100% polyester, but not 50/50 cotton/polyester. On performing a statistical analysis of their data, the authors reported "no significant differences were found in number of launderings." Nevertheless, they believe the data evidence the above trends.

4.4.2.5 Effect of temperature and humidity. In laboratory testing of 50/50 cotton/polyester (106 g/m^2) and 100% cotton (250 g/m^2), there was no effect of temperature and humidity on resistance to penetration.[35] Dicofol EC diluted to 0.12% with water in the form of a spray was the challenge. The temperature humidity conditions were: 85°F/75%RH, 72°F/65%RH, and 65°F/55%RH.

4.4.3 Nonwoven fabrics, including microporous PTFE

In laboratory testing with guthion (2-SC) diluted 3.5 mL/750 mL with water, similar penetration resistances were found for Gore-Tex, Tyvek, and Crowntex.[31] Guthion penetration of these fabrics was approximately 25 times less than through shirt-weight chambray.

Denim and twill were found to be more effective barriers than Tyvek to sprays of 0.12% solutions of captan, dicofol, ethion, and methyl parathion.[27]

In tests in which 0.12% (wt) solutions of chlorobenzolate, dicofol, and ethion were sprayed on twelve fabrics (10 nonwoven and 2 woven), penetration resistances were found to fall into three categories, as follows:[27]

- Highly Penetrated
  - Duragard® and chambray
- Moderate Penetration
  - Sontara® and an experimental 100% polypropylene nonwoven
- No Detectable Penetration
  - Tyvek, SMS, denim, and two other 100% polypropylene nonwovens

There was no detectable penetration of Gore-Tex by 0.12% (wt) sprays of dicofol, ethion, or methyl parathion.[27] In the same study, penetration of Gore-Tex by a similar solution of captan was detected.

In an orchard spraying study of guthion as a wettable powder, Saranex-laminated Tyvek, Gore-Tex, and an experimental composite had protection factors (i.e., holdouts) of greater than 99%, compared to regular clothing which had a holdout of 97.5%.[36] These results compare favorably with those of a previous study with the same pesticide and rubberized-cotton, Tyvek, and polyethylene-coated Tyvek.[29]

In permeation tests with butanone, isooctane, xylene, an aqueous herbicide concentrate, and an oil-based herbicide concentrate, breakthrough times were less than one minute for a nylon/microporous PTFE/nylon fabric.[37]

In an orange grove, airblast study with dicofol, applicator exposure was reduced by 38% for workers wearing Tyvek coveralls compared to 35/65 cotton/polyester, and by 27% for workers wearing gloves for a combined reduction of 65%.[38] The coveralls reduced mixer-loader exposure by 40%, but gloves increased exposure. (See the comments on the Maddy et al. study in the next section.)

In orchard spraying of a wettable powder, a PVC suit and a Gore-Tex suit provided equivalent protection.[39] Compared to standard clothing, a Gore-Tex suit reduced exposures by factors of up to 1000 for a nitrofen wettable powder.[40] In a side-by-side comparison with a nitrofen emulsifiable concentrate, significantly higher exposures occurred when handling the powder. This latter result is consistent with that of a previous comparison of exposures with wettable powders and emulsifiable concentrates.[41]

4.4.4 Film-coated or -laminated woven or nonwoven fabrics

The performances of many fabrics containing a continuous film of a plastic or rubber have already been described above in comparison to those for porous woven and nonwoven fabrics. Some additional examples follow.

An aqueous herbicide concentrate and an oil-based herbicide concentrate had breakthrough times of greater than six hours with a neoprene-coated nylon fabric.[37] In the same study, equivalent, high (97-99%) repellency was found for a siliconized nylon (130 g/m^2), nylon/microporous PTFE/nylon (150 g/m^2), and the neoprene fabric (270 g/m^2) to various pesticide simulates and formulations. Against the same liquids, a 35/65 cotton/polyester (250 g/m^2) exhibited repellencies ranging from 57-87%.

There was no detectable penetration of sprays of solutions (0.12% wt) of captan, dicofol, ethion, or methyl parathion through polyethylene- or Saranex-coated Tyvek.[27]

For the most part the investigations have focussed on polyethylene-laminated nonwovens (e.g., polyethylene-laminated Tyvek). Only a few studies have addressed PVC-coated fabrics (typically referred to as rainsuits) or other rubber or plastic coated materials. Almost without exception, the coated or laminated fabrics provided the highest resistances to penetration. This result should be expected since the fabrics, if properly manufactured, contain no holes. Transit of chemical would be by permeation only.

If permeation had occurred, it may have gone undetected because of poor contact of the absorbent pad with the back of the clothing material or poor efficiency of the pad for collecting the permeant. In the EPA studies described in Section 4.3.4.1, cotton gauze was evaluated and rejected as a collection medium for the latter reason.

The literature is not as rich in permeation data for coated-fabrics of the type that might be worn in agriculture as it is for glove data. Consequently, tables for clothing that are analogous to Tables 13, 14, and 16 cannot be developed specifically for clothing fabrics. Insights into the permeation resistance of coated fabrics can be gained, however, from the glove materials tables; many materials are used for both applications.

Attention must also be drawn to several new plastic film laminated non-wovens that exhibit improved permeation resistance to a broader range of chemicals than traditional fabrics. These newer fabrics are of proprietary composition and have the tradenames of Responder®, Chemrel® and Barricade®. Relative costs for hooded coveralls of these materials are compared with traditional fabrics in Table 18.

Table 18. Prices for hooded coveralls

Material	Price range, $*
Tyvek	5–7
Polyethylene-laminated Tyvek	9–10
Saranex-laminated Tyvek	15–18
Barricade	28–35
Chemrel	40–50
Responder	60–70

*Based on 1990 Lab Safety Supply Catalog for a single garment.

4.4.5 Garment design

Design considerations and prototyped ensembles for protection of orchard sprayers were developed and tested.[42] Specific recommendations were given for features and dimensions to be incorporated into a hooded-coverall. The results suggested to the authors that attention to styling and sizing would "definitely increase the wearability potential of protective garments."

Lloyd suggested that the "design has more influence on its protective efficiency than the nature of the material from which it is made" on the basis of field data that showed the relative protective efficiencies were equivalent or greater for garments based on porous, woven fabrics as compared to garments based on film-coated fabric that performed exceptionally well in laboratory permeation testing.[37] Apparently the porous fabrics had sufficient capacity to absorb the field spray while the spray may have penetrated openings in the garment based on the high performance film.

Based on data from a field exposure study, the design was deduced for a garment specifically for lawn-sprayers.[43] Among the conclusions was that multiple layers of clothing contribute considerably to protection. That is, two layers of a light fabric might be better than a single layer having the same total thickness. A laboratory study of double-layering demonstrated that methyl parathion penetration was reduced by a factor of 17 when a T-shirt weight, 100% cotton knit was placed under a plain-weave,

shirt-weight, 100% fabric.[44] When the cotton knit was replaced with a 100% polypropylene mesh knit fabric the penetration was reduced by a factor of 70. Furthermore, the retention of methyl parathion in the polypropylene fabric was significantly less than in the cotton knit.

References

[1] American Society for Testing and Materials. Standard Test Method F903–87–Resistance of Protective Clothing Materials to Penetration by Liquids. American Society for Testing and Materials, Philadelphia, 1987.

[2] International Organization for Standardization. ISO 6530—Clothing for Limited Protection Against Dangerous Liquid Chemicals – Resistance to Penetration – Marking.

[3] American Association of Textile Chemists and Colorists. AATCC Method 22–1985—Water Repellency: Spray Test. *Technical Manual of the American Association of Textile Chemists and Colorists*, 63, pp. 76–77, 1988.

[4] Schwope, A.D., R. Goydan, R.C. Reid, and S. Krishnamurthy. State of the Art Review of Permeation Testing and the Interpretation of Its Results. Am. Ind. Hyg. Assoc. J., 49, pp. 557–565, 1988.

[5] Ehntholt, D.E., R.F. Almeida, K.J. Beltis, D.L. Cerundolo, A.D. Schwope, R.H. Whelan, M.D. Royer, and A.P. Nielsen. Test Method Development and Evaluation of Protective Clothing Items Used in Agricultural Pesticide Operations. *Performance of Protective Clothing: Second Symposium, ASTM STP 989*, S.Z. Mansdorf, R. Sager, and A.P. Nielsen, Eds., American Society for Testing and Materials, Philadelphia, pp. 727–737, 1988.

[6] Ehntholt, D.J., I. Bodek, J.R. Valentine, A.D. Schwope, M.D. Royer, U. Frank and A.P. Nielsen. The Effects of Solvent Type and Concentration on the Permeation of Pesticide Formulations Through Chemical Protective Glove Materials. Chemical Protective Clothing Performance in *Chemical Emergency Response, ASTM STP 1037*, American Society for Testing and Materials, Philadelphia, 1989.

[7] American Society for Testing and Materials. Standard Test Method F739–85: Resistance of Protective Clothing Materials to Permeation by Liquids or Gases. American Society for Testing and Materials, Philadelphia, PA 19103.

[8] American Society for Testing and Materials. Standard Guide F1194–88: Documenting the Results of Chemical Permeation Testing of Protective Clothing Materials. American Society for Testing and Materials. Philadelphia.

[9] British Standards Institution. BS 4724: Method of Test for Resistance of Air Impermeable Clothing Materials to Penetration by Harmful Liquids. British Standards Institution, 3 York Street, Manchester, England M2 2AT.

[10] Operator Protection Research Group. The Resistance of Air Impermeable Protective Clothing Materials to Penetration by Liquid Chemicals. Report No. PC/1. Ministry of Agriculture, Fisheries and Food, Hatching Green, England, May 1986.

[11] British Standards Institution. Methods for the Resistance of Clothing Materials to Permeation by Liquids (Draft Revision of BS 4724). Part 2: Method for Determination of the Rate of Permeation (Air Impermeable Materials). Document 86/36003 DC. British Standards Institution. 3 York Street, Manchester, England M2 2AT, March 1986.

[12] International Organization for Standardization. Protective Clothing—Protection Against Liquid Chemicals—Method of Test for the Rate of Permeation through Impermeable Materials (Draft #6529). OSP Technical Committee 94, Subcommittee 13, SNV, Kirchenwag 4, Postfach, CH–8032, Zurich, Switzerland, December 1985.

[13] Dawson, P.B. and M.F. Gilchrist. Laboratory Methods for Evaluating the Protection of Permeable Protective Clothing against Chemical Warfare Agents. AD 824901. Defense Technical Information Service, 1967.

[14] American Society for Testing and Materials. Draft Method: Resistance of Protective Clothing Materials to Permeation by Liquids and Gases Under Conditions of Intermittent Contact. Committee F23, American Society for Testing and Materials, Philadelphia. 1990.

[15] Goydan, R., T.R. Carroll, A.D. Schwope, and R.C. Reid. A Method to Measure Protective Clothing Permeation Under Intermittent Chemical Contact Conditions. No. PB 89–161 509/AS, National Technical Information Service, Springfield, Virginia, 1989.

[16] Coletta, G.C., A.D. Schwope, I.J. Arons, J.W. King, and A. Sivak. Development of Performance Criteria for Protective Clothing Used Against Carcinogenic Liquids. National Institute for Occupational Safety and Health, Pub. No. 79–106, Cincinnati, 1978.

[17] Sansone, E.B. and Y.B. Tewari. Differences in the Extent of Solvent Penetration through Natural Rubber and Nitrile Gloves from Various Manufacturers. Am. Ind. Hygiene Assoc. J. 41, pp. 527–528, July 1980.

[18] Mickelsen, R.L. and R.C. Hall. A Breakthrough Time Comparison of Nitrile and Neoprene Glove Materials Produced by Different Glove Manufacturers. Am. Ind. Hyg. Assoc. J., 48, 11, pp. 941–947, 1987.

[19] Mickelsen, R.L., M.M. Roder, and S.P. Berardinelli. Permeation of Chemical Protective Clothing by Three Binary Solvent Mixtures. Am. Ind. Hyg. Assoc. J. 47, pp. 236–240, 1986.

[20] Ehntholt, D.J., I. Bodek, E.M. Chellquist, R. Goydan, C.J. Jantz, and A.D. Schwope. Laboratory Evaluation of the Degradation and Permeation Resistance of Polymer Gloves to Pesticide Formulations. Internal Report. EPA Office of Research and Development Contract No. 68–03–3293, Work Assignment 2–10, Cincinnati, 1987. (Contains Confidential Business Information.)

[21] Ehntholt, D.J., I. Bodek, T.E. Doerfler, A.D. Schwope, T.J. Stolki, C.H. Summers, and J. Valentine. Permeation Resistance of Polymer Glove Ma terials to Active Pesticide Ingredients and Carrier Solvents. Draft In ternal Report. EPA Office of Research and Development Contract No. 68–03–3293, Work Assignment 3–100, Cincinnati, 1988. (Contains Confidential Business Information).

[22] Ehntholt, D.J., I. Bodek, T.E. Doerfler, A.D. Schwope, T.J. Stolki, and J. Valentine. Permeation Resistance of Polymer Glove Materials to Various Strengths of Active Pesticide Ingredients and Carrier Solvents. Draft Internal Report. EPA Office of Research and Development Contract No. 68–03–3293, Cincinnati, 1989. (Contains Confidential Business Information).

[23] Schwope, A.D., P.P. Costas, J.O. Jackson, J.O. Stull, and D.J. Weitzman. *Guidelines for the Selection of Chemical Protective Clothing, 3rd Ed.*, National Technical Information Service No. AD–A179 164, Springfield, VA, 1987.

[24] Lloyd, G.A. Summarized Results of Permeation Tests on Protective Clothing Materials, Information Sheet No. 19, Operator Research Group, Harpenden Laboratory, England, 1986.

[25] Branson, D.H., G.S. Ayers, and M.S. Henry. Effectiveness of Selected Work Fabrics as Barriers to Pesticide Penetration. *Performance of Protective Clothing, ASTM STP 900*, R.L. Barker and G.C. Coletta, Eds., American Society for Testing and Materials, Philadelphia, pp. 114–120, 1986.

[26] Leonas, K.K. and J.O. DeJonge. Effect of Functional Finish Barriers on Pesticide Penetration. *Performance of Protective Clothing, ASTM STP 900*, R.L. Barker and G.C. Coletta, Eds., American Society for Testing and Materials, Philadelphia, pp. 177–186, 1986.

[27] DeJonge, J.O. and E. Easter. Protective Apparel for Dermal Exposure Reduction in Pesticide Application. Final report on EPA Contract No. 812486–01–0. Office of Research and Development. 1989.

[28] Freed, V.H., J.E. Davies, L.J. Peters, and F. Parveen. Minimizing Occupational Exposure to Pesticides: Repellency and Penetrability of Treated Textiles to Pesticide Sprays. Pesticide Reviews, 75, pp. 159–167, 1980.

[29] Staiff, D.C., J.E. Davis, and E.R. Stevens. Evaluation of Various Clothing Materials for Protection and Worker Acceptability During Application of Pesticides. Arch. Environm. Contam. Toxicol. 11, pp. 391–398, 1982.

[30] Kawar, N.S., R.A. Gunther, W.F. Serat, and Y. Iwata. Penetration of Soil Dust Through Woven and Nonwoven Fabrics. J. Environ. Sci. Health, B13(4), pp. 401–415, 1978.

[31] Orlando, J., D. Branson, and M. Henry. The Development and Evaluation of Protective Apparel for Pesticide Applications. *Determination and Assessment of Pesticide Exposure*, M. Siewierski, Ed., Elsevier, pp. 53–66, 1984.

[32] Hobbs, N.E. and B.G. Oakland. Use of Methylene Blue Dye to Predict Fabric Penetration by Malathion. *Performance of Protective Clothing: Second Symposium, ASTM STP 989*, S.Z. Mansdorf, R. Sager, and A.P. Nielsen, Eds., American Society for Testing and Materials, Philadelphia, pp. 738–744, 1988.

[33] Raheel, M. Resistance of Selected Textiles to Pesticide Penetration and Degradation. J. Environ. Health, 49, 4, pp. 214–219, 1987.

[34] Raheel, M. Dermal Exposure to Pesticides: The Barrier Effectiveness of Protective Clothing. J. Environ. Health, 51, 2, pp. 82–84, 1988.

[35] Anastasakis, M.T., K.K. Leonas, C. Dimit, J. Brothers, and J.O. DeJonge. Effect of Temperature and Humidity on Laboratory Pesticide Penetration Studies. *Performance of Protective Clothing: Second Symposium, ASTM STP 989*, S.Z. Mansdorf, R. Sager, and A.P. Nielsen, Eds., American Society for Testing and Materials, Philadelphia, pp. 692–696, 1988.

[36] Keeble, V.B., R.R. DuPont, W.J. Doucette, and M. Norton. Guthion Penetration of Clothing Materials During Mixing and Spraying in Orchards. *Performance of Protective Clothing: Second Symposium, ASTM STP 900*, S.Z. Mansdorf, R. Sager, and A.P. Nielsen, Eds., American Society for Testing and Materials, Philadelphia, pp. 573–583, 1988.

[37] Lloyd, G.A. Efficiency of Protective Clothing for Pesticide Spraying. *Performance of Protective Clothing, ASTM STP 900*, R.L. Barker and G.C. Coletta, Eds., American Society for Testing and Materials, Philadelphia, pp. 121–135, 1986.

[38] Nigg, H.N., J.H. Stamper, and R.M. Queen. Dicofol Exposure to Florida Citrus Applicators: Effects of Protective Clothing. Arch. Environ. Contam. Toxicol., 15, pp. 121–134, 1986.

[39] Norton, M.J.T., C.R. Drake, and R.W. Young. Protectiveness of Gore Tex and PVC Spray Suits in Orchard Pesticide Spraying, J. Environ. Sci. Health, B23, 6, pp 623–641, 1988.

[40] Putnam, A.R., M.D. Willis, L.K. Binning, and P.F. Boldt. Exposure of Pesticide Applicators to Nitrofen: Influence of Formulation, Handling Systems, and Protective Garments, J. Agric. Food Chem., 31, pp. 645–650, 1983.

[41] Maddy, K.T., L. Johnston, C. Smith, F. Schneider, and T. Jackson. Calif. Dep. Food Agric. Publ. No. HS–745, 1980.

[42] Fraser, A.J. and V.B. Keeble. Factors Influencing Design of Protective Clothing for Pesticide Application, *Performance of Protective Clothing: Second Symposium, ASTM STP 989*, S.Z. Mansdorf, R. Sager, and A.P. Nielsen, Eds., American Society for Testing and Materials, Philadelphia, pp. 565–572, 1988.

[43] Slocum, A.C., R.J. Nolan, L.C. Shern, S.L. Gay, and A.J. Turgeon. Development and Testing of Protective Clothing for Lawn Care Specialists, *Performance of Protective Clothing: Second Symposium, ASTM STP 989*, S.Z. Mansdorf, R. Sager, and A.P. Nielsen, Eds., American Society for Testing and Materials, Philadelphia, pp. 557–564, 1988.

[44] Obendorf, S.K. and C.W. Coffman. Pesticide Safety: Reducing Skin Exposure Through Protective Clothing, Human Ecology Forum, Cornell University, 17, No. 3, pp. 12–15, 1989.

Section 5

Eye and Face Protection

5 The Section in Brief

General guidelines for selecting equipment to protect the eyes and face from contact with pesticides include the following:

- Define the potential hazard, considering the need for protection from dusts, granules, liquid splashes, droplets, vapors, and so forth, as well as from impact from non-pesticide flying objects.
- Compare the potential hazard with the protective capabilities of goggles, face shields, safety glasses, and full-face respirators.
- Select equipment that will provide protection somewhat beyond that needed for the hazard.
- Fit the user with the protective device, making sure that it provides adequate coverage and, if necessary, that there is a good seal between the device and the wearer's face.
- Give instructions on the use, decontamination, and maintenance of the equipment, especially full-face respirators.

Types of Eyewear

Eyewear appropriate for use in environments containing pesticides include:

- **Goggles**—Both cover style (which may be worn over prescription glasses) and cup style goggles are acceptable. Models with polycarbonate lenses and indirect venting are preferred.
- **Face shields**—A face shield is needed when there is a risk of being splashed with the pesticide. The shield should be lightweight, and it should wrap around the wearer's face far enough to give adequate protection.
- **Shielded safety glasses**—When the pesticide label specifies only "protective eyewear," shielded safety glasses are the minimum acceptable level of

protection. The glasses must have both brow and side shields. Shielded safety glasses are comfortable and do not cause fogging or sweating.

Respirators

When working with pesticides under conditions that require a respirator, the use of eye protection is essential.

Although a full-face respirator provides complete eye protection, many workers prefer the half-face style (covers nose and mouth). A half-face respirator worn with a cover goggle may be sufficient, but combining the two devices may interfere with the face seal around the nose. To minimize the problem, it is best to choose a low-profile half-face respirator and to test the cover goggle with it before purchase.

Interpreting Pesticide Labels

The eyewear requirements listed on pesticide labels represent the minimum acceptable protection, and are as follows::

Label Requirement	Acceptable Equipment
Protective eyewear	• Safety glasses with brow, front, and temple protection or • Face shield or • Goggles or • Full-face respirator
Goggles	• Goggles or • Full-face respirator
Full-face respirator	• Full-face respirator

5 Eye and Face Protection

5.1 Introduction

Splashes, errant sprays, mists, clouds, etc., of pesticides vapors, aerosols, liquids, dusts, and granules are potential sources of facial contact with the pesticides. Although facial contacts would be expected to occur less frequently than, for example, contact with the hands, the health consequences of the contacts are potentially more serious, especially for contacts with the eyes.

In this section, the characteristics of eye and face protection products useful for protection from chemicals and pesticides are discussed. Occupational Safety and Health Administration's (OSHA) 29 CFR 1910.133 and American National Standard Institute's (ANSI) Z87.1 are used as the starting point for the presentation. The regulation and the standard are useful consolidations of information and guidance on the subject area, although they may not be directly applicable to the agricultural setting. ANSI Z87.1 provides specific guidance on definitions, categorization, design, construction, and uses of eye and face protection. Of particular interest are its sections entitled "Characteristics of Commercially Available Eye and Face Protection" and "Characteristics of Commercially Available Eye and Face Protection."

The section is supported by appendices that list and describe commercially available eye and face protection products and their sources.

5.2 OSHA Eye and Face Protection Requirements

Regulations for eye and face protection for workers under the purview of OSHA are contained in 29 CFR 1910.133 (see Appendix M). This regulation describes the employer's general responsibility and refers to the ANSI standard Z87.1-1968 as the source for guidance in the selection of eye and face protection for specific hazards. The safety and health of agricultural workers are outside of OSHA purview and reside within the EPA.

The National Safety Council's Accident Facts (1989 edition) indicates that in the United States, there were approximately 70,000 reported eye related injuries in 1988.[1] As a result of the concern over this ocular safety data,

the U.S. Department of Labor proposed revisions to 29 CFR 1910.133 in August 1989. The proposed revisions would bring the OSHA regulation into line with the new performance oriented ANSI Z87.1-1989 standard.[2] The proposed revisions are described in Appendix M. It is anticipated that a final standard will be approved during 1990. Assuming OSHA does not amend the new ANSI standard, manufacturers of eye and face protective equipment used by workers under OSHA's purview would be required to adhere to ANSI Z87.1-1989 in order to provide OSHA-acceptable products.

5.3 ANSI Z87.1-1989

The purpose of the standard is to provide minimum requirements for protective eye and face devices, and to aid in the proper selection, use, and maintenance of the devices. For a product to comply it must meet all requirements of the standard.

Until the acceptance of ANSI Z87.1-1989 in February 1989, the standard in force was dated 1979. The 1989 provisions change the guidelines from a design specification to a performance specification. Highlights of the new standard are illustrated in Appendix N. The earlier standard required that eyewear conform to design restrictions and pass several strength tests, such as flat transverse and edge transverse tests. Most of the restrictions and tests have been eliminated. Manufacturers of protective eyewear have welcomed the revisions since the previous standard hampered development of new designs and reduced the ability to incorporate new, lighter materials into the design. In other words, design freedom need not be limited as long as a device offers protection under measured test circumstances.

The new standard recognizes the Bureau of Labor Statistics[3] study that revealed the importance of providing angular protection for the eye in addition to frontal protection.

5.4 Selection Guidance

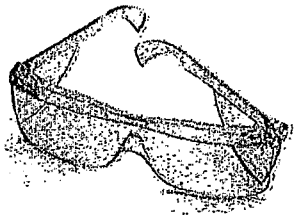
The process of selecting eye and face protection for pesticide handlers is difficult to generalize because of the wide range of exposure conditions that are present in agriculture. In some situations, workers are in close proximity to highly toxic pesticides where the danger of splash, irritating mists, or nuisance dusts might occur. At other times, the worker may only peripherally encounter the above dangers, yet requires appropriate protection. Common sense and fundamental technical principles should be used in determining the correct protective eyewear.

Historically, many individuals have used either no eye protection or spectacles as the primary method of protection in this environment. There are currently seven different types of spectacles for eye protection: no sideshield, non-removable lens, half sideshield, lift front, full sideshield, detachable sideshield, and headband temple. Spectacles are designed to protect the wearer primarily from direct impact and heat. The sideshields provide

additional protection from side impacts. Of the seven types of spectacles available, the models with full sideshields provide the greatest protection from flying objects. The full sideshield fits within the temple and forms a close alignment with the side of the face. The other types of sideshields do not provide as "tight" a fit with the side of the face and might allow a projectile to reach the eye.

No sideshield

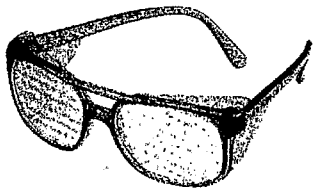
In addition to sideshields, spectacles consist of the following major components: front with bridge area; lens or lenses (the vast majority are polycarbonate); and temples (spatula or cable). The assembled devices are available in many combinations of the various major component types to provide the user with a wide choice of suitable equipment for impact resistance. The vast number of spectacle component combinations precludes listing all the options. The principal manufacturers of spectacles are listed in Appendix O.



Non-removable lens

Shielded safety glasses are comfortable, do not cause fogging or sweating, and give good eye protection in many situations. Safety glasses must have both brow and side shields. Types of protective eyewear appropriate for use in environments containing pesticides include:

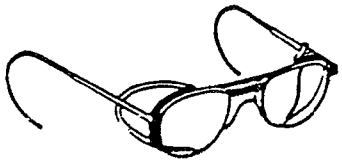
- Goggles
- Face shield
- Shielded safety glasses



Half sideshields

Goggles are defined by ANSI Z87.1-1989 as, "primary protective devices intended to fit the face immediately surrounding the eyes in order to shield the eyes from a variety of hazards." Goggles are available in two styles: cup goggles, to cover the eye sockets completely; and cover goggles, which may be worn over prescription (R_x) spectacles. Most cover goggles are designed to fit over the employee's prescription glasses. The sides of the cover goggle have a slight modification to allow the temple of the prescription glasses to easily pass through. The most popular model in the work place is the cover goggle. Although cup goggles are appropriate for pesticide environments, the number of models is limited compared to the vast variety of cover goggles.

Lift front



Full sideshield

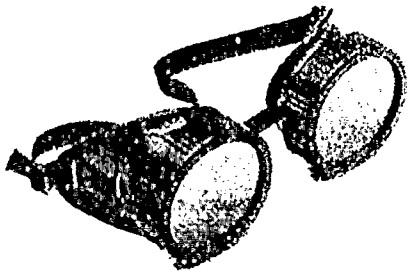
Goggles are available with both rigid and flexible frames, the majority of users favoring the more comfortable flexible frame. Typically, the flexible frames are translucent and thus increase the field of vision.

Detachable sideshield

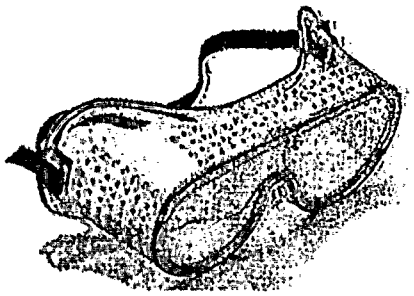
Goggles may have three types of ventilation: direct, indirect, or none. Directly ventilated goggles create the possibility of a liquid or aerosol entering through the ventilation port. To reduce and minimize the goggle lenses from fogging, indirect vented models are preferred. The indirect models exclude the direct passage of dust, liquids, light or particles.

Headband temple

Face shields are protective devices intended to shield the wearer's face, or portions thereof, in addition to the eyes. The face shield would be used when handling pesticides where it is highly likely that splashing will occur. Face shields are available with or without removable windows.



Cup goggles



Cover goggles with direct ventilation

Employees should be cautioned about wearing contact lens in certain, if not all, pesticide environments. Dusty or chemical environments may represent particular hazards to contact lens wearers. Soft contact lenses can be especially problematic. Their design makes them hydrophilic (absorb fluids), as a result they will also absorb chemical fumes. If an employee is working in these conditions, it is best that he not wear contact lenses.

Guidelines for selecting eye and face protection follow.

- Define the potential hazard, considering the need for protection from chemicals as well as from impact from flying objects.
- Compare the potential hazards with the performance capabilities of various eye and face protective equipment.
- Make a judgement in selection of the appropriate protective equipment so that the protection is greater than the estimated hazard.
- Fit the user with the protective device, taking extra care to ensure that an adequate seal exists between the goggle and the wearer's face to prevent any pesticide from entering.
- Give instructions on care and use of the equipment.

Table 19 lists the types of eye protection that satisfies eyewear requirements on pesticide labels.

Table 19. Selection guidance for eye and face protection

Label Requirement	Acceptable Eye Protection
Protective Eyewear	Safety glasses with brow, front, and temple protection, or Face shield, or Goggles, or Full-face respirator
Goggles	Goggles, or Full-fac respirator
Full-Face Respirator	Full-face respirator

5.5 Commercially Available Products

There is a wide selection of commercially available products within the types of eye and face protective devices discussed above. The features of these products are described in the following paragraphs.

5.5.1 Cover goggles-indirect ventilation and no ventilation

Cover goggles are by far the most popular type of goggle. Due to the wide range of options available the employer may want to obtain samples of various models from the suppliers. This will allow the employees to determine the model which has the best fit around the face, spectacle frames, etc. Appendices P and Q list commercially available products and their features.

5.5.1.1 Lens material. When purchasing these types of goggles, the first selection option is lens material, of which there are four choices: polycarbonate, polypropionate, acetate, and CR-39. Polycarbonate is the material of choice since it will not weaken if the surface becomes pitted and provides good chemical splash and impact resistance. Approximately 90% or more of the lenses are now made of polycarbonate material, typically 0.060-in thick. Polycarbonate is lighter and provides stronger impact resistance than hardened glass (available in spectacle frames only) and CR-39 materials.

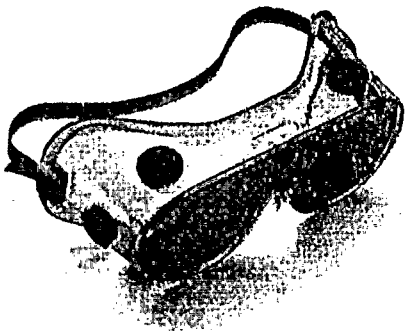
5.5.1.2 UV Protection. For employees working outside or in environments with high levels of ultra-violet light, a UV protector should be added to the lens. The UV protectors are either embedded in the polymer or applied as a coating to the lens. Each manufacturer's specifications vary slightly, however, most lenses with a UV treatment absorb 95% to 98% of the harmful rays up to 400 nm. Polycarbonate itself provides some UV protection, but not over the entire range of wavelengths that the treatment provides. To ensure the long term integrity of the UV filter, a lens which has the treatment blended into the polymer should be selected. If the UV protection is applied as a coating to the lens, it will lose its effectiveness if the lens becomes scratched.

5.5.1.3 Anti-fogging. Anti-fogging is an additional feature to consider. Many goggles have this option which would be important for pesticide handlers who pass through several different temperature zones in the course of their normal routine. There is no anti-fog coating or material that will provide the wearer a totally fog-free environment. The anti-fogging coating works best when the goggle is directly ventilated.

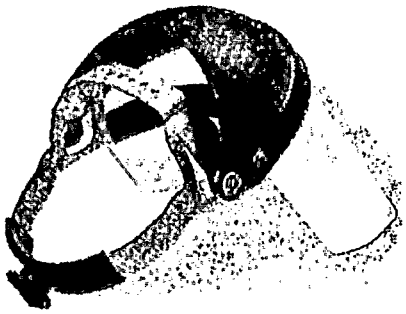
5.5.1.4 Tinting. Tinting is another feature to consider for individuals working in the sunlight. Tints should be chosen carefully and matched to the work place. Tints should not be chosen for cosmetic reasons since they reduce the light transmission through the lens and might alter the worker's effectiveness, or create a safety hazard.

5.5.1.5 Scratch resistance. For dusty environments or where there is a high number of particles hitting the lenses, scratch resistant coatings should be considered. It is questionable how effective these coatings actually are. They provide a certain level of resistance to scratching but are not an absolute answer. It is recommended that the employer not over pay for this feature. If scratching becomes a problem, then replacing the lens in the goggle might be a better alternative.

5.5.1.6 Prescription glasses. For employees required to wear prescription glasses, cover goggles provide the best solution. Cover goggles are designed to fit over the prescription glasses and still provide an adequate seal with the face. This method is recommended rather than trying to add an "insert" to the goggle with the employee's prescription embedded in it. The inserts are difficult for the optical laboratories to make, are expensive, may create some magnification problems for the employee, and may be difficult to adjust to.



Cover goggles with indirect ventilation



Face shield

5.5.2 Cup goggles-indirect ventilation

There are very few varieties of this type goggle as is evident from Appendix R. The polycarbonate lenses are approximately 50 mm round and vary in thickness from the standard 1.5 mm to 3 mm for heavy duty chipping and grinding applications. Some cup goggles have flat lenses while others are slightly curved. The curved surface can extend the field of view.

It is important to make sure that the soft sides of the cup goggle provide a complete seal around the periphery of the goggle/face interface.

5.5.3 Face shields

The majority of face shields have a polycarbonate window. The windows are typically 1 mm thick. It is important that the window adequately wrap around the wearer's face for full protection. A few models provide protection beneath the chin to deflect any projectiles. As with the goggles, the face shields are available with UV, anti-fog, and scratch resistant coatings. For comfort, it is important to find a shield that is light weight so that the employee will not hesitate to wear the shield when appropriate. Manufacturers of face shields are listed in Appendix S.

5.5.4 Headbands

For the most part, there are only two types of headband materials: neoprene and elastic. These may be offered in several colors beyond the standard black. Both materials are attached to the side of the goggle in a manner that allows a range of adjustment, using friction to hold the headband in the most comfortable location. The user tightens the headband until the goggle is snug creating a seal between the face and side of goggle. The neoprene material provides better durability while the elastic perhaps more comfort. Most goggles offer headbands as replacement items, this is especially important if the band becomes contaminated or deteriorates over time.

5.5.5 Use and maintenance

Once the proper protective device is chosen, it is important to educate the worker in the proper use of the device. Printed information that is provided with the device will vary from device to device, but may contain the following elements:

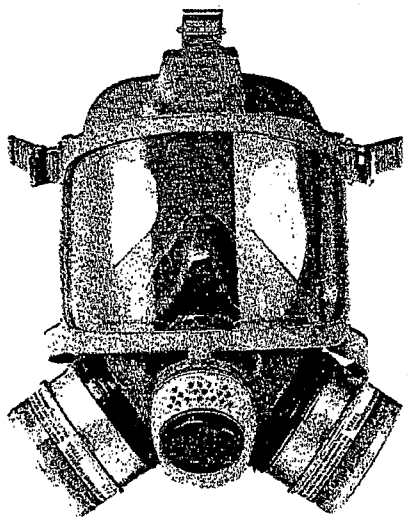
- The proper way to wear the device.
- The methods for adjusting the device for best and proper fit.
- Items to routinely check on the device when inspecting for wear or damaged parts.
- The maintenance procedures to follow.
- The proper method for cleaning the device.
- The proper method for storing the protector.
- All warnings, cautions, and limitations of using the device.
- The types and hazards for which the device is designed, and the level of protection provided. Protective devices do not provide unlimited protection.
- The meaning of any significant markings on the device.

5.5.6 Respirators

Although respiratory protection is outside of the scope this manual, the use of respirators may impact the selection of, or necessity for eye protection. Some consideration in this regard follows. When working with pesticides under conditions that require a respirator, often the use of eye protection is essential. By virtue of their design, a full-face respirator provides eye protection.

Half-face respirator

Under certain conditions, a half-face respirator and cover goggle combination will provide appropriate protection for the eyes. The principal difficulty when combining the two devices is the face seal, particularly around the nose. The cause of this problem is twofold: many people do not properly position and/or adjust the head and neck straps, and many of the half-face respirators have a large nose cup which elevates the lower edge of the cover goggle. Only a few brands of half masks have nose cup that are adequately tapered to allow a good seal. If a combination approach is desired, it is recommended that a low profile half-face respirator be used and the cover goggle that will be worn should be tested with it prior to purchase.



Full-face respirator

Many workers prefer to wear a half-face respirator rather than a full-face respirator when given the choice; they claim that these respirators are more comfortable, less claustrophobic, and provide better visual acuity and peripheral vision, and are cooler. Therefore, while full-face respirators may be the "most logical" choice, a half-face respirator with cover goggle still has a place in a well designed safety program. It is important to give workers some latitude in selecting the equipment of their choice, in the hope that this will increase their participation and thereby increase their protection.

References

[1] National Safety Council, Accident Facts, National Safety Council, 444 N. Michigan Ave., Chicago, IL 60661, 1989.

[2] American National Standards Institute, Z87.1–989. Practice for Occupational and Educational Eye and Face Protection. ANSI, Inc., 1430 Broadway, NY, NY 10018.

[3] Bureau of Labor Statistics, "Accidents Involving Eye Injuries," U.S. Department of Labor, Report #597, April 1980.

Section 6

Effect of Personal Protective Equipment on Job Performance

6 The Section in Brief

Clothing and other gear worn by workers for protection from pesticides may interfere with the workers' ability to do a job. Worker productivity may be reduced and, in some cases, the personal protective equipment could introduce new safety hazards by reducing mobility, dexterity, field of view, etc.

How PPE Affects Workers' Functions

Several key functional requirements of workers may be affected by one or more types of PPE:

Function	Affected by
Dexterity and tactility	• Hand protection
Mobility	• Face shield • Foot protection • Body protection • Thermal regulation
Vision	• Eye/face protection • Full-face respirator
Speech intelligibility	• Face shield • Respirator

Dexterity and Tactility. The use of chemical-resistant gloves impairs both dexterity (the ease with which a person can perform tasks with the hands) and tactility (the ability to sense by touching). Dexterity and tactility are affected by glove fit and by the thickness and physical properties of the glove material. Wearing double layers of gloves reduces tactility but may improve dexterity.

Mobility. The ease of motion while wearing a PPE garment can be affected by:

- **flexibility**—A flexible fabric allows greater ease of movement, because it decreases the energy it takes to move in the garment.

- **cut and fit**—When items are not manufactured in a "working position" or cut to accommodate movement, they need to fit more loosely so the body can move freely. Rubber gloves molded to the relaxed, curved shape of the hand, for example, allow ease of movement even when fitted close to the hand; flat gloves do not.

- **weight**—Items that are cut loosely accommodate body dimensions have extra material that may add weight, reduce mobility, and increase the potential for other safety hazards. These deficiencies reduce the effectiveness of the worker.

- **friction**—Mobility when wearing multiple layers of clothing requires overcoming the friction due to the layers rubbing against one another. Optimum clothing system design minimizes such friction.

Vision. Eye protection and respirators can affect the worker's field of view. The lens materials may also affect visual acuity (the ability to distinguish shapes and perceive contrasts).

Speech Intelligibility. Respirators and face shields can significantly reduce speech volume and crispness. The ability to communicate clearly can be particularly important in emergency situations.

The Effects of PPE on Worker Productivity

In almost all instances (with the possible exception of eye protection), the use of PPE will increase the time needed to perform a task. Tests have shown that this increase may be 10 to 40 percent, depending on the level of protection and the type of work being performed.

6 Effect of Personal Protective Equipment on Job Performance

6.1 Introduction

Clothing and other gear worn by workers for protection from pesticides may interfere with the worker's ability to do a job. Worker productivity may be reduced and, in some cases, the PPE may introduce new safety problems. For example, gloves will reduce dexterity and, therefore, increase the time required to perform certain hand-intensive tasks. The reduced dexterity may increase the potential for an accident. The magnitudes of the effects will depend on the amount and type of PPE that is worn and the demands of the tasks. For example, gloves would be expected to have a greater performance decrement on the task of fixing a clogged nozzle than that of carrying a 5-gallon pail of water.

In this section, estimates are developed for the functional impact of PPE on task performance. The quantitative estimates are based on sets of weighting factors and rating scales related to the functions that compose the task and specific items of protective gear. The purpose of this section is to establish a realistic perspective from which the economic impact of using or requiring PPE can be assessed. Furthermore, the results are combined in Section 8 with those related to chemical-resistant performance of the clothing (Section 4) and the thermal burden of clothing (Section 7) as a basis for a clothing selection decisions.

6.2 Mixer, Loader, Applicator Functions

6.2.1 Introduction

General descriptions of the activities of the persons who handle concentrates and application strength pesticides were given in Section 2. More specific descriptions representative of the tasks performed by mixers, loaders, and applicators are listed in Table 20. From these descriptions, the functional requirements of each task can be deduced. For example, a mixer must have certain levels of dexterity and visual acuity to open a screw-type cap. Those levels of dexterity and visual acuity will be different from those that are required to cut open and pour a bag of pesticide granules.

Table 20. Functional activities of mixers, loaders, and applications

Mixing and Handling • Opening containers, including turning caps, pulling tabs, cutting bags, tearing bags, turning bungs. Some of these activities are done with the hand and others are done with hand-held tools. • Lifting containers, ranging from ground to waist-height to climbing while carrying a container to the top of tank. • Measuring solid or liquid concentrates, including pouring liquids into pitchers or graduated cylinders or scooping solids onto a spring scale. • Pouring, including handling containers up to 80–100 pounds. • Operating a pump. • Operating a water valve
Loading • Connecting hoses • Opening and closing tank lids. The tank lids may range in size from that on a back-mounted tank to that on tank containing 500 or more gallons of liquid. • Climbing onto and off tanks • Driving • Hitching and unhitching trailers
Boom/Air Blast Spraying • Driving a tractor • Adjusting and cleaning nozzles • Performing minor inspections and maintenance of the vehicle in the field • Getting into and out of the driving position. This may require climbing.
Back-mounted Spraying • Walking, this may be indoors on smooth surfaces or outdoors on rough or hilly terrain • Moving arms back and forth and up and down • Shaking tank • Adjusting and cleaning nozzle

In general, the functional requirements of a worker can be categorized as they are related to:

- dexterity and tactility
- mobility
- vision
- speech intelligibility

6.2.2 Dexterity and tactility

Dexterity describes the facility with which a person can perform tasks with the hands. Tactility describes the facility with which one is able to sense by means of touching. **The use of chemical-resistive gloves impairs both dexterity and tactility.** The degree to which dexterity and tactility are affected is determined by several factors:

- glove fit
- material thickness (and/or layers of gloves worn)
- physical properties of the glove material (e.g., flexibility)

In general, two types of gloves are available for protection from pesticides: rubber and plastic. Descriptions of gloves in each of these categories and their chemical resistance were given in Section 3. From a functional perspective, the following generalizations may be made:

- Tactility is affected by material thickness and the physical properties of glove material. Tactility is reduced as the number of layers of glove material increase—as when double gloves are worn. **For the same thickness of glove material, rubber materials have less of an impact on tactility than do plastic materials.** Tactility can be affected by glove fit.
- Dexterity is strongly affected by glove fit and, to a lesser extent by the physical properties of the glove material. The fit of plastic gloves is generally poor compared with that of rubber gloves and consequently, plastic gloves would be expected to have a greater, negative effect on dexterity. Across the thickness range of rubber gloves (i.e., 2–25 mils), dexterity can vary significantly. Within the range most commonly used in agriculture (i.e., 12–20 mils for rubber gloves), thickness has little effect on dexterity.

6.2.3 Mobility

Mobility encompasses the range of motions that one can make and the ease with which one can make them. While the term dexterity has been used to designate fine motor control or the facility with which hand movement can take place, mobility will be used here to designate movements generally categorized under gross motor control. Chemical-resistant coveralls, aprons, and rubber boots can all reduce mobility. The effect is usually greatest during the first uses of PPE. Several studies have shown that the effect decreases as workers adapt to the garments.[1]

There are a number of factors that determine the extent to which specific garments affect mobility, among them: fabric flexibility and extensibility; garment cut, fit and weight; and the coefficient of friction of a garment against the skin or against other garments.

The factors of garment cut and fit interact. If the segments of a garment (sleeve, body, leg, etc.) are effectively related to one another, i.e., if they are positioned so that there is no strain when the wearer is moving and working, full range and ease of movement is possible even when the fit of a garment is quite snug. A simple example of this can be found by looking at the effect of a flat versus a shaped glove on ease of hand movement. When a rubber glove is molded into a working position (fingers curved as if ready to grip an object) a wearer needs to expend very little effort to move the glove into position to grip a tool or dial. This remains true for a well-molded glove even when it is fitted quite close to the hand. However, when a glove is manufactured flat, the hand has to work against the glove material to move it into a position to be ready for work. Even if material is elastic, this movement requires energy. (In fact, if the material is elastic, that energy is expended continuously because the glove is continually trying to move back to its original, flat position.) Therefore, when items are not manufactured in a working position, their fit needs to be looser. A looser fit allows the body parts involved to move more freely *inside* the garment rather than being hobbled by the restrictive cut.

In some instances, it is not economical to manufacture garments that are shaped in the working position, and fit, therefore, becomes critical to mobility. The interrelationship of cut and fit becomes particularly significant for larger items of clothing because the larger volume of material needed to compensate for items that are not well shaped contributes both to safety (loose edges for snagging, obstruction of vision) and to the cost of materials. There may also be significant metabolic effects when workers must drag layers of loosely fitted clothing over one another for long periods of time, especially if there are rough or rubberized surfaces involved and the clothing layers stick to one another during movement.

For garments that involve full body coverage, then, garment cut and fabric flexibility are primary factors in the ability to provide a wearer with east of movement. When a garment is cut to accommodate a specific movement, fit can be snug and fabric can be non-stretch and movement may still occur easily. On the other hand, a tight, ill-fitting garment can tear, thereby compromising its effectiveness as a chemical barrier. For this reason, when a garment is *not* cut to accommodate movement, fit must be looser. The resulting garment then has extra material that may add bulk, making movement more difficult. It also increases the likelihood that friction will occur between garment surfaces and add to movement difficulties. In either case, fabric flexibility decreases the energy it takes to move in a garment and thus allows greater ease of movement, particularly over the long term.

For isolated garments that cover smaller areas of the body—boots, gloves or aprons, etc.—fabric flexibility and weight tend to be the most important factors with the cut and fit of the item at a second level of importance. If a fabric is stiff and does not stretch, movement of the body part covered will be restricted even if the cut and fit of a garment are appropriate. On the other hand, the major joints of the body can continue to function around the outer edges of the items, e.g., all but the ankle joint of the leg can move freely if a stiff boot is in place and the shoulders and arms can continue to move around the edges of an apron. The *weight* of an item may affect full body mobility over the long term, particularly if the item is worn far from the center of gravity. For example, it requires more effort and is more tiring to lift one's leg to climb onto a tractor when wearing a heavy boot than when wearing a light one.

6.2.4 Vision

Two key elements of vision are field of view and visual acuity. Both elements may be affected by respiratory and eye/face protection.

6.2.4.1 Field of view. Of particular concern is the reduced field of view in the inferior and nasal areas caused by the nose cup and filter cartridges for respiratory protection, which interferes with tasks where workers must inspect mechanical equipment and read instructions, etc. Driving might also be impaired by restrictions in the temporal area of the visual field. Aviators or persons who must look up would also be affected by restrictions in the superior area.

On hooded garments with built-in, clear plastic face shields, restrictions in all directions can occur because the face piece does not turn when the wearer turns his or her head.

6.2.4.2 Visual acuity. Visual acuity is the ability to distinguish shapes and precise contrast boundaries. The plastics of some face shields, goggles, and eye glasses can distort vision because of curvatures that are not optically neutral. Furthermore, some plastics scratch easily and discolor, or develop a haze, as they age. Tinting, other coloration of the face piece, and fogging due to condensation can also reduce visual acuity.

6.2.5 Speech intelligibility

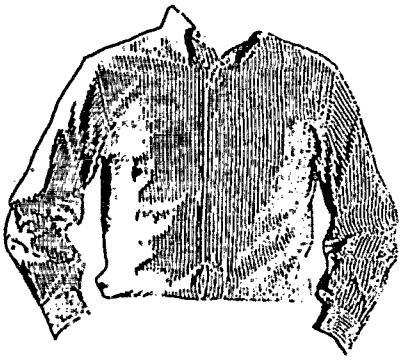
The intelligibility of speech requires that words be transmitted and received clearly and at an adequate volume. Speech intelligibility can be particularly important in emergency situations. Transmission deficiencies are considerably more important than are reception problems as the cause for loss of speech intelligibility because of the use of PPE. **Respiratory protection and face shields can significantly attenuate speech volume and crispness.** Hoods, even fairly thick rubber hoods, seem to have little or no impact on speech reception, although there may be some decrement in perception of the directionality of the source.[2]

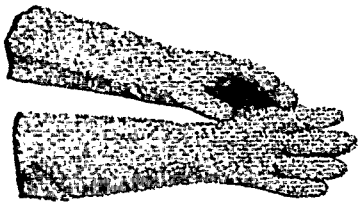
6.2.6 Relative importance of functional requirements

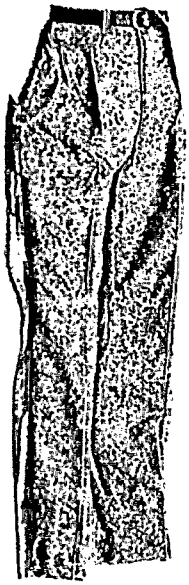
The relative importance of each of the above functional requirements to the completion of a task varies with the task. For example, range of motion is more important to a person who lifts, carries, and climbs than it is to a person who drives. Conversely, vision may be more important to a driver than to a person who lifts pesticide containers.

The extent to which the PPE will affect task performance will depend on the relative importance of the functional requirements. For example, the effect of boots would be minimal on a worker's ability to fix a pump. Such a task requires dexterity and visual acuity but little mobility. In general, the activities of pesticides handlers may be classified into three groups:

- Group 1—activities that require relatively greater hand dexterity and vision, such as boom spraying.
- Group 2—activities that require relatively greater mobility, such as back-mounted spraying.
- Group 3—activities that are intermediate to Groups 1 and 2, i.e., require a balance of all functional requirements, such as mixing and handling.







Protective clothing ensemble
Level 1

Table 21 is an estimate of the relative importance of each of the functional requirements for each of the Groups.

Table 21. Weighting factors for functional requirements by type of activity

Activity	Hand	Mobility	Vision	Speech
Group 1	0.40	0.15	0.40	0.05
Group 2	0.25	0.45	0.25	0.05
Group 3	0.32	0.32	0.32	0.05

6.3 Protection Levels

The components of PPE used by pesticides handlers will vary depending on the toxicity and form of the pesticide, the type of job being performed, availability of protective equipment, and so forth. Scores of variations in the composition of the protective ensemble exist in the field. For purposes of discussion, five clothing ensembles are defined in Table 22 and will be used as a basis for subsequent estimates of the effects of clothing on job performance. Furthermore, these same ensembles are used as a basis for heat stress calculations in Section 7.

Table 22. Protective clothing ensembles

Level	Description
1	Long-sleeved shirt and long-legged pants (cotton or cotton/polyester overall), and chemical-resistant gloves and shoes.
2	Cotton or cotton/polyester coveralls worn over a long-sleeved shirt and long-legged pants, chemical-resistant gloves, chemical-resistant hat or hood, and chemical-resistant boots.
3	Cotton or cotton/polyester coveralls worn over long-sleeved shirt and long-legged pants, chemical-resistant gloves, chemical-resistant boots, chemical-resistant apron, and goggles or face shield.
4	Nonwoven, polyolefin coverall (worn over long-sleeved shirt and long-legged pants), chemical-resistant gloves, chemical-resistant hat or hood, chemical-resistant boots, and goggles or face shield.
5	Rubber or plastic-coated coverall (worn over underwear) with hood, chemical-resistant gloves, chemical-resistant boots, and goggles and half-face respirator (or full-face respirator).

6.4 Effects of PPE on Worker Productivity

Many researchers have investigated performance decrements associated with various items of PPE. Typically these studies measure the time to complete a task while wearing PPE and compare that time to a control situation. The task may be a standard test or a simulation of the actual job that the worker will perform. The results are usually reported as, or can be translated into, a ratio of time with gear to time under the control condition, and are usually greater than one. For example, it might take 1.3 times as long to perform a peg board test while wearing chemical-resistant gloves as compared with the barehanded condition.

Most of the studies reported in the literature have focused on gloves, with fewer assessments of respirators and even less on other items of PPE wear. In some cases, no information was found on the performance decrement associated with components of PPE that might be worn in agriculture (e.g., aprons and nonwoven coveralls). Military PPE has been the subject of most of the studies. Many of the results, consequently, may not be directly transferable to agricultural applications.

6.4.1 PPE components

Performance decrements because of individual items of PPE have been estimated based on the technical literature and professional judgement, and are listed in Table 23. The baseline conditions for the estimates are a worker wearing a long sleeve shirt and pants fabricated from medium weight cotton or cotton/polyester, leather boots, and without gloves or eye/face protection. These estimates are under three headings: Fine, Gross, and Average. Fine indicates the effect on tasks requiring fine motor control; Gross indicates the effect on tasks requiring gross motor control; and Average is simply the arithmetic average of the two and is meant to represent the effect of PPE on most day-to-day activities. The performance decrement values listed in Table 23 are based on the following discussion.

6.4.1.1 Gloves. The times to apply various sizes of washers and nuts to bolts under bare-handed, gloved, and double-gloved conditions were measured in study of the effects of gloves on manual dexterity.[3] In all cases the total thickness of the gloves in each test was greater than 15 mils. The time to complete the task when bare-handed was 67.7 seconds. The various gloved conditions were found to increase the task time by 15 to 37%. Interestingly, the authors reported that:

The butyl glove resulted in the fewest number of dropped parts when it was the exterior glove. The viton glove material resulted in the poorest handling of those gloves tested.

Compared to bare-handed, and bare-handed with full-face respirator conditions, the time to complete the O'Connor Finger Dexterity test increased by a factor of 1.6 times due to the addition of 25-mil butyl rubber gloves. The time to complete the Purdue Pegboard Assembly test increased by a factor of 3.3 times.[2]

Protective clothing ensemble
Level 2

Protective clothing ensemble
Level 3

Table 23. Increase in task time due to PPE

	Fine	Gross	Average
Hand			
• gloves, flat, plastic	1.300	1.200	1.25
• gloves, < 15 mil	1.200	1.100	1.15
• gloves > 15 mil	1.300	1.200	1.25
Eye/Face			
• safety glasses	1.000	1.000	1.00
• goggles	1.050	1.025	1.04
• face shield	1.050	1.025	1.04
• face shield + goggles	1.100	1.050	1.08
Respiratory Protection			
• half-face respirator	1.050	1.050	1.05
• full-face respirator	1.2	1.100	1.13
Foot Protection			
• rubber boots	1.000	1.100	1.05
Body Protection			
• cotton or cotton/polyester pants and shirt or coveralls	1.000	1.000	1.00
• apron	1.050	1.100	1.08
• nonwoven coveralls w/o hood	1.050	1.150	1.10
• nonwoven coveralls w/hood	1.100	1.200	1.15
• coated fabric coveralls	1.250	1.400	1.33
Ice Vest	1.050	1.100	1.08

There was little or no effect of 25-mil butyl rubber gloves on the times required to complete gross motor control tasks. Times increased by 18%, however, for tasks requiring fine motor control.[1]

Compared to the bare-handed condition, elastomeric gloves between 12.5 and 14 mils in thickness affected the times required by males to complete four dexterity tests as follows:[4]

- O'Connor test by a factor of approximately 1.26
- Pennsylvania test by a factor of approximately 1.37
- Minnesota test by a factor of approximately 1.23
- Crawford test by a factor of approximately 1.31

In simulations of three medical tasks (i.e., infusion, decontamination, and completing patient forms), natural rubber latex gloves (7 mil) did not increase significantly the times required beyond those found for the bare-handed condition. When a 14-mil elastomeric glove was worn over the natural rubber gloves, the times increased by approximately 25%.[5]

Compared to bare-handed and the condition of wearing natural rubber latex gloves up to 13 mils in thickness, the time to complete a grooved peg board test increased by a factor of approximately 1.25 for 18-mil thick gloves of nitrile rubber, natural rubber, and a neoprene-natural rubber blend. Likewise the number of parts that could be successfully manipulated in a fixed amount of time decreased by approximately 35% when wearing the thicker gloves.[6]

The time to perform a Purdue pegboard test increased by a factor of 1.25 times when wearing a flat, polyethylene glove (2 mils). Compared to the bare-handed condition, the times for 5-7 mil natural rubber gloves were not significantly different; however, the time for a 10-mil neoprene glove was higher by a factor of 1.16 times.[7]

6.4.1.2 Boots. No information was found on the effect of boots on task completion time. Boots, however, did not decrease significantly the railwalk distance.[2] The study did not address the time required to cover the same distance with and without boots.

6.4.1.3 Respirators. There was little or no effect of wearing a full-face respirator on the times required to perform the O'Connor Finger Dexterity test and the Purdue Pegboard Assembly test when bare-handed.[2] A full-face respirator decreased significantly the railwalk distance.[2]

There was little or no effect of a full-face respirator on the times required to complete gross motor control tasks. Times increased by 18%, however, for tasks requiring fine motor control.[1]

The times to run a specified distance increased by approximately 6 to 11% due to wearing a full-face respirator. A considerable portion of this increase was attributed to the filter (i.e., the resistance to breathing).[8]

6.4.1.4 Encapsulating ensembles. Three full-encapsulating ensembles were investigated for the effects on the time to complete several tasks representative of those that might be performed by medical personnel involved in the evacuation of casualties.[5] Although there was considerable variability between subjects and the three ensembles, it is possible to generalize the findings for the purposes of this analysis, as follows. Compared to the control conditions, the time to run 200 yards increased by a factor of 1.4 times. The time to complete a simulation of intravenous infusion increased by a factor of 2 times. The time to apply antishock trousers increase by a factor of 1.4 times. The time to complete a resuscitation simulation increased by a factor of 1.3 times.

The overall effect of full encapsulating, chemical protective clothing on missile repair tasks that were characterized by the manipulation of small parts, hand tools, and fine eye/hand coordination was an increase in task times by a factor of 1.45 times.[1]

Protective clothing ensemble
Level 4

Protective clothing ensemble
Level 5
(Note: the integral booties shown on this coverall are worn inside boots)

6.4.2 PPE ensembles

Whereas Table 23 shows the effects of individual items of PPE on performance, the overall effect of a clothing ensemble on performance is of more interest. The total effect is estimated based on the makeup of the clothing ensemble and on the assessments of those items that affect each function and the relative importance of the function to completing the task. Several of the items of PPE would be expected to affect more than one function. For example, a full face respirator would affect speech intelligibility and vision. Similarly, a single functional requirement may be affected by more than one component of the protective ensemble. For example, mobility may be affected by the body protection, foot protection, and eye/face protection.

These various overlapping effects are summarized as follows:

Functional requirements	Affected by:
Hand Dexterity and Tactility	Hand protection
Mobility	Face shield Foot protection Body protection Thermal regulation
Vision	Eye/face protection Full face respirator
Speech Intelligibility	Face shield Respirator

Where a functional requirement is affected by more than one item of the ensemble, the overall effect on the function is estimated as a compound of the individual effects. Thus, if the speech intelligibility decrement due to a face shield is 1.05, and for a respirator is 1.15, then the total speech intelligibility decrement would be 1.21 (1.05 times 1.15).

A performance decrement factor for each functional requirement for each protection level and for each level of activity (i.e., fine, gross, and average) can be estimated. These estimates are summarized in Table 24 and are either taken directly from Table 23 or calculated from the values in Table 23 using the compounding technique described in the previous paragraph.

That performance decrement factor is multiplied by the weighting factor for the relative importance of each functional requirement for each type (i.e., Group, as per Table 21) of worker activity for each level of protection. The total of the products for each type of activity for each protection level is the estimate of the increase in time to perform the activity owing to the items of PPE associated with the protection level. These overall performance decrements are summarized in Table 25.

Thus, PPE can be expected to increase the time to perform a task from 10% to approximately 40%, depending on the level of protection and the type of work being performed. These estimates do not include the time required to don and doff the clothing, which could be significant for protection levels 4 and 5.

Table 24. Performance decrements as function of type of work and protection level

Function	Motor control	Protection level 1	2	3	4	5
Hand	Fine	1.30	1.30	1.30	1.30	1.30
	Gross	1.20	1.20	1.20	1.20	1.20
	Average	1.25	1.25	1.25	1.25	1.25
Mobility	Fine	1.00	1.05	1.05	1.10	1.38
	Gross	1.00	1.21	1.27	1.32	1.74
	Average	1.00	1.13	1.16	1.21	1.56
Vision	Fine	1.00	1.00	1.05	1.10	1.21
	Gross	1.00	1.00	1.03	1.08	1.13
	Average	1.00	1.00	1.04	1.09	1.17
Speech	Fine	1.00	1.00	1.00	1.05	1.21
	Gross	1.00	1.00	1.00	1.05	1.13
	Average	1.00	1.00	1.00	1.05	1.17

Table 25. Overall performance decrements due to PPE

Activity	Protection level 1	2	3	4	5
Group 1	1.12	1.13	1.15	1.18	1.27
Group 2	1.05	1.14	1.18	1.22	1.42
Group 3	1.08	1.12	1.14	1.17	1.31

References

[1] Waugh, J.D., P.W. Kilduff, "Missile Component Repair While Wearing NBC Protective Clothing," U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, maryland, Technical Memorandum 1–84, January 1984.

[2] Bensel, C.K., R.A. Teixeira, D.B. Kaplan, "The Effects of U.S. Army Chemical Protective Clothing on Speech Intelligibility, Visual Field, Body Mobility and Psychomotor Coordination of Men," U.S. Army Natick Research, Development and Engineering Center, Natick, MA, Report Reference Natick/TR 87/037, September 1987.

[3] Plummer, R., T. Stobbe, R. Ronk, W. Myers, H. Kim, and M. Jaraiedi. Manual Dexterity Evaluation of Gloves Used in Handling Hazardous Materials. Proceedings of the Human Factors Society 29th Annual Meeting, Vol. II, R. Swezey, Ed., 1985.

[4] Robinette, K.M., H.G. Armstrong, C. Ervin, and G.F. Zehner. Dexterity Testing of Chemical Defense Gloves. AAMRL–TR–86–021. Wright Patterson Air Force Base, 1986.

[5] Schwope, A.D., C. Mond, and W. Augerson. Chemical Defense Medical Personnel Ensemble. Final Report. US Air Force Contract No. F33615–84–C0653, Wright Patterson Air Force Base, 1987.

[6] Mond, C., C. Jantz, A.D. Schwope, and R.S. Stricoff. Predicting Dexterous Performance of a Gloved Hand. Report to Radian Corporation, Austin, Texas, on National Institute for Environmental Health and Science contract, 1987.

[7] Schwope, A.D., P.P. Costas, C.R. Mond, R.L. Nolen, M. Conoley, D.B. Garcia, D.B. Walters, and A.T. Prokopetz. Gloves for Protection from Aqueous Formaldehyde: Permeation Resistance and Human Factors Analysis, Appl. Ind. Hyg., 3, 6, pp. 167–176, June, 1988.

[8] Cummings, E.G., W. Blevins, C.M. Greenland, and F.N. Craig. The Effect of Protective Masks on the Soldier's Ability to Run a Half Mile. Defense Technical Information Center (DTIC) AD 211687, 1958.

Section 7

Heat Stress

7 The Section in Brief

A worker whose body temperature rises above a safe level may be affected by heat stress—a general term that refers to conditions ranging from heat cramps through the more serious heat exhaustion and the potentially life-threatening heat stroke. Heat stress is marked by a variety of symptoms ranging from muscle spasms to dizziness, nausea, and coma.

The potential for heat stress is influenced by many factors, including ambient temperature, relative humidity, amount of sunshine, wind speed, amount and type of PPE, and the workload.

Whether a worker actually develops heat stress symptoms also depends on the worker, including his/her level of hydration, fitness, weight, height, and degree of acclimitazation. As a general rule, workers who have worked two hours or more in hot environments, or in PPE that restricts heat loss from the body, for seven or more days in a row are considered to be *acclimatized.*

PPE and Heat Stress

Unfortunately, PPE used for protection from pesticides can increase the potential for heat stress. The PPE features that keep pesticides out also serve to prevent body heat from escaping. People cannot work as long or as hard when the PPE they are wearing reduces the body's ability to maintain its thermal balance. Under some environmental conditions, certain activities cannot be performed without jeopardizing the health of the worker unless auxiliary cooling is provided. The risk that PPE may aggravate heat stress must be balanced with the PPE's potential worker protection benefits.

Work/Rest Cycles

One way to reduce the risk of heat stress is to modify the work/rest cycle, i.e., reduce the work time and increase the rest time during each hour on the job.

This chapter includes guidance for establishing work/rest cycles for acclimatized workers wearing varying levels of PPE under a range of conditions (Tables 38–41). The tables are based on NIOSH criteria that EPA has modified so that decisions can be made on the basis of readily available climatic data—temperature, relative humidity, wind speed, and amount of sunshine.

Every work situation is different, but the information in this chapter can provide **estimates of acceptable work/rest cycles**. These estimates can be used as an indicator of whether a particular pesticide-related task might need to be limited because of the danger of heat stress to workers.

7 Heat Stress

7.1 Introduction

Heat stress results when the body is unable to maintain normal (safe) temperatures while performing various tasks. Heat stress can manifest itself in a range of clinical symptoms (Table 26).[1] PPE used for protection from pesticides can increase the potential for heat stress. The very characteristics that are desirable in PPE for minimizing worker contact with pesticides inhibit heat loss from the body. These characteristics include penetration and permeation resistance, and high integrity seams, closures, and interfaces.

The potential for heat stress is influenced by a wide variety of factors, including ambient temperature, relative humidity, insolation, wind, amount and type of PPE and workload. The risk of heat stress must be balanced with the potential benefit of worker protection.

The Office of Pesticides Programs (OPP) needs a method for estimating the potential for heat stress due to protective equipment in order to assess the possible implications of its regulations and to provide guidance to pesticides handlers and workers as required in the Worker Protection Standards for Agricultural Pesticides. To be useful for these dual purposes, the method must be scientifically defensible, reasonably accurate, and utilitarian in field conditions. The methodology must treat the three key parameters associated with agricultural pesticide application: levels of PPE, work rates, and weather conditions.

One approach is that taken by the State of California. California has promulgated regulations specifying ambient conditions under which those pesticides that require "waterproof or impervious" clothing can be handled.[2,3] Paragraph 6738(d)(3) of the regulation states:

If the ambient temperature exceeds 80°F during the daylight hours or 85°F during the nighttime hours (sunset to sunrise), pesticides requiring waterproof or impervious full body protective clothing shall not be handled by employees unless they are handled pursuant to (A) or (B) above or employees use cooled chemical suits or other control methods to maintain an effective working environment of below 80°F during daylight hours or 85°F during nighttime hours.

Table 26. Signs and Symptoms of Heat Stress[1]

- Heat cramps are associated with heavy sweating with inadequate electrolyte replacement. Signs and symptoms include:
  - Muscle spasms
  - Pain in the hands, feet, and abdomen
- Heat exhaustion occurs from increased stress on various body organs including inadequate blood circulation due to cardiovascular insufficiency or dehydration. Signs include:
  - Excessive fatigue
  - Physical exhaustion
  - Elevated core temperature, >101°F
  - Heavy sweating
  - Dizziness
  - Nausea
  - Fainting
- Heat stroke is the most serious form of heat stress. Temperature regulation fails if the body temperature rises to critical levels. Immediate action must be taken to cool the body before permanent injury or death occur. Competent medical help must be obtained. Signs and symptoms may include:
  - Core temperature above 106°F
  - Altered perspiration
  - Shivering
  - Nausea
  - Dizziness and confusion
  - Coma

Subparagraphs (A) and (B) referred to in the above excerpt from the regulation pertain, respectively, to the use of closed mixing and loading systems, and to the use of air-conditioned, enclosed cabs. In each of these cases, clothing meeting the full body protection criteria must be available but need not be worn.

The California regulation applies to only one type of clothing (analogous to Level 5 defined in Table 22) and is based on the assumption of light, continuous work. Thus, the regulation does not address all of OPP's requirements for PPE guidance pertinent to heat stress. California's experience with its regulation, nevertheless, should be monitored closely since useful lessons may be learned.

Many researchers have developed indices or models for predicting the human response to work in the heat.[4] Some of these researchers have proposed standards that would limit or curtail work as a result of heat stress risk. But in general not one of the publicly available models meets all of the requirements imposed by OPP's various regulatory directives.

The principal purpose of this section is the presentation of methodology by which work/rest cycles appropriate for agricultural operations, in particular those of pesticide handlers, can be estimated. The method for estimating the work/rest cycles is based largely on the NIOSH criteria for occupational exposure to hot environments.[5] NIOSH has recommended various work/rest cycles on the basis of metabolic work rate and the wet bulb globe temperature (WBGT). Since the measurement of WBGT requires instrumentation

that is not likely to be widely available in the agriculture setting, the following presentation includes a procedure for predicting the WBGT using readily available weather data. Also the NIOSH scheme for adjusting WBGT to take into account various levels of PPE has been tailored to the five ensembles defined in Table 22 of Section 6.

This section reviews the factors that may contribute to heat stress in pesticides handlers wearing PPE and the various approaches for assessing and reacting to human response to the heat.

7.2 Workload for Pesticide Workers

7.2.1 Maximum work capacity

The ability of an individual to do physical work is usually restricted by a physiological limit called the maximum oxygen uptake; i.e., the ability of the body to deliver oxygen to the working muscles. In general, average maximum work capacities range from slightly under 600 kcal/hr for less fit women to over 1200 kcal/hr for young men in excellent physical condition (to convert kcal/hr to watts multiply by 1.15). For an average 20 year old male, the maximum work capacity is approximately 900 kcal/hr. For most individuals, maximum work capacity is only sustainable for a brief period of time, usually 6 minutes or less.[6]

7.2.2 Energy expenditure for pesticide worker tasks

Table 27 provides data for selected tasks that are typical of those performed during agricultural operations.[7] These average energy expenditure rates show that the level of heat production for pesticide handlers would not be expected to exceed 430 kcal/hr and, in the absence of heavy manual labor, would seldom exceed 260 kcal/hr. As an additional reference point, general ranges of work rates for a broader range of activities are given in Table 28.

Table 27. Estimated work rates for agricultural activities[7]

	Activity	Work rate, kcal/hr
Driving	Truck, open road, low speed	90
	Tractor, general	260
	Tractor, harrowing, seated	300
	Tractor, harrowing, standing	430
Loading	Dirt	420
	Sacks	352
Flying	Fixed-wing, routine	110
	Fixed-wing, spray pattern, rough air	160
Farming	Planting seedlings	300
	Weeding	310
	Hoeing	380
	Shoveling	410
Washing	Car	220
	Truck	250

Table 28. Estimates of general work rates[8, 9]

Class	Work rate, kcal/hr	Examples
Resting	< 100	
Light	101–200	**Sitting:** light hand work (writing, typing, drafting, sewing, bookkeeping); hand and arm work (small bench tools, inspecting, assembly, or sorting of light materials); arm and leg work (driving car under average conditions, operating foot switch or pedal). **Standing:** drill press (small parts); milling machine (small parts); coil taping; small armature winding; machining with power tools. **Walking:** ≤3 kph (2 mph).
Moderate	201–300	**Hand and arm work:** nailing and filling. **Arm and leg work:** off-road operation of trucks, tractors, or construction equipment. **Arm and trunk work:** air hammer operation, tractor assembly, plastering, intermittent handling of moderately heavy materials, weeding, hoeing, picking fruits and vegetables. **Pushing/pulling:** light-weight carts and wheelbarrows. **Walking:** 3–5 kph (2–3 mph).
High	301–400	**Arm and trunk work:** transferring heavy materials; shoveling/sledge hammer work; sawing; planing or chiseling hardwood; hand mowing; digging; chipping castings; laying concrete blocks. **Pushing/pulling:** heavy-weight carts and wheelbarrows. **Walking:** 6 kph (4 mph).
Very High	> 400	**Arm and trunk work:** heavy and fast to maximum pace ax work, shoveling, digging. **Climbing:** stairs, ramps; ladders. **Lifting:** > 44 pounds at 10 lifts per minute. **Walking, jogging, running:** > 6 kph (4 mph).

7.3 Properties of Protective Clothing and Their Contribution to Heat Stress

7.3.1 Clothing insulation

Clothing insulation (or thermal resistance) is a measure of the resistance to heat flow from the body to the ambient environment due to the clothing item. Heat flow is described by the relationship:

Heat flux/area = (Skin Temperature - Ambient Temperature)/Thermal Resistance

The three factors which contribute to the insulation of any clothing item are the thermal resistance of:

- The clothing materials,
- The air spaces between each layer of clothing and between the material and skin, and
- The air in the boundary layer at the surface of the clothing

The insulation value of clothing is often measured in clo, an arbitrary unit roughly equivalent to the insulation value of a men's winter suit with vest. 1 clo is equal to 0.18°C m^2 hr/kcal. Thus, a clothing ensemble with a total insulation of 1 clo has a heat loss rate per unit area of 5.55 kcal/m^2/hr for each °C of temperature difference between the inside and the outside of the ensemble. The insulation value of samples of clothing materials can be measured by a variety of methods. In ASTM Method D1518, the heat input required to maintain an electrically heated surface at a fixed temperature difference above ambient is measured.[10] A compilation of clo values for fabrics of the types worn by pesticide handlers is given in Table 29.

Table 29. Thermal properties of fabrics used in clothing worn by pesticide handlers[11]

Fabric	Fiber content	Weight, g/m^2	Thickness, mm	Insulation, clo	Permeability index, i_m	Permeability index ratio, i_m/clo
Broadcloth	100% cotton	114	0.325	0.15	0.72	4.80
Duck	100% cotton	340	0.742	0.20	0.34	1.70
Twill	100% cotton	435	0.88	0.18	0.27	1.50
Twill	50/50 cotton/ polyester	461	0.89	0.18	0.26	1.44
Chambray	100% cotton	139	0.48	0.22	0.57	2.59
Denim	100% cotton	265	0.75	0.17	0.35	2.06
Tyvek	Nonwoven polyethylene	41	0.31	0.13	0.085	0.65
SMS	Nonwoven polypro-pylene	61	0.61	0.19	0.63	3.32
Typro	Polyester/ wood pulp	75	0.47	0.17	0.75	4.41

The clo value for a fabric is different from the clo value for an ensemble of that fabric. Actual clothing ensembles typically consist of several layers of different clothing articles. The insulation of ensembles is a composite of the insulation of the various articles and depends on the way in which they are worn due to the influence of the air gaps between layers on the overall insulation. A predictive tool has been developed to estimate ensemble insulation from the insulation of cloth samples.[12] However, the most commonly used method is to measure the thermal properties of clothing ensembles using a life-sized thermal manikin following procedures which are similar to those used for individual samples.[13] ASTM has recently standardized the method.[14]

7.3.2 Pumping coefficient (p)

The insulation of a clothing ensemble is altered by wind and wearer motion. This change in insulation is characterized by a pumping coefficient (p). This coefficient describes the rate of loss of insulation with increasing effective air motion, where effective air motion is defined as a composite of the air motion generated by wind plus the air motion generated by wearer activity. It is measured experimentally by determining the change in insulation of ensembles on articulated, thermal manikins designed to simulate walking at various speeds while air velocity is changed. Wind reduces the thermal resistance of the external air boundary layer (from 0.8 clo in essentially still air to as low as 0.2 clo in a 12 mph breeze). It also penetrates clothing and causes it to move. Thus, increased cooling due to pumping occurs due to reduction in the boundary layer thermal resistance, air penetration of the clothing, and pumping of air through ensemble openings due to wearer motion or wind action on the clothing.[6]

7.3.3 Moisture permeability index (i_m)

Sweat produced by the wearer can either evaporate and be transferred to the ambient environment by passage through the clothing or evaporate into the interclothing space and gradually build up the humidity inside the garment to the point where further sweat evaporation becomes limited or ceases. Unless sweat can evaporate, it provides no cooling benefit.

The moisture permeability index (i_m) characterizes the facility with which moisture vapor moves through the clothing. Values for the i_m of fabrics that compose typical clothing used in agricultural operations are included in Table 29. A permeability index of "1" implies an evaporative heat loss equivalent to that of a psychrometric wet bulb thermometer—that is, a thermometer with a fully wetted surface and ventilated by a fan or slung at the end of a chain to produce maximum evaporative cooling. By contrast, if the thermometer were wrapped in a vapor barrier membrane, no evaporative cooling could occur and the permeability index (i_m) would be zero. Adding an impermeable layer will produce a more significant reduction in the moisture permeability index than adding additional layers of permeable clothing.

The moisture permeability index (i_m) is measured in a manner directly analogous to ASTM D1518. In the moisture permeability test, 100% saturated air is maintained on one side of the fabric and air at 50% relative humidity at the same temperature as the saturated air is supplied to the other

side. Due to the concentration difference, moisture diffuses through the fabric. The rate of diffusion is estimated from the heat of vaporization of water and the power required to evaporate water at a rate necessary to maintain the 100% saturated air. The procedure is in the initial stages of standardization by ASTM Committee F23.

7.3.4 Permeability index ratio (i_m/clo)

Since the "coolness" of a fabric is a function of both clothing moisture permeability and insulation, the ratio, i_m/clo, is used as an index of overall thermal comfort. The larger the value of this ratio, the more evaporative cooling is available compared to the resistance to dry heat transfer from the clothing. Thus, better protective clothing from a thermal comfort viewpoint would have larger i_m/clo values. Values of the ratio are shown in Table 29.

7.3.5 Representative PPE combinations for agricultural workers

In Section 6 (Table 22), five PPE combinations, representative of different levels of protection from pesticides, were defined. The thermal comfort rating for the ensembles would be expected to decrease as one moves from Level 1 to Level 5. Level 5 is the least comfortable and has associated with it the greatest risk for heat stress. As described in the remainder of this section, one means for reducing the risk of heat stress is to modify the work/rest cycle, reducing the relative amount of work, as the potential for heat stress increases.

7.4 Work/Rest Cycles

As discussed above, the likelihood of heat stress is dependent on the PPE, the work rate, and the conditions present in the ambient environment. These conditions include temperature, humidity, wind speed, and insolation. In this section, various approaches to assessing the likelihood of heat stress are summarized. The NIOSH, wet bulb globe temperature (WBGT) methodology is selected as most appropriate for use by OPP and is adapted herein for agricultural use.

Methodologies for predicting or minimizing heat stress fall into two major categories:

- **Mathematical Models** that predict the physiological response of the body to working in different environments, considering factors such as work rate and clothing worn. The determination of heat stress is done by establishing threshold values for parameters such as core temperature, body heat storage, sweat rate, skin temperature, etc.
- **Decision Rules** that provide an estimate of heat stress based on empirical data considering physiological factors. In general, decision rules consolidate a variety of related factors into a single value which predicts heat stress.

7.4.1 Mathematical models

In an EPA-sponsored study, various methods of assessing, predicting, and avoiding heat stress were reviewed. Several of the key models are briefly characterized in Table 30 and the types of inputs into and outputs from these and other models are summarized in Tables 31 and 32. Of the models, the Natick Model and the Givoni/Goldman Model would appear to be most adaptable to the needs of pesticide handlers. Neither of these models, however, is in the public domain and, at present, the interpretation of the outputs of the Givoni/Goldman model requires someone skilled in the area and the Natick model is not completed. Consequently, neither of these models were selected for further consideration in this guidance manual.

Table 30. Characteristics of heat stress models

Model	Inputs	Outputs	Comments
ALFIE[15]	Worker physical characteristics, work rate, and wet bulb, dry bulb, and globe temperatures.	Heat stress indices	Not applicable to all levels of protection.
Natick HP41CV[16]	Clothing type, work rate, environmental conditions	Work/rest cycle, water requirements, maximum work period	Available on handheld calculator. Model not complete and not in public domain.
Effective heat strain index[17]	Clothing insulation, work rate, air velocity, and dry bulb, wet bulb, and globe temperatures	Required sweat evaporation, available sweat evaporation, % skin wettedness	Available on handheld calculator. Not applicable to moisture vapor impermeable clothing.
Gagge-Nishi [18, 19, 20]	Same as above entry	Core temperature, shivering and sweat rate	Permeability calculated from insulation. Questionable accuracy in hot environments.
ISO/'DP 7933[21]	Same as above entry	Allowable exposure times	Not applicable to all levels of protection.
Wissler [22, 23, 24]	Same as above plus weight and mean skin fold thickness and clothing permeability	Core temperature, skin temperature, sweat rate	Considers personal coolers. Requires expert to use. Limited validation.
Stolwijk/Hardy[25]	Dry bulb, relative humidity, air velocity, metabolic rate	Core temperature, shivering rate, and sweating rate	Not applicable to all levels of protection.
Givoni/Goldman [26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38]	See Table 31	Body heat storage, sweat wetted area, sweat rate, core temperature, heart rate, comfort	Not in public domain. Requires expert to use.

Table 31. Examples of inputs used in heat stress prediction models

Anthropological makeup • Age • Sex • Height • Weight • State of fitness/training
Physiological status • Heat acclimatization • Level of hydration
Clothing and equipment • Description of PPE worn
Scenario • Number and type of tasks • Duration of each task
Environment • Geographic locale • Terrain • Time of year and day • Temperature • Humidity • Wind • Solar load

Table 32. Outputs from various heat stress models

• Heart rate • Deep body temperature as function of time • Mean skin temperature as function of time • Equilibrium (final) deep body temperature • Equilibrium (final) heart rate • Required evaporative cooling (E_{req} in Watts) • Sweat production required (g/hr) • Rate of dehydration, based on water intake (if any) (g/hr) • Maximum evaporative potential (E_{max} in Watts) • % sweat wetted skin (E_{req}/E_{max}) • Cooling power of the environment • Effective clothing insulation (clo eff) • Effective clothing moisture permeability ($i_m$eff) • Comfort vote (PMV) • Heat stress indices

7.4.2 Decision rules

Decision rules offer the advantage of ease of use and implementation, although they may be based on experience and empiricism rather than fundamental heat transfer and physiological principles. Furthermore, the definition, application, and interpretation of the rules varies among researchers. For example, while the wet bulb globe temperature (WBGT) is often used as the environmental measure on which the rules are based, the threshold limiting values vary depending on the researcher. The use of other indices such as the heat stress index (HSI),[39] wet globe temperature (WGT),[40] effective temperature (ET),[41] corrected effective temperature (CET),[42] and apparent temperature (AT)[43] is dependent on the environmental conditions (e.g., whether radiation, humidity, air velocity, etc. are dominant factors).

The EPA-sponsored study cited above recommended that further consideration be given to the NIOSH WBGT decision rule, the Ramsey WBGT decision rule, and the effective heat strain index as the basis for this guidance manual.[4] Following the conclusion of that study, the NIOSH WBGT decision rule was selected because it appeared to best meet the requirements for a scientifically based, peer reviewed method that could be adapted to the field. The NIOSH decision rule model is described in Section 7.4.3, and guidelines for applying it to agricultural workers are given in Section 7.4.4.

7.4.3 NIOSH WBGT decision rule

The NIOSH recommended standard for heat stress control is described in detail in Reference 5. The following discussion is a summary of this information. In developing a heat stress control program, one should consult the original reference as it contains additional, detailed information on the derivation, application, and limitations of the standard.

As the measure of environmental load on a worker, the NIOSH WBGT decision rule uses the Wet Bulb Globe Temperature given by:

$$WBGT = 0.7T_{NWB} + 0.2T_G + 0.1T_{AIR} \quad \textit{with solar load} \quad (1)$$

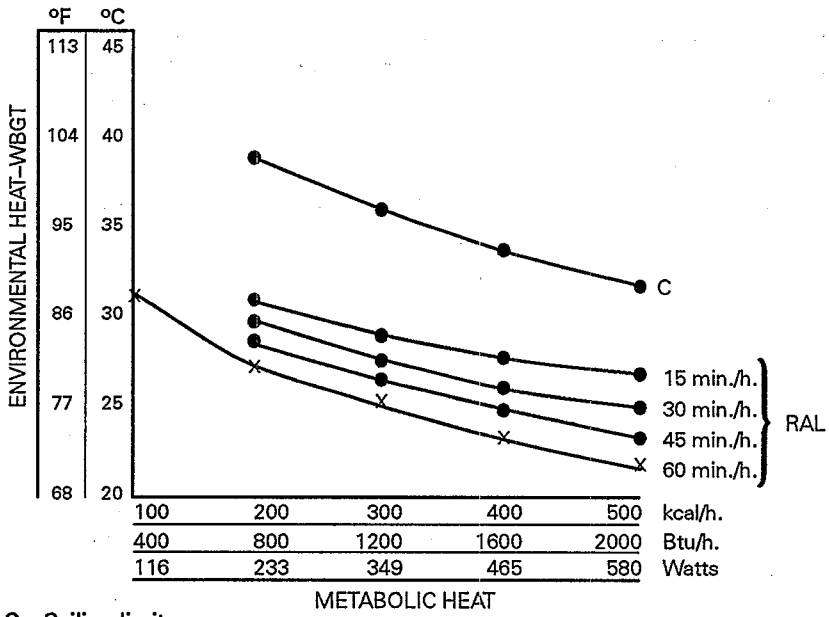
$$WBGT = 0.7T_{NWB} + 0.3T_G \quad \textit{with no solor load} \quad (2)$$

where:

- T_{NWB} is the natural wet bulb temperature - the temperature measured with a wet bulb thermometer exposed to ambient air velocity, °F or °C
- T_G is the black globe temperature - a measure of the radiation load, °F or °C
- T_{AIR} is the dry bulb temperature, °F or °C

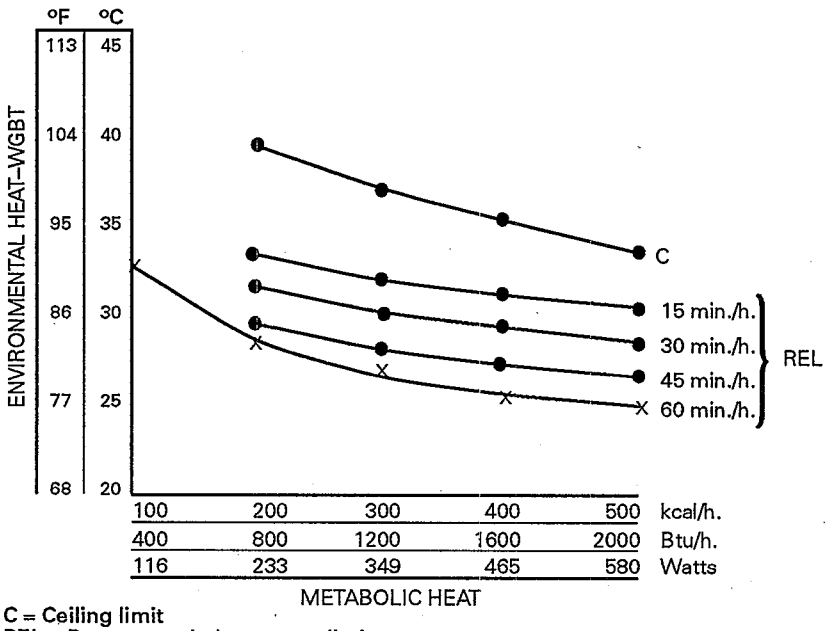
The WBGT is combined with the metabolic work rate to yield work/rest cycles for both acclimatized and unacclimatized workers. The metabolic work rate is the time-averaged, hourly work rate. Acclimatized workers are those who have worked two hours or more in hot environments for seven or more days. These relationships are given in Figures 3 and 4. Each curve gives recommended work/rest cycles (shown at the right of the curve) corresponding to metabolic rates and WBGT.

Figure 3. Recommended heat-stress alert limits. Heat-Unacclimatized Workers[5]



C = Ceiling limit
RAL = Recommended alert limit
*For "standard worker" of 70 kg (154 lbs) body weight and 1.8 m^2 (19.4 ft^2) body surface.

Figure 4. Recommended heat-stress exposure limits. Heat-Acclimatized Workers[5]



C = Ceiling limit
REL = Recommended exposure limit
*For "standard worker" of 70 kg (154 lbs) body weight and 1.8 m^2 (19.4 ft^2) body surface.

The Recommended Alert Limits (RALs) in Figure 3 are for workers who are not acclimated. The RALs represent conditions under which "almost all healthy workers . . . should be able to tolerate total heat without substantially increasing their risk of incurring acute health effects." The Recommended Exposure Limits (RELs) in Figure 4 apply to heat-acclimatized persons and represent the conditions under which "almost all healthy workers . . . should be capable of tolerating the total heat without incurring adverse effects." The "ceiling limit" is the set of conditions at which all work should stop. **Note, the RALs and RELs are for a "standard worker" of 70 kg (154 lbs) and 1.8 m² (19.4 ft²) body surface area.**

According to the NIOSH criteria, healthy workers are defined as those who are not excluded from placement in hot environment jobs by explicit specifications, which are given in Reference 4. These exclusionary criteria include factors such as age, stature, gender, percent body fat, medical and occupational history, specific chronic diseases or therapeutic regimens, and the results of such tests as the maximum aerobic capacity, electrocardiogram, pulmonary function tests, and chest X-rays.

The metabolic rates are one hour time-weighted averages. For example, if a worker works at a rate of 300 kcal/hr for 45 minutes and then rests (metabolic rate of 80 kcal/hr) for 15 minutes, the one hour time weighted average is:

$$(300 \times 45 + 80 \times 15) / 60 = 245 \text{ kcal/hr} \qquad (3)$$

The relationships given are for a "standard" worker, i.e., one who weighs 70 kg (154 lbs) and has a surface area of 1.8 m² (19.4 ft²). The metabolic work rate for persons with other body weights or surface areas are estimated by simple proportions. For example, if a task is estimated to require 300 kcal/hr for a 70 kg worker then an 80 kg worker would require:

$$300 \times (80/70) = 343 \text{ kcal/hr.} \qquad (4)$$

The RALs and RELs are for workers wearing a long-sleeved, shirt (cotton or cotton/polyester) and long-legged pants (cotton or cotton/polyester). If clothing ensembles with different thermal properties are used, the work/rest cycles must be modified. NIOSH suggests modifications based on adjustments to the WBGT. Guidelines provided by NIOSH are summarized in Table 33. NIOSH specifies that the air temperature or the adjusted air temperature must be used in place of the adjusted WBGT for encapsulating ensembles fabricated from moisture-impermeable materials. Adjusted air temperature (T_{ADB}) is estimated as follows:

$$T_{ADB} = (T_{AIR} + T_{MR}) / 2 \qquad (5)$$

Table 33. NIOSH recommended adjustments to threshold values for clothing differences

Clothing type	Adjustment
Two layer cotton or cotton/polyester system	Lower WBGT threshold limit by 2°C (3.6°F)
Partially air and vapor impermeable clothing	Lower WBGT threshold limit by 4°C (7.2°F)
Encapsulating, air-impermeable clothing	Use dry bulb (T_{AIR}) or adjusted dry bulb (T_{ADB}) in place of WBGT and use physiological monitoring if temperature is greater than 20°C (68°F)

The Mean Radiant Temperature (T_{MR}) is defined as:

$$T_{MR} = T_G + (1.8V_{AIR}^{0.5})(T_G - T_{AIR}) \qquad (6)$$

where V_{AIR} is the velocity of the wind in meters per second (m/s).

The three clothing ensembles for which NIOSH recommends adjustments to the WBGT only partially represent the five levels of protection defined in Table 22 of Section 6. Based on interpolation and other literature sources, estimated WBGT adjustments are given in Table 34 for the five, Table 22 ensembles.

Table 34. Estimated WBGT adjustments for five levels of pesticide handler's clothing

Clothing level*	Adjustment to WBGT, °C
1	0
2	+2.5
3	+3.5
4	+5
5	Use T_{ADB} or T_{AIR}**

* See Section 6, Table 22
** See Section 7.4.4.3

In addition to the work/rest cycles in Figures 3 and 4, NIOSH recommends monitoring the physiological condition of the workers according to a schedule based on the T_{ADB}.[44] Excerpts from the recommended monitoring schedule are shown in Table 35. Criteria for acceptable physiological conditions are summarized in Table 36. Corrective actions, which may be taken if these criteria are not met, are summarized in Table 37.

Table 35. NIOSH recommended monitoring frequency[44]

	Frequency	
T_{ADB}	**Level 1 Clothing**	**Level 5 Clothing**
24°C (75°F)	Every $2^1/_2$ hours	Every 2 hours
32°C (90°F)	Every 45 minutes	Every 15 minutes

7.4.4 Application of NIOSH decision rule to pesticide handlers

In the following paragraphs, the NIOSH Decision Rule is adapted for agricultural pesticide applications. Most significantly, procedures have been developed and are used for estimating WBGT on the basis of commonly available weather data: T_{AIR}, V_{AIR}, amounts of sunshine, and relative humidity. The outcomes of applying the rule are recommendations for work/rest cycle that will minimize the risk of heat stress. By applying the rule under various PPE use scenarios, one can estimate and compare the impact of PPE on performance. There are two alternative procedures for using the modified NIOSH rule:

Alternative 1

- For PPE levels 1 through 4, use Tables 38 through 41 for the conditions that best approximate the weather, work rate, and PPE for the particular work scenario in question. The estimated work/rest cycles in Tables 38 through 41 apply to acclimatized "standard" workers. For PPE level 5 ensembles see Section 7.4.4.3.

Alternative 2

- Estimate the work rate (Section 7.4.4.1).
- Measure or estimate the WBGT (Section 7.4.4.2).
- Adjust the WBGT for the PPE worn (Section 7.4.4.3).
- Use either Figure 3 or 4 to determine the appropriate work/rest cycle.

7.4.4.1 Estimation of work rate. Work loads for various pesticide handler activities have been estimated from Tables 27 and 28 and are listed in Table 42. In order to apply the modified NIOSH rule, a value of metabolic work rate should be selected for the activity which most closely matches the pesticide handler's. If the activity is not covered specifically by any of the three tables, estimates can be made by interpolation and comparison with similar activities.

7.4.4.2 Estimation of WBGT. WBGT takes into account air temperature, relative humidity, wind velocity, and insolation (i.e., amount of sunshine). The measurement of WBGT yields a single number that, when adjusted for the level of protection, can be used directly with Figures 3 and 4 to estimate appropriate work/rest cycles. Instruments are commercially available for making the measurement. In many agricultural situations, such instruments will not be available. The only available information will be data provided by the weather service or measured on site with common instruments. The objective of this subsection is to present and document a procedure for estimating WBGT from commonly available weather data.

Table 36. Vital signs measurements

Parameter	Criteria
Recovery heart rate (measured at beginning of rest cycle)	Pulse at 30 to 60 seconds after sitting = p_1 Pulse at 150 to 180 seconds after sitting = p_3 If $p_3 \leq 90$, worker is okay to continue work at present level If $p_3 > 90$ and/or $p1 - p3 < 10$, corrective action is necessary. See Table 37.
Core temperature	Core temperature should not exceed 38°C (100.4°F) for extended periods. Oral temperature may be substituted for rectal temperature but normal care (e.g., no food or liquid 15 minutes prior to reading, mouth closed, etc.) must be taken to get an accurate reading. Oral temperature would be 0.5°C (0.9°F) lower than rectal temperature.

Table 37. Corrective action

Cause of heat stress	Action
Internal heat generation	Modify task to reduce effort. Change work/rest cycle. Use auxiliary power to reduce effort.
Environmental load	Reduce radiation load by awnings, etc. Increase air speed Provide conditioned space • Recovery area • Tractor cab Provide personal cooling • ice vest • vortex cooler, etc.
Other considerations	Carefully break in unacclimatized workers Encourage high liquid intake Medical monitoring Heat alert programs during heat waves

Table 38. Work/Rest Cycles—Level #1 PPE (see Table 22 on page 96 for description of PPE levels)

	Partial sun												Full sun												
%RH	10				50				80				10				50				80				
MPH	20	10	5	1	20	10	5	1	20	10	5	1	20	10	5	1	20	10	5	1	20	10	5	1	
70F																									
L	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	L
M	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	M
H	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	H
VH	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	VH
80F																									
L	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	L
M	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	M
H	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	H
VH	5	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5	4	4	3	VH
90F																									
L	5	5	5	5	5	5	5	5	5	5	4	4	5	5	5	5	5	5	5	5	4	4	3	2	L
M	5	5	5	5	5	5	5	5	3	3	3	2	5	5	5	5	5	5	5	4	3	2	2	1	M
H	5	5	5	5	5	5	5	4	2	2	1	1	5	5	5	5	5	4	4	3	1	1	1	1	H
VH	5	5	5	5	4	3	3	3	1	1	1	1	5	5	5	5	3	3	3	2	1	1	1	1	VH
100F																									
L	5	5	5	5	3	3	3	2	1	1	1	1	5	5	5	5	3	2	2	1	1	1	1	1	L
M	5	5	5	5	2	2	1	1	1	1	1	1	5	5	5	5	1	1	1	1	1	1	1	1	M
H	5	5	5	5	1	1	1	1	1	1	1	1	5	5	5	5	1	1	1	1	1	0	0	0	H
VH	5	5	5	5	1	1	1	1	0	0	0	0	5	5	5	4	1	1	1	1	0	0	0	0	VH
110F																									
L	5	5	5	5	1	1	1	1	0	0	0	0	5	5	5	5	1	1	1	1	0	0	0	0	L
M	5	5	5	4	1	1	1	1	0	0	0	0	5	5	4	3	1	1	1	0	0	0	0	0	M
H	4	4	4	3	1	0	0	0	0	0	0	0	4	3	3	2	0	0	0	0	0	0	0	0	H
VH	3	3	3	2	0	0	0	0	0	0	0	0	3	2	2	1	0	0	0	0	0	0	0	0	VH

Work Load: L=Light Work; M=Moderate Work; H=Heavy Work; VH=Very Heavy Work
Work Time Per Hour, Minutes: 5=60; 4=<60; 3=<45; 2=<30; 1=<15; 0=0

Table 39. Work/Rest Cycles—Level #2 PPE (see Table 22 on page 96 for description of PPE levels)

	Partial sun												Full sun												
%RH	10				50				80				10				50				80				
MPH	20	10	5	1	20	10	5	1	20	10	5	1	20	10	5	1	20	10	5	1	20	10	5	1	
70F																									
L	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	L
M	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	M
H	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	H
VH	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	VH
80F																									
L	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	L
M	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	4	M
H	5	5	5	5	5	5	5	5	4	4	4	3	5	5	5	5	5	5	5	5	4	3	3	2	H
VH	5	5	5	5	5	5	5	5	3	3	3	2	5	5	5	5	5	5	4	3	3	2	1	1	VH
90F																									
L	5	5	5	5	5	5	5	5	1	1	1	1	5	5	5	5	5	5	5	3	1	1	1	1	L
M	5	5	5	5	4	4	4	3	1	1	1	1	5	5	5	5	4	3	3	2	1	1	1	1	M
H	5	5	5	5	3	3	2	2	1	1	1	1	5	5	5	5	2	2	2	1	1	1	1	1	H
VH	5	5	5	5	2	2	2	1	1	1	1	1	5	5	5	5	2	1	1	1	1	1	1	0	VH
100F																									
L	5	5	5	5	1	1	1	1	1	1	1	1	5	5	5	5	1	1	1	1	1	1	1	1	L
M	5	5	5	5	1	1	1	1	1	1	1	0	5	5	5	4	1	1	1	1	0	0	0	0	M
H	5	5	5	4	1	1	1	1	0	0	0	0	5	4	4	3	1	1	1	1	0	0	0	0	H
VH	4	4	4	3	1	1	1	0	0	0	0	0	4	3	3	2	1	0	0	0	0	0	0	0	VH
110F																									
L	5	5	4	3	1	1	1	1	0	0	0	0	4	4	3	1	1	1	1	0	0	0	0	0	L
M	3	3	3	1	0	0	0	0	0	0	0	0	3	2	2	1	0	0	0	0	0	0	0	0	M
H	2	2	1	1	0	0	0	0	0	0	0	0	2	1	1	1	0	0	0	0	0	0	0	0	H
VH	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	VH

Work Load: L=Light Work; M=Moderate Work; H=Heavy Work; VH=Very Heavy Work
Work Time Per Hour, Minutes: 5=60; 4=<60; 3=<45; 2=<30; 1=<15; 0=0

Table 40. Work/Rest Cycles—Level #3 PPE (see Table 22 on page 96 for description of PPE levels)

	Partial sun												Full sun												
%RH	10				50				80				10				50				80				
MPH	20	10	5	1	20	10	5	1	20	10	5	1	20	10	5	1	20	10	5	1	20	10	5	1	
70F																									
L	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	L
M	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	M
H	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	H
VH	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	VH
80F																									
L	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	L
M	5	5	5	5	5	5	5	5	5	5	4	4	5	5	5	5	5	5	5	5	4	4	3	3	M
H	5	5	5	5	5	5	5	5	3	3	3	3	5	5	5	5	5	5	5	4	3	3	2	1	H
VH	5	5	5	5	5	4	4	4	2	2	2	2	5	5	5	5	4	4	4	3	2	2	1	1	VH
90F																									
L	5	5	5	5	5	5	4	4	1	1	1	1	5	5	5	5	4	4	3	2	1	1	1	1	L
M	5	5	5	5	3	3	3	2	1	1	1	1	5	5	5	5	3	2	2	1	1	1	1	1	M
H	5	5	5	5	2	2	2	1	1	1	1	1	5	5	5	5	2	1	1	1	1	1	1	1	H
VH	5	5	5	5	1	1	1	1	1	1	1	0	5	5	5	4	1	1	1	1	1	0	0	0	VH
100F																									
L	5	5	5	5	1	1	1	1	1	1	1	1	5	5	5	5	1	1	1	1	1	1	1	0	L
M	5	5	5	4	1	1	1	1	0	0	0	0	5	5	5	3	1	1	1	1	0	0	0	0	M
H	4	4	4	3	1	1	1	1	0	0	0	0	4	4	3	2	1	1	1	0	0	0	0	0	H
VH	3	3	3	2	0	0	0	0	0	0	0	0	3	3	2	1	0	0	0	0	0	0	0	0	VH
110F																									
L	4	3	3	2	1	1	1	0	0	0	0	0	3	3	2	1	1	1	0	0	0	0	0	0	L
M	2	2	2	1	0	0	0	0	0	0	0	0	2	1	1	1	0	0	0	0	0	0	0	0	M
H	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	H
VH	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	VH

Work Load: L=Light Work; M=Moderate Work; H=Heavy Work; VH=Very Heavy Work
Work Time Per Hour, Minutes: 5=60; 4=<60; 3=<45; 2=<30; 1=<15; 0=0

Table 41. Work/Rest Cycles—Level #4 PPE (see Table 22 on page 96 for description of PPE levels)

	Partial sun												Full sun												
%RH	10				50				80				10				50				80				
MPH	20	10	5	1	20	10	5	1	20	10	5	1	20	10	5	1	20	10	5	1	20	10	5	1	
70F																									
L	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	L
M	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	M
H	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	4	H
VH	5	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5	4	4	3	VH
80F																									
L	5	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	5	5	4	4	2	L
M	5	5	5	5	5	5	5	5	3	3	3	2	5	5	5	5	5	5	5	4	3	2	2	1	M
H	5	5	5	5	5	4	4	4	2	2	2	1	5	5	5	5	4	4	3	3	2	1	1	1	H
VH	5	5	5	5	3	3	3	3	1	1	1	1	5	5	5	5	3	3	2	2	1	1	1	1	VH
90F																									
L	5	5	5	5	3	3	2	2	1	1	1	1	5	5	5	5	3	2	1	1	1	1	1	1	L
M	5	5	5	5	2	1	1	1	1	1	1	1	5	5	5	5	1	1	1	1	1	1	1	1	M
H	5	5	5	5	1	1	1	1	1	1	1	1	5	5	5	4	1	1	1	1	1	1	0	0	H
VH	5	5	4	4	1	1	1	1	0	0	0	0	5	4	4	3	1	1	1	1	0	0	0	0	VH
100F																									
L	5	5	5	5	1	1	1	1	1	0	0	0	5	5	5	3	1	1	1	1	0	0	0	0	L
M	5	4	4	3	1	1	1	1	0	0	0	0	4	4	3	2	1	1	1	0	0	0	0	0	M
H	3	3	3	2	1	0	0	0	0	0	0	0	3	2	2	1	0	0	0	0	0	0	0	0	H
VH	2	2	2	1	0	0	0	0	0	0	0	0	2	1	1	1	0	0	0	0	0	0	0	0	VH
110F																									
L	2	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	L
M	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	M
H	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	H
VH	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	VH

Work Load: L=Light Work; M=Moderate Work; H=Heavy Work; VH=Very Heavy Work
Work Time Per Hour, Minutes: 5=60; 4=<60; 3=<45; 2=<30; 1=<15; 0=0

Table 42. Metabolic rates for typical pesticide handlers activities

Activity	Description	Metabolic Rate, kcal/hr
Mixing and Handling	• Open containers • Tear open bags • Lift containers (5 to 50 lbs) • Measure concentrate • Pour contents into mixing tank • Operate pump • Turn on water spigot • Empty pitcher or bucket into mixing tank • Climb with or without load onto mixing tank	300*
Loading	• Connect hoses • Open/close tank lid • Climb onto mix tank • Drive	280+
Boom or Air Blast Spraying	• Drive tractor • Adjust and clean nozzle • Check vehicle • Climb on and off tractor	270++
Backpack Spraying	• Walk while carrying tank and sprayer • Shake container • Adjust and clean nozzle • Climb with and without load	330+++

*50% moderate (250 kcal/hr) plus 50% heavy (350 kcal/hr) = 300 kcal/hr

+70% moderate (250 kcal/hr) plus 30% heavy (350 kcal/hr) = 280 kcal/hr

++80% moderate (250 kcal/hr) plus 20% heavy (350 kcal/hr) = 270 kcal/hr

+++25% moderate (250 kcal/hr) plus 75% heavy (350 kcal/hr) = 330 kcal/hr

Heat and mass transfer analyses were performed for the wet bulb thermometer to evaluate the impact of radiation and wind velocity, and for the black globe thermometer to estimate the relationship between the globe temperature, wind velocity, and air temperature for typical radiation loads (e.g. partial cloud cover, sun not directly overhead) and extreme loads (e.g., clear sky, sun directly overhead, dirt or sand in work area).

The natural wet bulb temperature, T_{NWB}, is in practice only slightly greater than the psychrometric wet bulb temperature. The largest difference occurs when the air velocity is low so that the effect of radiation is more important. This can be shown as follows.

The heat balance on a wet bulb thermometer is given by:[45]

$$(h_c + h_r)\,(T_{AIR} - T_{WB}) = \left[\frac{(h_D h_{fg})}{(R_w T)}\right](p_{WB} - p_{AIR}) \qquad (7)$$

where the left side is the heat gain from convection and radiation, the right side is the heat lost by evaporation, and:

h_c	is the convective heat transfer coefficient, BTU/hr ft^2 °F
h_r	is the radiative heat transfer coefficient, BTU/hr ft^2 °F
T_{AIR}	is the ambient dry bulb temperature, °F
h_D	is the mass coefficient, ft/hr
h_{fg}	is the heat of vaporization of water at T_{WB}, BTU/lb
R_w	is the gas constant for water, ft lb$_f$/lb °R
T	is the mean temperature $(T_{AIR} + T_{WB})/2$, °R
p_{AIR}	is the partial pressure of water vapor in the ambient air, lbf/ft^2
p_{WB}	is the partial pressure of water vapor at the wet bulb temperature, lbf/ft^2
Note:	°R = °F + 498
	°F = 1.8 °C + 32

The above equation can be rewritten as:

$$T_{WB} = T_{AIR} - \frac{(h_D h_{fg})}{(h_c + h_r)\,R_w T}\,(p_{WB} - p_{AIR}) \qquad (8)$$

When making a wet bulb temperature reading, the bulb is ventilated at 1000 fpm or greater. At this velocity, the radiative heat transfer coefficient is negligible compared to the convective heat transfer coefficient, and the ratio of the diffusion coefficient over the convective heat transfer coefficient is independent of velocity.[45] At wind speeds greater than 3 mph, the natural wet bulb temperature can be approximated by the wet bulb temperature, i.e.,

$$\text{For } V_{AIR} > 3 \text{ mph},\ T_{NWB} \approx T_{WB} \qquad (9)$$

For wind speeds less than 3 mph, the radiative heat transfer becomes more significant and reduction of the above equation yields

$$For\ V_{AIR} < 3\ mph,\ T_{NWB} = T_{AIR} - \left[\frac{11.8\ V^{0.79}}{1 + 11.8V^{0.79}}\right](T_{AIR} - T_{WB}) \qquad (10)$$

Thus, the natural wet bulb temperature can be estimated for calculating the WBGT when only the dry bulb temperature, the wet bulb temperature (or the relative humidity), and the wind speed are known.

The globe temperature depends primarily on dry bulb temperature, solar radiation, and wind velocity. As shown in Table 43, the radiation "collected" by a black globe is dependent on the angle of the sun to the earth (i.e., dependent on season, latitude, time of day) and cloudiness or haziness of the sky. At equilibrium, this heat gain from the sun is equal to heat loss by radiation to the environment and by cooling due to air movement. This condition is described by the equation:[45,46,47,48]

$$Gain = (\sigma T_G^4 - 0.814\sigma T_{AIR}^4) + (1 + 0.3V_{AIR})(T_G - T_{AIR}) \qquad (11)$$

Where:

T_G = black globe temperature, °R
σ = Stefan-Boltzmann Constant = 0.1713×10^{-8} Btu/hr ft^2°R^4
V = Wind velocity, mph

Table 43. Estimates[46,47,48] of solar load (gain) on a black globe, BTU/hr ft^2

Location	Season	Time	Clear	Medium cloud	Hazy
Florida (28°N)	Summer	9:00 a.m.	79.6	75.6	52.5
		noon	75.3	73.5	52.9
	Spring/ Fall	9:00 a.m.	81.8	75.9	54.1
		noon	84.7	76.4	52.8
	Winter	9:00 a.m.	80.7	76.1	54.1
		noon	81.9	76.9	54.8
Upper Midwest (44°N)	Summer	9:00 a.m.	79.9	75.1	49.3
		noon	75.1	73.4	49.5
	Spring/ Fall	9:00 a.m.	78.3	74.6	49.2
		noon	73.5	73.0	51.2
	Winter	9:00 a.m.	73.3	71.2	44.9
		noon	69.2	70.3	49.6

7.4.4.3 Adjustments to WBGT for PPE levels. Different pesticides and tasks related to handling pesticides require different types of PPE. While a virtually limitless range of clothing ensemble variation may be found in the field, five have been selected for purposes of this discussion. (See Table 22 in Section 6.)

WBGT adjustment factors for these ensembles are listed in Table 34. Two publications were used as the principal sources of information to guide the development of adjustment factors for the ensembles not covered directly by NIOSH.[8,49] Among the three sources, there seems to be general agreement (i.e., within 1°C) for the adjustment factors for PPE Levels 1 through 4.

For Level 5, which is a hooded coverall of an air-impermeable material, there is less agreement. As mentioned earlier, NIOSH suggests the use of either T_{ADB} or T_{AIR} in place of WBGT; the former seems to be preferred. Ramsey suggests adding 7°C to the WBGT. Paull et al. suggest adding up to 11°C to the WBGT. Pertinent to work/rest cycles, using T_{ADB} in place of WBGT would allow longer work periods per hour than would the +7°C adjustment suggested by Ramsey which in turn would allow longer work periods per hour than would the +11°C adjustment recommended by Paull. In general and regardless of which of the three approaches is followed, the eventual conclusion is that some rest period is required each hour once the temperature reaches 80°F. The length of the rest period will be dependent on the work rate and the solar load. With reference to Tables 27 and 42, work rates for pesticides mixing, loading, and application are likely to be in the range of 200–300 kcal/hr. At these work rates and again depending on the solar load, consideration towards the need for rest periods should begin at 65°F. Note that the California regulation discussed in Section 7.1, which sets the limit of 80°F (85°F at night) for activities with Level 5-type PPE, was based on the assumption of light, continuous work at 80°F, with light work defined as a rate of <200 kcal/hr. It should be imminently evident that caution and judgement are required whenever the use of PPE Level 5 is contemplated or necessitated. One approach to obtaining the perspective within which to make the judgement is to determine work/rest cycles based on both the T_{ADB} and the +11°C adjustment to the WBGT, and then compare and assess the results.

7.4.4.4 Examples of procedure. Three variations follow pertinent to the application of the above methods to estimate work/rest cycles for an acclimatized "standard" worker. In each example, the process is to measure or estimate the WGBT, adjust it for the level of PPE; and then use Figures 3 or 4 to determine the work/rest cycle.

Example 1

PPE level	2
Work rate	250 kcal/hr
WBGT	28°C

With reference to Table 34, the adjustment to the WBGT is +2.5°C for PPE Level 2. Thus the adjusted WBGT becomes 30.5°C. For this WBGT and the work rate of 250 kcal/hr, the work/rest cycle from Figure 4 is 30 minutes of work per hour.

Example 2

PPE level	2
Work rate	250 kcal/hr
T_{AIR}	80°F (26.7°C)
%RH	50
Wind velocity	10 mph
Insolation	bright sun

A work rate of 250 kcal/hr is considered Moderate (Table 28). Go to Table 39. Under the major heading Full Sun, locate the column for 50%RH and 10 mph wind. Go down the column to the group of rows designated 80°F. Read the entry, "5," for moderate (M) work rate. The entry of 5 corresponds to a work/rest cycle of 60 minutes of work per hour, i.e., there is no limit on work time due to the risk of heat stress.

Example 3

PPE level	2
Work rate	250 kcal/hr
T_{AIR}	80 °F (26.7°C)
%RH	50
Wind velocity	10 mph
Insolation	bright sun, summer, noon, 28°N

Calculate WBGT using T_{NWB} and T_G estimated according to Section 7.4.4.2. The estimation of T_{NWB} begins with the determination of T_{WG}. T_{WB} is determined using Figure 5 with the values given above for T_{AIR} (dry bulb temperature) and the relative humidity. For a T_{AIR} of 80°F and a 50%RH, T_{WB} equals approximately 67°F, as indicated by the star in Figure 5 at the intersection of the line going vertically up at 80°F on dry bulb temperature axis and the dashed curve representing 50%RH. Since the wind speed is greater than 3 mph, $T_{NWB} = T_{WB}$, or 67°F (see equation 9).

T_G is estimated using equation 11 with the gain set equal to 75.3 BTU hr ft^2, the specified wind velocity, and T_{AIR}. The value of 75.3 BTU/hr ft^2 was selected from Table 43 for the conditions of bright summer, noon sun at 28°F. The solution of the gain equation for T_G is an iterative process in which one tries different values of T_G to find the value that will make the right side of the equation equal the gain. This process can be done by hand with a calculator or using the "solve" feature now found in many spreadsheet softwares and even on some calculators. In this case T_G was found to be 89.5°F.

The values for T_{NWB}, T_G, and T_{AIR} are then substituted into:

$$WBGT = 0.7\ T_{NWB} + 0.2\ T_G + 0.1\ T_{AIR}$$

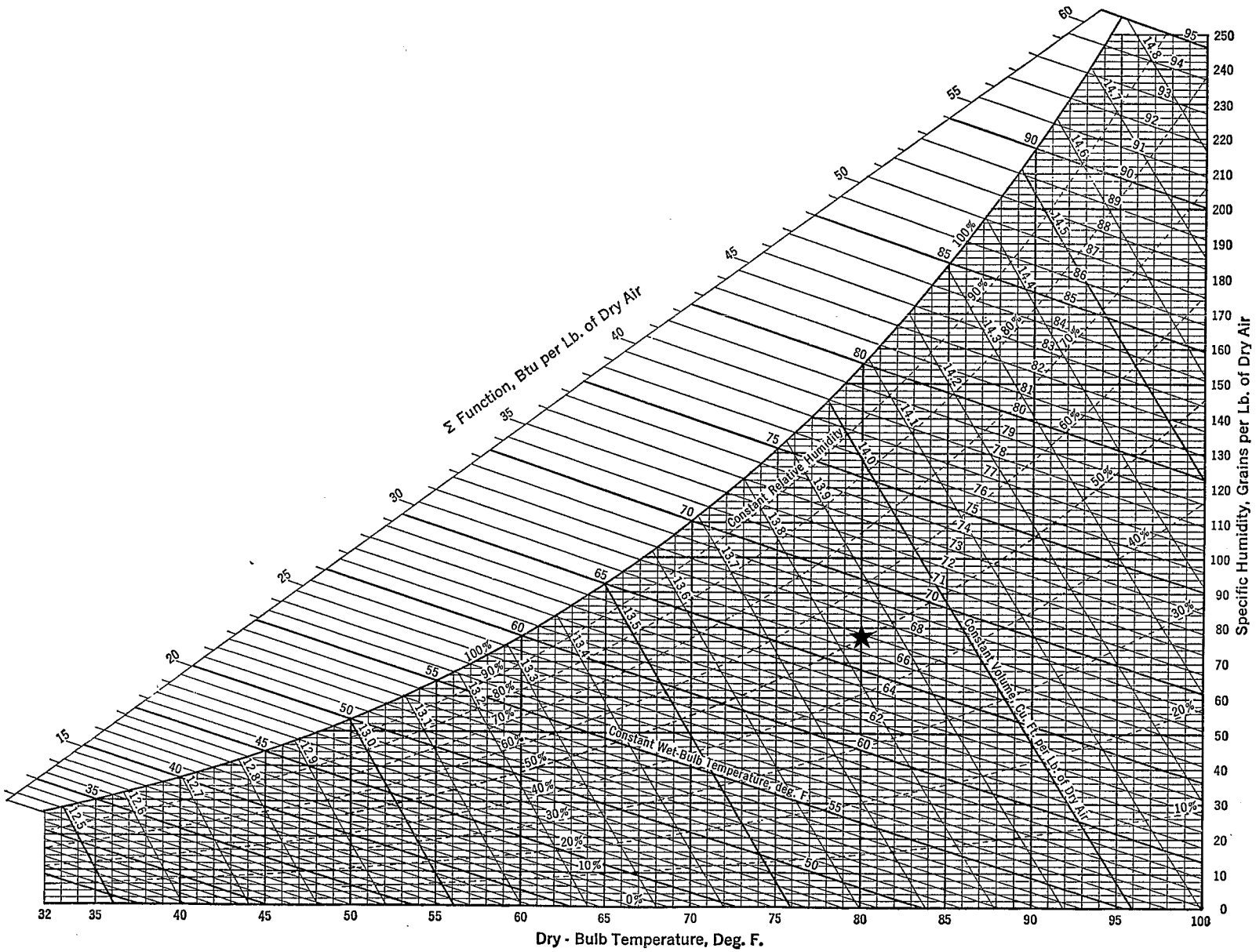
$$= 0.7\ (67) + 0.2\ (89.5) + 0.1\ (80)$$

$$= 72.8°F$$

This WBGT is then adjusted [+2.5°C (4.5°F)] for PPE Level 2. Using Figure 4 with the adjusted WBGT (77.3°F) and the metabolic work rate (250 kcal/hr), one estimates the work/rest cycle as 60 minutes of work per hour or no rest period required.

7.4.4.5 Relevance to OPP. This procedure will estimate the work/rest cycle that is appropriate for pesticide handlers wearing PPE when environmental conditions may lead to heat stress. If the work/rest cycle required is very restrictive, then the use of the pesticide may be impractical. The interpretation of the significance of the reduction in acceptable work time is somewhat subjective and must be compared to the potential benefits of using the pesticide. For example, if the cost of nighttime work is not prohibitive considering the savings relative to lost crops, then the limitation in work time is acceptable. If the savings from using the pesticide are small or the pesticide cannot reasonably be applied at night, then its use would not be justified. In regulatory actions, if severely limited work/rest cycles are predicted by this method, then the manufacturers of the pesticide should be required to justify its use based on the limitation.

Figure 5. Psychrometric chart.



Source: Ellenwood, F.O. and C.O. Mackey. Thermodynamic Charts, 2nd Ed. John Wiley & Sons, NY, 1944.

7.5 Summary

PPE that is worn to reduce dermal exposure to pesticides handlers can potentially contribute to thermal discomfort or heat stress illness to the wearer. Whether significant thermal discomfort or heat illness actually occurs is a function of many factors, including anthropological make-up (e.g., age, physical fitness, height, weight), heat acclimatization, level of hydration, number and duration of tasks performed, and environmental factors (temperature, humidity, wind, precipitation, and solar load), as well as the effects of PPE on the wearer's ability to eliminate excess heat.

The problem of predicting the combinations of factors that result in worker heat stress has been studied by many groups, particularly the military and the nuclear power industry. These studies have resulted in a wide variety of measures for predicting when the potential for heat stress may limit worker performance. For OPP's purposes, the NIOSH WBGT approach was selected and adapted because it has been widely accepted and because it is relatively simple to apply. The use of the procedure described in this section will provide estimates of acceptable work/rest cycles which can be used as an indicator of whether the use of a pesticide might be limited due to the danger of heat stress to workers.

References

[1] U.S. Environmental Protection Agency. Standard Operating Safety Guides. Office of Emergency and Remedial Response, Hazardous Response Support Division, Edison, NJ, November 1984.

[2] Gibbons, D.B. Personal Protection for Workers from Pesticide Exposure. Paper presented at the American Industrial Hygiene Conference, Dallas, TX, May 18–23, 1986.

[3] California Department of Food and Agriculture. Current Pesticide Worker Safety Regulations from Title 3, Food and Agriculture, Chapter 6, Pesticides and Control Operations, Group 3 of the California Administrative Code. Sacramento, CA, September 16, 1986.

[4] Lawrence, W.T. and C. Mond. An Analysis of Heat Stress Models for Agricultural Pesticide Operations. Draft Report. Work Assignment 2–130, EPA Contract No. 68–03–3293, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, OH, May 1988.

[5] National Institute for Occupational Safety and Health. Criteria for a Recommended Standard . . . Occupational Exposure to Hot Environments. U.S. Department for Health and Human Services. DHHS(NIOSH) Publ. No. 86–113, 1986.

[6] Goldman, R.F. Heat Stress in Industrial Protective Encapsulating Garments, in *Protecting Personnel at Hazardous Waste Sites*, Levine and Martin, Eds., Butterworth Publishers, Stoneham, MA, pp. 215–266, 1985.

[7] Passmore, R. and J.V.G.A. Durnin. Energy, Work, and Leisure. Heinemann, London, 1967.

[8] Ramsey, J.D. Abbreviated Guidelines for Heat Stress Exposure. Am. Ind. Hyg. Assoc. J., June 1978.

[9] ISO/TC 159. ISO 7243: Hot Environments – Estimation of Heat Stress on Working Man, based on WBGT Index, 1982-09-01, Ref. No. 1S0–7243–1982.

[10] American Society for Testing and Materials. Standard Method D1518—Thermal Transmittance of Textile Fabrics and Batting between Guarded Hot Plate and Cool Atmosphere. ASTM, Philadelphia, 1977.

[11] Jones, B.W. Evaluation of the Thermal Properties of Fabrics for Use in Clothing Worn by People Applying Pesticides. Technical Report 88-06 submitted to Arthur D. Little, Inc., EPA Contract No. 68-03-3293, August 1988.

[12] Jones, B.W. and E.A. McCullough. Computer Modeling for Estimation of Clothing Insulation. CLIMA 2000, Copenhagen, Denmark, August 25–30, 1985.

[13] McCullough, E.A., R.H. Rohles, and S.A. Knoz. Measuring the Thermal Insulation and Permeability of Protective Clothing Using a Copper Manikin. Proceedings of the 1983 International Conference on Protective Clothing Systems, Stockholm, Sweden, pp. 205–214, August 23–27, 1983.

[14] American Society for Testing and Materials. Standard Test F1291–90—Method for Measuring the Thermal Insulation of Clothing Using a Heated Manikin. ASTM, Philadelphia, PA, 1990.

[15] Frievalds, A. Development of an Intelligent Knowledge Base for Heat Stress Evaluation. Inter. J. Ind. Ergonom., **2**, pp. 27–35, 1987.

[16] Pandolf, K., L. Stroschein, L. Drolet, R. Gonzalez, and M. Sawka. Prediction Modeling of Physiological Responses and Human Performance in the Heat. Computers in Biology and Medicine, **16**, 5, pp. 319–325, 1986.

[17] Kamon, E. and C. Ryan. Effective Heat Strain Index Using Pocket Computer. Am. Ind. Hyg. Assoc. J., August 1981.

[18] Gagge, A.P., A.P. Fobelets, and L.G. Berglund. Standard Predictive Index of Human Response to the Thermal Environment. ASHRAE Trans., **92**, Part 2, pp. 709–731, 1986.

[19] Haslam, R.A. and K.C. Parsons. A Comparison of Models for Predicting Human Response to Hot and Cold Environments. Ergonomics, **30**, 11, pp. 1599–1614, 1987.

[20] Kwon, Y.G. and J.D. Ramsey. Evaluation of Impermeable Protective Garments Using Heat Transfer Models. Proceedings of the Human Factors Society, 30th Annual Meeting, 1986.

[21] Subcommittee 5 – Ergonomics of the Physical Environment. Draft Standard: 150/DP7933 – Analytical Determination of Thermal Stress. Working Group – Thermal Environments.

[22] Wissler, E.H. Simulation of Fluid-Cooled or Heated Garments that Allow Man to Function in Hostile Environments. Chem. Engr. Sci., **41**, 6, pp. 1689–1698, 1986.

[23] Wissler, E.H. Modelling of Human Performance in Hyperbaric Environments. ASHRAE Trans., **94**, Part 1, 1988.

[24] Wissler, E.H. Mathematical Simulation of Human Thermal Behavior Using Whole Body Models. *Heat Transfer in Medicine and Biology.* Plenum Press, NY, 1985.

[25] Stolwijk, J.A.J. and J.D. Hardy. Control of Body Temperature. *Handbook of Physiology,* pp. 45–67, 1976.

[26] Breckenridge, J.R., and R.F. Goldman. Human Solar Heat Load, ASHRAE No. 2218 Semiannual Meeting, New Orleans, LA, January 23–27, 1972. pp. 110–119.

[27] Breckenridge, J.R., and R.F. Goldman. Effect of Clothing on Bodily Resistance Against Meteorological Stimuli. In: Progress in Biometeorology, Vol. 1, Part II. S. Watrom and Janneke J. Bouma, Eds. Lesse The Netherlands: Swets and Zeitlinger, 1977. pp. 194–208.

[28] Roller, W.L., and R.F. Goldman. Estimation of Solar Radiation Environment. Int. J. Biometeor., 2(3): 329–336, 1967.

[29] Breckenridge, J.R., and R.F. Goldman. Solar Heat Load in Man. Journal of Applied Physiology, 3(5): 659–664, November 1971.

[30] Givoni, R., and R.F. Goldman. Predicting Rectal Temperature Response to Work, Environment, and Clothing. Journal of Applied Physiology, 32(6): 812–822, June 1982.

[31] Givoni, R., and R.F. Goldman. Predicting Heart Rate Response to Work, Environment, and Clothing. Journal of Applied Physiology, 32(2): 201–204, February 1973.

[32] Givoni, B., and R.F. Goldman. Predicting Effects of Heat Acclimatization on Heart Rate and Rectal Temperature. Journal of Applied Physiology, 35(6): 875–879, December 1973.

[33] Shapiro, Y., K.B. Pandolf, and R.F. Goldman. Predicting Sweat Loss Response to Exercise, Environment, and Clothing. European Journal of Applied Physiology and Occupational Physiology, 48: 83–96, 1982.

[34] Pandolf, K.B., and R.F. Goldman. Convergence of Skin and Rectal Temperature as a Criterion for Heat Tolerance. Aviation, Space, and Environmental Medicine, September 1978. pp. 1095–1100.

[35] Goldman, R.F. Prediction of Human Heat Tolerance. Environmental Stress. Academic Press, 1978. pp. 53–69.

[36] Goldman, R.F. Prediction of Heat Strain, Revisited 1979–180. In: Proceedings of a NIOSH Workshop On Recommended Heat Stress Standards, National Institute for Occupational Safety and Health, F.N. Dukes-Dobos and A. Henschel, eds. U.S. Department of Health and Human Services, Cincinnati, Ohio, December 1980. pp. 96–109.

[37] Goldman, R.F. Establishment of the Boundaries to Comfort by Analyzing Discomfort. In: Thermal Analysis-Human Comfort-Indoor Environments, NBS Spec. Publ. 491, GPO 1977. pp. 52–64.

[38] Goldman, R.F. Environment, Clothing and Personal Equipment, and Military Operations. In: Proceedings of 1974 Army Science Conference, Vol. I, U.S. Military Academy, West Point, NY, August 1974.

[39] Belding, H.S. and T.F. Hatch. Index for Evaluating Heat Stress in Terms of Resulting Physiological Strains. Heating, Piping, and Air Conditioning, 27, pp. 129–135, August 1985.

[40] Parker, R.D.R. and F.D. Pierce. Comparison of Heat Stress Measuring Techniques in a Steel Mill, J. Am. Ind. Hyg. Assoc., **45**, 6, pp. 405–415, 1984.

[41] Gonzalez, R.R. and L. Bergland. Prescription and Proscription of Heat Stress by Assessment of Heat Exchanger and a New Effective Temperature. Advances in Bioengineering Symposium Proceedings, Pierce Foundation and Yale University School of Medicine, pp. 181–189, 1978.

[42] Lee, D.H.K. Seventy-five Years of Searching for a Heat Index. Environmental Research, **22**, pp. 33–356, 1980.

[43] Roberts, D.L., S.H. Schuman, and D.J. Smith. Preventing Heat Related Hazards Important for Outdoor Workers. Occupational Health & Safety, **56, 6,** pp. 20–24, June 1987.

[44] Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities. Department of Health and Human Services (NIOSH) Publication No. 85–115. 1985.

[45] Rohsenow, W.M. and H.Y. Choi. *Heat, Mass, and Momentum Transfer.* Prentice Hall, Inc., Englewood Cliffs, NJ, 1961.

[46] Roller, W.L. and R.F. Goldman. Estimation of Solar Radiation Environment, Int. J. Biometeor., **2**, 3, pp. 329–336, 1967.

[47] Brenkenridge, J.R. and R.F. Goldman. Solar Heat Load in Man. J. Appl. Physiology, 3, 5, pp. 659–663, 1971.

[48] ASHRAE Handbook, 1985 Fundamentals, ASHRAE, 1791 Tullie Circle, N.E., Atlanta, GA, 1985.

[49] Paull, J.M. and F.S. Rosenthal. Heat Strain and Heat Stress for Workers Wearing Protective Suits at a Hazardous Waste Site. Am. Ind. Hyg. Assoc. J., **48**, 5, pp. 458–463, 1987.

Section 8

PPE Selection and Use

8 The Section in Brief

For many pesticide-related tasks, personal protective equipment is an essential barrier between the worker and the chemical. For reasons of productivity, economy, and worker comfort and acceptance, the goal is always to use the minimum level of PPE that is necessary to protect the wearer from the potential hazard.

To achieve this goal, the following process is recommended:

1. Define the potential threat, considering both acute and delayed adverse effects and the exposure scenario.

   Factors to consider include:
   - form of the pesticide,
   - toxicity of the pesticide,
   - degree of control the worker has over the potential exposure,
   - duration and frequency of the activity, and
   - other specific characteristics of the work task.

2. Considering the threat, decide what level of protection is needed.

   In this *Guidance Manual*, five representative levels of protection have been described. The choice of one or a combination of these PPE configurations depends on the specific situation.

3. Select appropriate PPE.

   This step includes choosing a material that will be protective in the situation and determining what is commercially available at an acceptable cost. Charts in this chapter list approximate prices of common PPE items in various materials.

4. Adjust the work regimen, if necessary.

   Items to consider include the reduced productivity associated with PPE, the potential for heat stress, and the possibility that available PPE may not provide full protection.

5. Promote worker acceptance of the PPE by instructing them about its use and importance.

   Compliance comes when workers understand the importance of PPE to their personal well-being.

6. Distribute the PPE and oversee its use.

   To be effective, the PPE that is supplied must be worn by the workers, and it must be used correctly. It is important to make sure that PPE items remain free of tears, punctures, abraded areas, and other defects during use.

7. Maintain PPE correctly to keep it in good working order. Replace PPE periodically, even if it does not show wear.

8. Dispose of used PPE correctly or, if the PPE is reusable, decontaminate, repair, and store it so it can be reissued.

   PPE that has been damaged or torn or that has otherwise served its useful life must be disposed of. Absorbent items contaminated with small to moderate amounts of Category I or II pesticides, or with large amounts of Category III or IV pesticides, should be laundered and aerated before disposal. They may then be disposed of in the same way as triple-rinsed containers.

   When absorbent materials such as cotton or cotton/polyester coveralls are contaminated with high levels of Category I or II pesticides, they must be disposed of (not burned or buried on the farm). No attempt should be made to decontaminate such PPE, either for reuse or prior to disposal. Such items must be disposed of in the same way as unrinsed containers.

8 PPE Selection and Use

8.1 Introduction

The process of selecting and using chemical-resistant PPE encompasses multiple steps and decision points, starting with a definition of the hazard and ending with the disposal of used PPE. The process is depicted in Figure 6, which serves as the outline for this section.

Briefly, those persons responsible for the health of a pesticide handler must:

1. define the potential threat in terms of the toxicity of the pesticide to be handled and the conditions under which it will be handled (i.e., the exposure scenario).
2. on the basis of the threat, establish the level of protection that is required.
3. select items of PPE that combine to meet the requirements for the level of protection established in Step 2. The selection process must take into account the effectiveness and costs of the available clothing.
4. on the basis of the selected PPE, adjust the work regimen to take into account reduced productivity associated with the PPE, the potential for heat stress, and the possibility that the available PPE may not fully meet all the protection requirements.
5. instruct workers in the use of the PPE and its importance, as a means for promoting worker acceptance of the PPE.
6. distribute the PPE and oversee its use.
7. after its use, either dispose of the PPE by appropriate means or decontaminate, repair, store, and reissue it for another use.
8. replace PPE periodically, even though it does not show wear.

Consistent with these steps, the elements of Figure 6 are described in greater detail in the remainder of this section.

Figure 6. Selection and use of personal protective equipment

8.2 Toxicity

Pesticides vary significantly in their potentials for harming humans and their modes of action. The pesticides having the most potential for acute adverse effects are classified as Category I compounds. Less than a teaspoon of some of these compounds, if taken orally, could cause death. Other Category I compounds may be absorbed through the skin with lethal or severely debilitating consequences. Still other compounds in Category I could cause severe damage to the eyes or skin. Compounds in Category II are less toxic, i.e., higher doses are required to cause the same types of effects as relatively smaller doses of Category I compounds. Category II compounds are generally described as moderately toxic. Category III are considered slightly toxic.

The acute toxicity category of the pesticide is an important factor for the level of PPE that is required. Consideration must also be given to providing PPE for pesticides that may have delayed adverse effects. For a given pesticide handling activity, a higher level of protection would be required for a more highly toxic compound. The mode of action of the pesticide also influences the level of protection. For example, compounds that are severely corrosive to the eyes would require particular attention to the selection and use of eye protection. Compounds that are readily absorbed through the skin or are highly corrosive to the skin would require specific attention to body protection, particularly for the hands. In addition to providing dermal protection, glove use is important for compounds that have high oral toxicities since there is the possibility that pesticide handlers might put food or tobacco (chewing or smoking) into their mouths before thoroughly washing their hands.

8.3 Exposure Scenarios

As indicated in Figure 6 and outlined below, many factors combine to define the exposure scenario. In turn, the scenario combined with the toxicity of the pesticide determines the level of protection that should be used.

8.3.1 Form of the pesticide

From the perspective of defining the type of PPE that might be required, pesticides may be conveniently divided into four categories: (1) solids with little or no solubility in water; (2) solids with high solubility in water; (3) aqueous liquids and suspensions that contain no organic solvents; and (4) liquids and suspensions that contain organic solvents. Common woven and nonwoven fabrics with sufficiently small pore sizes would be expected to provide a reasonable level of protection from solids. There is concern, however, that perspiration could dissolve water soluble solids present on the outside of the fabric and that the perspiration-wet fabric would provide a route for the pesticide to contact the skin. For aqueous liquids and suspensions that contain no organic solvents or active ingredients that behave as solvents, any PPE item that is a barrier to water would be expected to provide protection. Of concern would be the integrity of the seams, interfaces, edges, and closures. Those formulations that contain active ingredients that

behave as solvents must be treated similarly to those that contain an organic solvent. It is for those pesticide formulations that contain an organic solvent that the selection process becomes complex, requiring consideration of the potential for chemical permeation and degradation as described in Section 4.

8.3.2 Degree of control

Pesticide formulations and handling situations vary in the degree of exposure that a pesticide handler can expect. For example, some solids are in the form of wettable powders. In one scenario, the pesticide handler might be required to open and pour a bag of such a powder into a mixing tank containing water. Depending on the wind, the rate of pouring, and size and shape of the tank into which the powder is poured, the worker may be exposed to a cloud of the powder. Alternatively, that same powder might be available in a water-soluble bag. In this case, the bag does not have to be opened and can be added directly into the mixing tank; the potential for exposure is greatly reduced. Similarly, some liquid handling systems are completely closed and there is very little potential for exposure due to splashes and spills.

The level of PPE required for persons using engineering controls to reduce exposure may be significantly less than for situations in which there are multiple opportunities for worker exposure.

8.3.3 Duration and frequency

Both duration and frequency of pesticide handling and exposure affect the level of PPE that might be required. The type of PPE that might be required for a person who mixes pesticide for one $^1/_2$-hour period each morning and afternoon would differ from that for a person who is exposed to mists from airblast sprays for the entire work day. PPE should be removed when the pesticide handling activity is completed.

8.3.4 Work task

The work task is another important determinant of the level of PPE that is required for worker protection. The task largely defines the direction from which the potential exposure may occur. In some tasks the potential exposure is mostly from overhead, in others from the front, in others the back and shoulders, and in still others from below the knees. Thus, the required types of PPE for the same pesticide may vary, depending on the mode of application and the specific activity of the pesticide handler. For example, weed sprayers riding a boom may require thorough PPE coverage of the lower parts of the body, but little or no protection above the waist. Mixers may only require frontal coverage—a need that could be satisfied by a combination of gloves, sleeves, apron (or sleeved-apron), and boots, leaving the back open for the dissipation of metabolic heat.

8.4 Level of Protection

Level of protection is that combination of gloves, boots, garment, goggles, etc., that is necessary to provide protection from the potential hazard. The

goal is always to use the minimum level of PPE that is necessary. By so doing, costs, effect on productivity, and potential for heat stress are minimized, and the likelihood for worker acceptance (compliance) is increased.

In Section 6, Table 22, five levels of protection were defined. The levels were defined as a means for illustrating the range of effects that PPE might have on productivity and, subsequently in Section 7, the potential for heat stress. The five levels are also suggestive of the levels of PPE that might be worn for typical pesticide handler activities, as summarized in Table 44. Note, however, that other combinations of PPE items may be used and, in many situations, may be more appropriate than any one of the five levels. There are too many extenuating circumstances in agriculture for rigid specification of the composition of the protective ensembles.

Table 44. Association of PPE levels with pesticide handler activities

	Level of clothing*	
Activity	**Toxicity category I&II**	**Toxicity category III**
Mixing/Loading	4	1
Applying		
Airblast spraying	5	1
Boom spraying	2 or 4	1
Greenhouse	2 or 4	1
Airplane	2	1

*As defined in Section 6, Table 22.

8.5 PPE Performance

After the types of PPE components necessary for protection have been established, one must pick specific PPE items that will satisfy the requirements. The task begins by reviewing the information in Section 4 for chemical resistance and Section 3.7 for physical properties. From this information, one selects the materials of construction for the PPE items. For example, if the need is for hand protection and foot protection for >4 hours from a pesticide concentrate containing aliphatic petroleum distillates as the carrier solvent, then with reference to Table 16, nitrile might be selected as the material of construction.

8.6 Availability

After the types of PPE items and their materials of construction have been determined, sources for the PPE must be identified. This step is accomplished by reference to the appendices, as summarized in Table 45. Each appendix contains an extensive listing of commercially available PPE and is organized under the subheadings of the materials of construction. The description of each product includes its source, style number, sizes, and other

key features of importance to the purchasing decision. These features have been described in Sections 3 and 5, respectively, for clothing and eye/face protection.

Table 45. Product appendices

Appendix	Product type
A	Gloves
B	Sleeves
C	Boots and overshoes
D	Hats
E	Hoods
F	Aprons
G	Sleeved-aprons
H	Garments, nonwoven and microporous fabric
I	Garments, coated- or laminated fabric
P	Cover goggle, indirect ventilation
Q	Cover goggle, no ventilation
R	Cup goggle, indirect ventilation
S	Faceshields

8.7 Cost

An individual item of PPE may pass through several vendors between its point of manufacture and the point of sale to the person responsible for the health and safety of a pesticide handler. Along the chain, there is an opportunity for mark-ups and discounts; the magnitudes of which are highly dependent on the volume of the purchase and the market conditions. Vendors and distributors are constantly changing prices in order to reflect changing raw materials, labor costs, and competition. For all these reasons, item-by-item price information is not included in this document.

Cost information, nevertheless, is critical to any purchase decision. As a guide, typical price ranges for many of the products described in earlier sections of this document are summarized in Tables 46 through 51. The information in these tables should be used for guidance only, actual prices could be higher or lower by factors of two, three, or more. It is often the case that products having essentially the same catalogue descriptions vary significantly in quality, composition, and price. The price ranges may not be representative of the average. The price estimates are based on information gleaned from price sheets and catalogues available in the authors' files at the time this document was generated. For some products, there was only one source for the prices.

Table 46. Approximate prices for chemical-resistant gloves

Glove type (unsupported)	Approximate price/pair*
Butyl rubber	$12 (13 mil); $28–32 (32 mil)
Natural rubber	$1–1.5 (depending on thickness)
Neoprene	$4–5 (17 mil); $7–20 (> 22 mil)
Neoprene + natural rubber blend	$1.5–2.5
Neoprene/natural rubber	$4
Nitrile rubber	$2 (15 mil); $6–8 (22 mil)
Nitrile + PVC blend	$4–5
Nitrile/natural rubber	$3
Polyethylene	$0.04
Polyvinyl chloride (PVC)	$1–1.5
Silver Shield® and 4H®	$3
Viton®	$30–45 (10 mil); $50–100 (14 mil)

*based on smallest quantity purchase. Price/pair decreases for large quantity purchases. In general, prices are for 14–20 mil thick gloves. Prices vary among brands. Final price to ultimate user will depend also on the mark-ups taken through the distribution chain.

Table 47. Approximate prices for chemical-resistant sleeves

Sleeve type	Approximate price/pair*
Chemrel®	$6
Neoprene	$3.5
Neoprene-Nylon-Neoprene	$20
Nitrile	$5
Nitrile-Fabric-Nitrile	$7
Polyethylene	$2
Polyethylene-Tyvek®	$1.5–3
Polyvinyl Chloride	$1.5–3
Rubber (SBR?)-Fabric	$5
Saranex®-Tyvek	$3–4
Silver Shield®	$8
Tyvek	$1–2

*based on smallest quantity purchase. Price/pair decreases for large quantity purchases. Prices vary among brands. Final price to ultimate user will depend also on the mark-ups taken through the distribution chain.

Table 48. Approximate prices for chemical-resistant aprons

Apron type	Approximate price*
Chemrel®	$10
Neoprene	$7
Neoprene-Nylon-Neoprene	$13–16
Neoprene, sleeved	$35
Nitrile	$5–15
Polyethylene	$0.5
Polyethylene-Polyester	$2
Polyethylene-Tyvek®	$1.5–2
Polyvinylchloride	$3–5
Polyvinylchloride-Nylon	$7
Polyvinylchloride-Polyester	$12
Polyvinylchloride, sleeved	$10–13
Silver Shield®	$11
Saranex®-Tyvek	$2.5–3.5
Styrenebutadiene-Cotton	$15
Tyvek	$1
Tyvek, sleeved	$3

*based on smallest quantity purchase. Price decreases for large quantity purchases. Prices vary among brands, depending on quality of fabrics, type of seam, and type of end finish. Final price to the ultimate user will depend also on the mark-ups taken through the distribution chain.

Table 49. Approximate prices for jackets, pants, and coveralls

Garment type	Approximate price*
Tyvek®, coverall	$2.5–4.5
Tyvek, coverall with attached hood and booties	$4–6
PVC coverall, rainsuit	$5–12
Polyvinylchloride- or Polyurethane- or Neoprene-coated fabric, jacket	$15–40, depending on thickness of coating, type of seams, whether coated on one or both sides. In general, PVC items cost less than Polyurethane items and Neoprene items, which are the most expensive.
Polyvinylchloride- or Polyurethane- or Neoprene-coated fabric, pants or bib pants	$15–40, depending on thickness of coating, type of seams, whether coated on one or both sides. In general, PVC items cost less than Polyurethane items and Neoprene items, which are the most expensive.
Butyl-Nylon, jacket	$80–90
Butyl-Nylon, bib pants	$70–80
Butyl-Nylon, coverall	$120–140
Polyethylene-Tyvek, coverall	$8–11
Saranex®-Tyvek, coverall	$15–18
Barricade®, coverall	$30–40
Chemrel®, coverall	$40–50
Responder®, coverall	$60–70

*based on smallest quantity purchase. Price decreases for large quantity purchases. Prices vary among brands, depending on quality of fabrics, type of seam, and type of end finish. Final price to the ultimate user will depend also on the mark-ups taken through the distribution chain.

Table 50. Approximate prices for head protection

Head protection type	Approximate price*
Hoods	
Tyvek®	$0.60–0.80
Tyvek with snap at chin	$2
Saranex®-Tyvek, elasticized	$1.5–3
KleenGuard®, elasticized	$1
Butyl-Nylon, for jacket	$15
PVC-Nylon, for jacket	$5
Neoprene/PVC	$13
Neoprene-Nylon-Neoprene	$8–10
Polyethylene-Tyvek	$1.5–2
Hats	
PVC-Nylon-PVC, Sou'wester	$10–15

*based on smallest quantity purchase. Price decreases for large quantity purchases. Prices vary among brands, depending on quality of fabrics, type of seam, and type of end finish. Final price to the ultimate user will depend also on the mark-ups taken through the distribution chain.

Table 51. Approximate prices for chemical-resistant footwear

Footwear type and height	Approximate price/pair*
Boots	
Polyvinylchloride, 16"	$12–16
Polyurethane + natural rubber, 12"	$16–20
Natural rubber, 6"	$25–30
Natural rubber, 12"	$30–35
Natural rubber, 16"	$35–45
Natural rubber with steel toes and metatarsal	$55–75
Shoecovers	
Tyvek®	$1–1.5
Polyethylene-Tyvek	$2–3
Saranex®-Tyvek	$5
Chemrel®	$7
Kleenguard®	$1
Polyvinylchloride	$2–5
Natural rubber, 16"	$15–20
Natural rubber, 10"	

*based on smallest quantity purchase. Price decreases for large quantity purchases. Prices vary among brands, depending on quality and thickness of material, type of sole, and type of lining. Final price to the ultimate user will depend also on the mark-ups taken through the distribution chain.

8.8 Impact on Productivity

8.8.1 Job function

The effect of PPE on task performance and, therefore, productivity was discussed extensively in Section 6. In virtually all cases (with the possible exception of eye protection), the use of PPE will increase the time needed to complete a task. Certain PPE, furthermore, may preclude the performance of certain tasks. For example, the glove that provides chemical protection for >4 hours may reduce dexterity to a point where the worker cannot repair a clogged nozzle. For situations such as this, the preferred glove may be one that provides protection for considerably shorter times but has less negative effect on dexterity. Protection would be obtained by replacing the glove more frequently.

The negative effect of PPE on worker productivity combined with its recurring costs are leading many persons to pursue engineering controls and other alternatives to PPE as the route to worker protection.

8.8.2 Heat stress

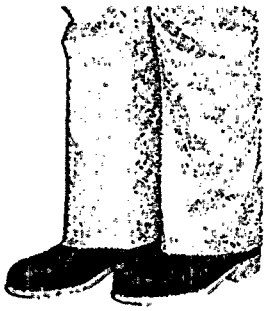
Similar to functional impacts, all PPE (with the possible exceptions of gloves and eye and face protection) to a greater or lesser extent increases the potential for heat stress when working in warm environments. This subject was discussed extensively in Section 7. As higher levels of PPE are prescribed, persons in positions of responsibility must consider the potential for heat stress. If the potential is significant, the expectations for worker productivity must be reduced. Humans simply cannot work as long or as hard under conditions in which the body is hindered (by PPE) in its attempt to maintain thermal balance. Under some environmental conditions, certain activities cannot be performed without jeopardizing the health of the worker unless auxiliary cooling is provided to the worker.

8.9 Worker Training and Compliance

To be effective, PPE must be used and maintained properly. Training is required. A myriad of federal and state programs are in place and being planned to promote the correct use of PPE by pesticide handlers. Compliance comes when workers understand the importance of the clothing to their personal well-being and that of persons with whom they may come into contact. For example, workers need to know why they should wear gloves, that there are major performance differences between glove types, that one glove does not work in all applications, that gloves must be decontaminated on at least a daily basis, and that a glove with a hole in it may be worse than no glove. Pesticide that reaches the inside of a glove does not readily evaporate and, thus, is available for skin exposure during the entire time that the glove is worn. Compliance also results when supervisors monitor and encourage the *proper* use of PPE as an essential element of the work routine.

8.10 PPE Use

PPE use begins the moment the worker inspects the item for defects prior to donning it. It ends when the item has been safely doffed and made ready for thorough decontamination or disposal without transferring contamination to other persons and things. As introduced in Section 8.9, proper use between these two points in the process requires training, monitoring, and encouragement.



Pant legs should be worn outside boots to avoid spills running into boots.

Garment closures must be kept closed. Sleeves must be kept rolled down, and the integrity of the glove-sleeve and other interfaces maintained. PPE that becomes damaged must be replaced. PPE that becomes severely contaminated must be doffed immediately. Pant legs must be kept on the outside of the boots. Aprons must be kept tied and in place. Goggles and faceshields must be kept in position, not pushed up on the head or hung around the neck.

Once clothing has been used for handling pesticides, it should never be used for any other activity. To do so would risk transferring contamination to other persons, animals, and things outside of the pesticides handling environment.

8.11 Decontamination

The decontamination of PPE is discussed extensively in Section 9. The subject is complex; there are many unanswered questions and there are many situation-specific considerations. Again education and training are the keys here.

8.12 Maintenance and Storage

To be effective, personal protective equipment must be free of tears, punctures, abraded areas, and other defects. All closures (e.g., zippers, drawstrings, etc.) must be functional. To ensure that these conditions exist, the PPE should be inspected before, during, and after each use. If defects are found before the PPE is used, the PPE should be returned to the point of purchase, repaired, or discarded. If a defect develops during the use, the PPE should be doffed and replaced as soon as safely possible. Damaged PPE should then be repaired or discarded. Similarly, if the defect is found after use, the PPE should be repaired or discarded. In practice, it is very difficult to repair an item of PPE that incorporates continuous films of plastic or rubber to the extent necessary to return its barrier effectiveness to its intended, as-new level. *Taping over punctures, tears, etc. is unacceptable.* The tape may be dissolved by the carrier solvents present in many pesticides formulations, may not produce a leak-proof seal, or may not have sufficient strength to prevent propagation of the tear or puncture.

Used PPE should be stored in well-ventilated, dry, shaded buildings, shelters, or outdoor areas, and certainly not in or near the living quarters. Sunlight and moisture degrade many plastic and rubber materials. PPE should be stored in an area separate from street clothing. There is always a possibility that the decontamination process did not remove all of the pesticide. Outdoor air should be circulated through the storage area. Since PPE performance is strongly dependent on its materials of construction, care should be taken to store it in a manner that items that look alike but are of dissimilar materials are kept separate in order to reduce the likelihood of using an inappropriate item of PPE. For example, black neoprene gloves should be not be mixed with black PVC gloves.

8.13 Disposal

PPE that has become severely contaminated, damaged, worn or otherwise served its useful life must eventually be discarded. There are various alternatives for disposal; selection of the most appropriate will be largely determined by the degree to which the item of PPE is contaminated and the toxicity of the pesticide. First and foremost, any PPE that has been used, even once, for handling pesticides must never be returned to general wear, resold, or given away (donated). The clothing should always be presumed to contain some residual level of pesticide.

Disposal of PPE that is known or suspected to be contaminated with pesticide is more problematic. Absorbent materials, such as cotton or cotton polyester coveralls, that are contaminated with high levels of Category I or II pesticides should be disposed of by the same procedures as are used for unrinsed containers. No attempt should be made to decontaminate such PPE for reuse. Absorbent garments that are contaminated with small to moderate amounts of Category I or II or with larger amounts of Category III or IV pesticides should be laundered and aerated prior to disposal. Once correctly laundered, these garments may be disposed of as the equivalent of a triple-rinsed container. **Contaminated clothing should not be burned or buried on the farm.**

Section 9

Decontamination/ Laundering

9 The Section in Brief

The degree of difficulty of removing pesticides from PPE items depends on the chemicals and the PPE materials and whether the pesticide is on the surface or has been trapped or absorbed by the PPE.

Location of Contaminants

The location of contaminants on or within the PPE item depends on several factors, including:

- the form of the pesticide when it contacted the PPE (gas, liquid, solid),
- if a liquid or gas, the specific interaction of the contaminant with the PPE materials,
- the temperature, and
- duration of contact.

Timeliness

One of the most important guidelines for decontamination is to do it as soon as possible. As the elapsed time between pesticide contact and decontamination/laundering increases, absorption increases and decontamination becomes more difficult. Conventional wisdom is that PPE should be decontaminated daily.

Laundering

Although it is not 100 percent effective, laundering with detergent and water is the preferred, practical route to decontamination. The variations among contaminants and laundering conditions make generalized recommendations difficult, but the following are generally accepted as essential elements of effective laundering:

Air
Hang garments outdoors to air

Prerinse
Use one of three methods:
- Hose off garments outdoors
- Rinse in separate tub or pail
- Agitate in automatic washer

Pretreat (heavily contaminated or heavily soiled items)
Use heavy-duty liquid detergent or a prewash product

Washer Load
Wash garments separately from family wash
Wash garments contaminated with the same pesticide together

Load Size
Wash only a few garments at a time

Water Level
Use full water level

Water Temperature
Use hot water, 140°F or higher

Wash Cycle
Use normal 12-minute cycle

Laundry Detergent
Use a heavy-duty detergent
Use amount recommended on package, or more for heavy soil/hard water

Rinse
Use two full, warm rinses

Dry
Line dry (to avoid contaminating dryer)

Clean Washer
Run empty washer through complete cycle, using hot water and detergent

9 Decontamination/ Laundering

9.1 Background

Work clothing and other PPE that come into contact with pesticides become contaminated with them. A contaminated item is a potential hazard to the worker and to others who may handle it. The item is also a vehicle for transfer of the contamination to other items and areas. To reduce or eliminate the hazard, decontamination of such items is often specified and attempted. Decontamination is the removal of an unwanted chemical from garments or gear, rendering it safe for doffing, storage, reuse, disposal, or some other postuse action.

Worker safety does not always require 100% removal of the contaminant. For example, the removal of gross amounts of contaminant may be all that is necessary to safely doff and dispose of a clothing item. In deciding to decontaminate PPE, one must consider the cost and whether the decontamination process might exacerbate the hazard.

The contaminant of prime concern is usually the active ingredient(s) of the pesticide formulation. Other components of the formulation, however, may also represent health hazards or affect the extent to which the item is contaminated or the difficulty of decontamination. The materials of construction of the item also affect the extent of contamination and the ease of decontamination.

Contaminants may be present on the surface of the item, trapped in interstices of fibers, or molecularly absorbed into the matrix of PPE. The location of the contaminant significantly affects the ease with and extent to which an item can be decontaminated. Contaminant location is dependent on several factors including:

- the form of the pesticide when it contacted the PPE (i.e., gas, liquid, solid)
- if a liquid or gas, the specific interaction of the contaminant with the materials of construction of the PPE
- the temperature
- duration of contact

Garments and other PPE vary widely in form and materials of construction. (See Sections 3, 4, and 5.) Briefly, garments are usually either woven or knit

fabrics of natural (e.g., cotton and wool) and synthetic (e.g., nylon, rayon, and polyester) fibers, or nonwoven fabrics based on synthetic fibers (e.g., polyethylene and polypropylene). Blends of cotton/polyester are durable, easy to care for, and are common. Some fibers are treated with stain-, soil-, or water-repellents. In some cases, the fabrics are coated with a nonporous, rubber or plastic film. Nonporous, rubber or plastic films, sheets, and coatings are the basis for most chemical-resistant clothing. Scores of different compositions of plastic and rubber are used. Many other items of protective equipment are made from molded plastic and rubber. All forms of PPE may contain topographical irregularities and voids that can entrap contaminants on both micro- and macro-scopic scales.

In agriculture, water and detergent/water solutions are the conventional, active means for removing contaminants from clothing. These solutions can be used in work areas where pesticides are handled or outside of this work environment. When used outside the work environment, standard home laundry procedures and equipment are frequently used. Contaminants are also removed by aeration. Dry cleaning and other available means for decontamination are not widely used in agriculture.

If one considers the tens of thousands of pesticide formulations, hundreds of different materials of construction of protective equipment, and the limitless number of potential exposure conditions, one realizes that decontamination rules for each instance of contamination are not practical. Useful generalizations, however, can be generated based on an understanding of some fundamental principles. These principles are discussed in this section.

9.2 Forms of Contamination

Contamination occurs when a chemical contacts and remains with the PPE. The chemical may stick to the surface; become entrapped in fiber interstices, pores, folds, and corners; adsorb to surfaces; or be absorbed into the molecular structure (i.e., matrix) of the item. The applicable mechanism(s) is dependent on the specific interaction between the formulation and materials of construction of the PPE item. These interactions may differ for the concentrate, the field strength form of the pesticide, and the pesticide residue after carriers and water evaporate.

Pesticide mixers typically encounter pesticides in their concentrated forms, e.g., emulsifiable concentrates, wettable powders, and encapsulated pellets. In many cases, the mixer dilutes the concentrate with water. Most concentrates contain other ingredients that serve as carriers, diluents, surface active agents (surfactants), fillers, and "stickers." Gaseous agents may be diluted with inert gases.

The loader, who may also be the mixer and/or the applicator, transfers the field strength pesticide from the mixing tanks to the application containers. The loader's most likely potential exposure is to field strength pesticides.

Applicators, by definition, apply field strength pesticide. Pesticides are applied in the form of smokes, mists, fogs, aerosols, vapors, liquids, dusts, and granules. Thus, PPE can come into contact with solids, liquids, and gases. Once applied, the pesticide may remain in its original form, evaporate, dissolve, dry to form powders or dusts, degrade, and so forth.

9.2.1 Pesticides applied in the form of solids

Pesticides handled as dusts, powders, granules, and other solid forms are potential contaminants of surfaces, fiber interstices, and other points of physical entrapment. On porous surfaces and fabrics, solids can work their way into the interstices where they become mechanically trapped. Entrapment may occur in two places: between yarns or filaments and between the fibers making up each yarn. Unless dissolved by perspiration or another moisture source or the solid has a high vapor pressure, these contaminants are not likely to diffuse into the molecular structure of the PPE materials. Entrapment can also occur in seams, closures (e.g., zippers), folds, corners, and interfaces between PPE components.

9.2.2 Pesticides applied in the form of liquids

9.2.2.1 Solutions. Some inorganic and organic pesticides are soluble in water and are applied as true aqueous solutions (i.e., a single-phase liquid); other pesticides are applied as neat liquid or as a solution in an organic liquid carrier. Generally, water-soluble substances will be sorbed readily into garments made with hydrophilic fibers or components (e.g., rayon, cotton, and other natural fibers). Most rubber or plastic items absorb little or no inorganic compounds from aqueous solutions. Items based on synthetic polymers, however, are likely to absorb neat organic liquids or chemicals contained in organic liquid carriers.

9.2.2.2 Aqueous emulsions and suspensions. The active ingredients of most pesticides are organic liquids or solids that have little or no solubility in water. These compounds, aided by surfactants and other components of the formulation, may be adsorbed by or become trapped in the interstices of hydrophilic fiber structures. They have even been observed in the lumen of cotton fibers.[1] In addition, they may be absorbed by hydrophobic materials (e.g., polyolefin fabrics, plastic eye and face protectors, and rubber gloves and boots). The amount of contaminant absorption increases with increased residence time on the item, temperature, and concentration of the contaminant. Absorption may be exacerbated by other components of the formulation. Oils, hydrocarbons, and other organic carrier solvents in emulsifiable concentrates are examples of components that can promote the absorption process. Solvents and surfactants by their nature and presence are intended to aid penetration, wetting, and sticking.

Contaminants that diffuse into (i.e., absorb) the molecular network of the item can be very difficult to remove, as compared to those that remain on the surface or are entrapped in pores, folds, and interstices. Absorption of chemicals by rubber and plastics was discussed in Section 4. Briefly, the amount and rate of absorption depends on the specific interactions of the chemicals in the formulation with the material of construction of the PPE; absorption increases with increasing temperature.

The degree of difficulty of removing an absorbed contaminant is exemplified in Paragraphs 9.2.3 and 9.3.3.

Similar to solutions, multiphase liquids may dry, leaving contaminant residues on the surface and within the pores, folds, and interstices of the item.

9.2.3 Pesticides applied as gases

Gases may be absorbed or adsorbed depending on the specific interaction of the gas with the materials of the protective gear.

Even volatile gases that are absorbed can be difficult to remove as exemplified by ethylene oxide (ETO). ETO is widely used for medical clothing and devices sterilization, in industrial sterilization, and for agricultural fumigation and sterilization. Washing does not remove all of the ETO from a thoroughly permeated garment. For polymers and rubbers sterilized with ETO, long aeration times are required for the slow, diffusive evaporation of ETO. The FDA tested ETO-sterilized, polymeric, intraocular lenses and found that, in some cases, more than 105 days (with aeration at 90°F and with 10 air exchanges per hour) were required to reduce the ETO to the 25-ppm limit recommended by FDA.[2] For several polymeric materials, the ETO content remained above levels considered safe, even after 15 days of aeration.[3] In the hospital, ETO-sterilized garments and materials require aeration periods ranging from days to weeks before they are returned to service.[4]

9.3 Decontamination Processes

Decontamination is the removal of an unwanted chemical from PPE rendering it safe for doffing, reuse, disposal, or some other postdecontamination action. In practice, total removal of the contaminant is rare. Although the residues may be so low as to be inconsequential, uncertainty about the residue level is a continuing problem.

The decontamination processes discussed in this section are:

- Laundering
- Dry cleaning
- Aeration
- Chemical treatments
- Use of sorbents

Under each heading, the discussion is subdivided according to the materials of construction of the PPE: cotton and cotton/polyester fabrics, polyolefin fabrics, and nonporous plastic and rubber items.

The discussions on laundry and dry cleaning are based principally on information gathered from two important, recent review publications:

- "Limiting Pesticide Exposure Through Textile Cleaning Procedures," C.N. Nelson and J.R. Fleeker, Eds., North Central Cooperative Series #314, North Dakota State University at Fargo, March 1988.[5]

- "Cleaning Protective Apparel to Reduce Pesticide Exposure," J. Laughlin and R.E. Gold, in *Reviews of Environmental Contamination and Toxicology*, vol. 101, pp 93-119, Springer-Verlag Inc., New York, 1988.[6]

In many cases, this discussion uses verbatim quotes from one or the other of these publications. These quotes, along with the names of the original researchers, are indicated by italics. Both of these publications are supported by extensive reference and bibliographical sections.

9.3.1 Laundering

9.3.1.1 Introduction. Although simple in concept, laundering is a complex process involving chemical and physical events. Laundering relies upon a removal agent (soap, detergent, or solvent), a diluting medium (water), heat, and agitation to dissolve or suspend and remove soil or contaminant. *Detergency has been described as removal of soil by one of the following mechanisms:*

(1) lowering surface and interfacial tensions;
(2) solubilization of soil;
(3) suspension and/or emulsification of removed soil;
(4) inactivation of water hardness; and
(5) neutralization of acid soil, particularly the saponification of fatty acids (soap formation).[7]

Effective laundering strongly depends on the nature of the interaction of the specific pesticide formulation with the materials of construction of the specific item of protective clothing or equipment. Laundering is most effective for removing of particulate and water soluble contaminants present on surfaces.

In practice, the efficiency of the laundering process is never 100%, because not all contaminant is removed and some redeposition of contaminants occurs. In addition, laundering efficiency varies across the myriad combinations of pesticides, PPE substrates, and laundering conditions. Freshly washed, perfumed, optically bright clothing may contain residual pesticide; actual cleanliness may be illusory. The degree of risk that remains with cleaned and reused garments is proportional to contaminant toxicity and retained amount.

The laundering of garments to remove agricultural pesticides has been widely studied by many land-grant institutions and much is known about the effectiveness and limitations of the process. The literature, however, contains many conflicting reports and inadequately detailed experiments, making generalizations difficult. Nevertheless, health risks can be minimized by the proper application of the information provided herein.

9.3.1.2 Cotton and cotton/polyester fabrics

9.3.1.2.1 Introduction—A general agreement exists within the technical and Cooperative Extension communities on the essential elements of effective laundering. These guidelines are presented in Figure 7.

Figure 7. Guidelines for laundering pesticide-contaminated clothing[13]

Air
Hang garments outdoors to air.

Prerinse
Use one of three methods:
- Hose off garments outdoors
- Rinse in separate tub or pail
- Agitate in automatic washer

Pretreat (heavily contaminated or heavily soiled garments)
Use heavy-duty liquid detergent or a prewash product

Washer Load
Wash garments separately from family wash
Wash garments contaminated with the same pesticide together

Load Size
Wash only a few garments at a time

Water Level
Use full water level

Water Temperature
Use hot water, 140°F or higher

Wash Cycle
Use normal 12-minute cycle

Laundry Detergent
Use a heavy-duty detergent
Use amount recommended on package or more for heavy soil/hard water
[There seems to be no advantage to using bleach or ammonia]

Rinse
Use two, full, warm rinses

Dry
Line dry (to avoid contaminating dryer)

Clean Washer
Run complete, but empty, cycle, using hot water and detergent

9.3.1.2.2 Contamination type—In general, non-oily particles (e.g., wettable powders, encapsulated formulations, and dusts) are more thoroughly removed from cotton and cotton/polyester fabrics by home laundry detergents than are oily soils. Apparently, the presence of oily substances enables the soil to wet and penetrate the fibers.

Water soluble contaminants are more readily removed than those compounds with low water solubility. Keaschall et al. concluded that water solubility of the active ingredient may be a more reliable indicator of the relative ease of removal than its chemical class.[8] This conclusion is supported by Fleeker et al. who found that carbaryl was readily removed by aqueous extraction as compared to chlorothalonil; the solubility of carbaryl in water is 100 times greater.[9]

Keaschall et al. studied 11 pesticides for three chemical classes: organophosphates, organochlorines, and carbamates. Differences in after-laundering residue were found both among chemical classes, with largest overall residue for organochlorines and smallest for carbamates, and within classes, with greatest variability for organophosphates.[8] Combinations of pesticides in one fabric were more difficult to remove than were pesticides singly applied to fabric specimens.[10]

Easley et al. reported that methyl parathion residues following laundering were directly related to the methyl parathion concentrations in the challenge liquid. For methyl parathion concentrates the residues were not reduced to safe levels even after ten launderings. Consequently, the authors recommended disposal of garments that are heavily contaminated with highly toxic concentrates.[11,12]

9.3.1.2.3 Detergent type—*The four synthetic laundry detergent components most likely to change from one branded product to another are the surfactant, builder, anti-redeposition agent, and optical brightener. The surfactant is the basic cleaning ingredient in the detergent.*

Powdered or granular detergents are typically based on anionic surfactants such as pentasodium tripolyphosphate (STPP) or tetrapotassium pyrophosphate (TKPP). Anionic surfactants are sensitive to water hardness; the harder the water, the less effective the detergent.

Nonionic surfactants, sometimes in combination with anionic surfactants, are used in heavy duty liquid detergents. The effectiveness of these detergents is less affected by water hardness and water temperature. *Easley et al. found that a nonionic heavy duty liquid detergent removed higher percentages of methyl parathion* compared with phosphate, high phosphate, and carbonate detergent powders.[2] *Olsen et al. found that heavy duty liquid detergent was less effective than either carbonate or phosphate detergent for paraquat removal.*[13] Raheel found that heavy duty liquid detergent was more effective in removing either oil-based pesticide formulation or pesticide residues from oleophilic surfaces such as durable-press (DP) finished cotton/polyester fabrics.[14]

Keaschall et al. found a prewash surfactant treatment was more effective than laundering without a prewash product in lowering the residue of 11 pesticides.[8] Several researchers have shown reduced pesticide residues after laundering when the fabric was pretreated with a dry-cleaning solvent.

There seems to be no advantage to pretreating with or using bleach or ammonia in laundering.

9.3.1.2.4 Temperature—The effect of water temperature on the effectiveness of laundering seems to depend on the pesticide and the fabric. (See page 106 of the Laughlin and Gold publication.) Contaminant residues decrease as the temperature is increased, to a certain point. *Olsen et al. observed essentially no difference between 49°C and 60°C, confirming the work of Easley et al.*[14, 11]

The NC-170 study found that hot water (60°C) and warm water (49°C) washes were equally effective in removing pesticides. Water temperatures below 30°C were ineffective.[5]

9.3.1.2.5 Water

Hardness. In any decontamination process involving use of water, the water itself may play a role in effectiveness. Water makes up 99%+ of the wash and rinse solutions of most laundries. The water hardness is of primary concern. Water pH can also be important. The concentrations in the water of calcium and magnesium ions (as well as others such as manganese and iron) determine water hardness. Hardness varies across the contiguous 48 states. Water from wells, farm pits and ponds, and remote water sources may vary considerably in hardness from those of "city water" in the same geographical region. The performance of many laundry detergents, particularly those based on anionic surfactants, decreases with increasing water hardness.

Laughlin and Gold report no degradation in the performance of an anionic detergent at hardnesses below 600 ppm. Above this level, performance could be retained by the use of a prewash treatment. Heavy-duty liquid detergents were less affected by water hardness than solid detergents. Furthermore, they found that water hardness seems to affect more negatively the effectiveness of pesticide removal from fabrics treated with soil-repellents than from unfinished fabrics.[15]

pH. The acidity or alkalinity of a solution is characterized by its pH. The pH scale runs from 1 (most acid) to 14 (most alkaline), with 7 indicating neutrality. The pH of a solution can have a significant effect on solubilization (or precipitation) of contaminating pesticide chemicals, depending on their chemical makeup. Detergent products can be formulated to produce any desired level of alkalinity dictated by requirements for the cleaning task. Since alkalinity is useful in removing acidic, fatty, and oily soils, most detergents are more effective when on the alkaline side. Ideally, the wash solution is made up using neutral water so as not to unbalance pH cleaning requirements. In practice, water is rarely neutral. Some natural waters are highly acidic, and others are becoming more and more acidic due to the acid rain phenomenon.

9.3.1.2.6 Timeliness—Unless one is willing to aerate protective gear for long times (weeks or months), decontamination is best effected as soon as possible after contact with pesticide. Early decontamination minimizes chemical absorption. As the elapsed time between pesticide exposure and laundering increases, absorption increases and effective decontamination becomes more difficult. Goodman et al. showed significantly higher methyl parathion residues for fabrics that were laundered after five days of repeated daily doses as compared to fabrics receiving the same daily dose but laundered daily.[16] Kim et al. in a study involving fonofos and alachlor concluded that "immediate washing resulted in significantly greater residue removal."[17]

Obendorf and Klemash used electron microscopy to study oily soil distribution in fibers. As the soil diffused into the fiber matrix and penetrated into the lumen and convolutions in cotton, its removal became more difficult.[18] Conventional wisdom is that clothing should be laundered daily.

9.3.1.2.7 Process—Pre-rinses, multiple wash cycles, and postwash rinse cycles can all contribute to reduced levels of residual contamination. More vigorous agitation has been shown to reduce surface contamination but to have less of an effect on contamination in the lumen and crevices of cotton.[19] As mentioned earlier, laundering is a dilution process, therefore the more cycles and volumes of water used, the lower will be the residue all else being equal.

9.3.1.2.8 Fiber and fabric effects—A tightly woven textile fabric may be more effective in excluding dusts and powders, but if contaminated, more difficult to clean. Conversely, a loosely woven fabric may not exclude impinging pesticides, but may be more easily cleaned in washing. A dense fiber network may hold liquids by capillarity within the fabric and decontamination of the interior fibers may be difficult, even with strenuous washing. Contaminants are more difficult to remove from tightly woven or crimped fabrics, which tend to trap contaminants at fiber cross-over points at depressions, respectively. Light weight fabrics are more easily thoroughly laundered; however, tightly woven fabrics seem to initially entrap less contamination.

Several studies indicate that pesticide retention was essentially the same for all cotton and cotton/polyester fabrics. (See bottom paragraph on page 99 of Laughlin and Gold publication.) *Easter reported that captan in wettable powder was more difficult to remove from cotton than from synthetic fibers, due to geometric bonding and entrapment of particles in fiber surface crevices or interstices.*[19] *Easter and DeJonge found that azinphosmethyl, made from an oil-base concentrate, was more difficult to remove from cotton than from synthetic fibers.*[20] Obendorf and Solbrig reported that whereas malathion and methyl parathion were found in the lumen of cotton, they were not found in the polyester fibers of a cotton/polyester fabric.[1]

9.3.1.2.9 Fabric finishes—Soil- and water-repellent (although not durable press) fabric finishes seem to reduce the level of contamination but make decontamination more difficult. Laughlin et al. reported that methyl parathion residues after laundering were similar for unfinished fabric, a durable-press finished fabric, and fluorocarbon soil-repellent finished fabric, but the initial contamination of the soil-repellent finished fabric was only 20% of that of the other two fabrics. The authors conclude that the soil-repellent finish promoted soil redeposition during laundering.[21]

Within the last few years, soil-release finishes have been introduced. The laundering results are not definitive, but Laughlin and Gold have concluded that an acrylic acid soil-releasing finish cannot be recommended over a fluorocarbon soil-repellent finish.[6]

Most laundering studies have shown that the effectiveness of fabric finishes in reducing pesticides penetration decreases with the number of launderings.

Starch has been suggested as a finish that facilitates the decontamination process by trapping the pesticide at the surface of the fiber. Upon laundering, the starch dissolves in water and carries away the pesticide. Obendorf et al. found that an 8% (w/w) add-on of starch reduced the area of contamination when methyl parathion was applied to polyester/cotton fabric. Starching at this level also helped remove the methyl parathion from the 65/35 polyester/cotton fabric.[22] Laughlin et al. did not observe this effect, but noted that the amount of starch add-on in their study may have been too low.[23]

9.3.2.1.10 Contamination transfer—Laughlin et al. concluded from laundry studies involving methyl parathion that "the percentages of methyl parathion transferred in laundry were minuscule; however care should be exercised in laundering of pesticide contaminated clothing in the home. Wettable powder formulations may be the most easily removed from the original fabric and most readily transferred to the clean fabric due to the particulate nature of their composition."[24]

9.3.1.3 Polyolefin fabrics. Clothing based on nonwoven, polyolefin fabrics (e.g., Tyvek and SMS) is typically thought of as single-use or disposable. This clothing, however, can be laundered and reused. Dupont, the manufacturer of Tyvek spunbonded olefin, provides guidance on launderability, suggesting detergent and conditions appropriate for both home and commercial cleaning. (See Appendix T.) In its guidance document, Dupont notes that water soluble substances can be removed but that the oleophilic nature of Tyvek allows industrial oils to soak into its fibrous structure. The removal of chemicals that are absorbed into fibers can be difficult.

In contrast to cotton and cotton/polyester fabrics, no information could be found in the literature on the removal of pesticides from polyolefin fabrics. Easter reported, however, that the removal of an oil-based pesticide was more difficult from nylon, which is another oleophilic fiber, than from denim.[20]

9.3.1.4 Rubber and plastic items.
Similar to polyolefin fabrics, there is little or no information in the literature regarding the laundering of rubber and plastic items to remove pesticide contamination. Surface decontamination of these items is typically performed by hand. The same nonionic or anionic detergents can be used with warm water. The items can be air dried. Lloyd emphasizes that plastic and rubber items should not be soaked since this procedure results in redistribution of contamination; rather, the item should be rinsed.[25]

Washing the external surface of plastic and rubber items has little or no effect on chemicals that have been absorbed by the item. Absorption occurs by a rate process, i.e., diffusion. Decontamination (desorption), therefore, is also a rate process. Desorption takes time and can be accelerated by increasing the temperature.

Plastic or rubber gloves, boots, eye/face protectors, and so forth that have become contaminated with pesticide must be reused with caution. As mentioned in the Paragraph 9.2.3, long times may be required before the contamination level is reduced to safe levels. Again to minimize absorption, one should remove the contaminant from the surface of the plastic or rubber item as soon as possible following contact and should use plastic and rubber items that absorb the least.

9.3.2 Dry cleaning
Dry cleaning is the second most widely used technique for removing soil from clothing. The main difference between dry cleaning and laundering processes is the solvent—water in laundering and nonaqueous, liquid organic solvents in dry cleaning. Common dry cleaning solvents are hydrocarbon liquids (e.g., Stoddard solvent) and halogenated hydrocarbon liquids (e.g., perchloroethylene). Surfactants are added and moisture content is controlled to yield approximately 70% RH in a dry cleaning unit. Closed-system, dry cleaning equipment is elaborate and necessitates solvent recovery and reuse. Details of the process of dry cleaning are described in Kirk-Othmer.[26]

9.3.2.1 Cotton and cotton/polyester fabrics. Dry cleaning solvents are able to wet and penetrate cotton and cotton/polyester more readily than water/detergent solutions. Furthermore, the dry cleaning solvents, which are organic liquids, generally have significantly higher capacity for organic pesticides than do the water/detergent solutions. In view of these considerations, dry cleaning would seem to be the preferred method for decontaminating work clothing of pesticides. Ringenberg et al. reported that dry cleaning was more effective in removing emulsifiable concentrate of chlorpyrifos than was a solvent-based pretreatment followed by laundering.[27]

Cost and process considerations, however, have precluded the use of dry cleaning for pesticide decontamination. Since dry cleaning solvents are recovered and reused, there is the possibility that contaminants removed from one batch could be transferred to the next batch. This was found in the NC-170 study.[5] Furthermore, the International Fabricare Institute advised

its members to avoid dry cleaning garments containing pesticides and chlorinated contaminants because of toxic residues and contaminated filter wastes.[28] Ideally the dry cleaning unit would be used only for pesticide contaminated items and the solvents renewed when a new pesticide is present. The NC-170 study concluded that there was no advantage of dry cleaning over laundering.[5]

9.3.2.2 Polyolefin fabrics. Although polyolefin fabrics are probably resistant to dry cleaning solvents and these solvents would be expected to function as vehicles for pesticide removal, no information was found in the literature on the effectiveness of dry cleaning to remove pesticide from polyolefin based fabrics.

9.3.2.3 Rubber and plastic materials. No information was found in the literature on dry cleaning as a process for removing pesticide from protective gear. Dry cleaning solvents, however, can be deleterious to plastics, rubbers, coatings, repellent finished, etc. They may extract or dissolve plasticizers, stabilizers, and additives from the item. The dissolution or extraction of soil repellent treatments and coatings could compromise the protective function of a garment. Materials may become embrittled or exhibit stress cracking. In some cases, the solvents may even dissolve materials, finishes, adhesives, sealants, etc. of the protective item.

9.3.3 Aeration

Considerations pertinent to aeration as a decontamination process apply equally across all material types and, therefore, the discussion is not divided under the headings of Cotton and Cotton/Polyester Fabrics, Polyolefin Fabrics, and Plastic and Rubber Items.

Liquid and gaseous chemicals evaporate with time. The rate of evaporation depends on the temperature, the flowrate of air over the chemical, and the vapor pressure of the chemical. At ambient temperatures, many carrier and diluent solvents in pesticide formulations would be expected to evaporate from contaminated items fairly rapidly. Oils and other liquids with low vapor pressures would not be expected to evaporate rapidly. Evaporation of absorbed chemical can only occur after that chemical has diffused to the surface of the item. The diffusion process can be rapid or very slow, depending on the specific interaction of the chemical with the material of construction of the protective item.

Aeration of contaminated garments is an option for decontamination in some instances, and is recommended by many state farm agencies before laundering. Aeration, however, has practical limitations. Fleeker et al. reported that as low as 65% but typically between 80 and 90% of the chlorothalonil and Carbaryl applied to cotton and cotton/polyester remained after 21 days aeration in flowing air at room temperature.[29]

Laughlin and Gold studied the evaporative dissipation of methyl parathion from laundered protective apparel fabrics and found that some pesticide was eliminated to air, but residual pesticide was detected even after

4032 hours.[30] Evaporation rate is a strong function of temperature. In general, except for the most volatile compounds, aeration times are impractically long at normal outdoor temperatures. For some fabrics examined, soil-repellent finish hindered evaporative dissipation of pesticide.

9.3.4 Chemical treatments

Certain pesticides can be detoxified by reaction with acids or bases. Basic solutions are used by the military as one means for decontamination/detoxification of chemical warfare agents, many of which are chemically similar to agricultural pesticides. Chemical treatment requires specific knowledge of the pesticides formulation if the proper treatment is to be selected and safely carried out.

Importantly, application of acid or base is contraindicated in some instances. It is not recommended that alkaline materials such as lye or lime be used with pyrethroids, Fenvalerate, or Pydin, since they will decompose. Acidification of lime-sulfur spray solutions may result in decomposition and release of hydrogen sulfide, a toxic gas. More generally, Lloyd states that "few pesticides appear to be degraded effectively by hydrolysis with acids and aqueous alkalies for example and there is a risk of forming more toxic derivatives in some cases on treatment with oxidizing reagents."[26]

Chemical decontamination raises concerns relative to the hazards of bringing additional chemicals onto a farm, of having persons with little or no background in chemistry using them, and of potentially generating additional, uncharacterized, potentially hazardous wastes.

9.3.4.1 Cotton and cotton/polyester fabrics. No information could be found in the literature on the effectiveness of acids or bases in the decontamination of cotton or cotton/polyester fabrics of pesticides. There is some concern about the possible degrading effects that such solutions might have on the fabrics themselves.

9.3.4.2 Polyolefin fabrics. No information could be found in the literature on the effectiveness of acids and bases in the decontamination of polyolefin fabrics. In contrast to cotton and cotton/polyester fabrics, however, acidic and basic solutions would not be expected to significantly degrade polyolefin fabrics.

9.3.4.3 Rubber and plastic items. Virtually all plastic and rubber materials used in protective gear are resistant to acidic and basic solutions. Consequently, immersion in or washing with these solutions would be an effective means for decontaminating the surfaces of protective items of pesticides that are detoxified by reaction with acids or bases. Basic solutions, for example, will detoxify many organophosphorus pesticides. Acids or bases applied to the surface, however, will have little or no effect on absorbed contaminants.

9.3.5 Sorbents

Consideration of sorbents applies equally across all material types and, therefore, the discussion is not divided under the heading of Cotton and Cotton/Polyester Fabrics, Polyolefin Fabrics, and Plastic and Rubber Items.

Adsorbent materials (e.g., clays, diatomaceous earth, chromatographic resins, charcoal, zeolites, etc.) can be used to remove surface liquid contamination and for scavenging vapors as they desorb from the contaminated items. In some situations, for example a spill, sorbents are very effective and practical. The military plans the use of sorbent powders in certain chemical warfare scenarios. Several difficulties exist, however, with the general use of sorbents for decontamination in agriculture.

Sorbents must somehow be applied to the contaminated item, and then removed and contained. For decontamination of absorbed chemicals, the sorbent must be left on the item for very long times, sufficient for the contaminant to diffuse from the item and into the sorbents. Although much of the sorbent might be removed from the garment by brushing, complete removal of the sorbent would require laundering, which begs the question—Why not wash the item with detergent in the first place?

9.4 Current Agricultural Decontamination Practices

Existing, published recommendations for decontamination are for the most part in concurrence, although they sometimes are nonspecific, instructionally different, and conflicting. Examples are reproduced in Appendices U, V, and W. In practice, the decontamination of PPE to reduce pesticide exposure represents a complex task, and one without national standards or controls. This situation seems to recognize the reality of agriculture but may compromise the safety of pesticide handlers. A survey of farm families in Iowa found that decontamination is by conventional rinse and wash-laundering using available detergents, and that the extent of laundering awareness and frequency of decontamination varied considerably.[31]

Washing (laundering) with aqueous solution containing detergent is the preferred, practical route to decontamination, inadequacies not withstanding. The procedure is familiar, relatively safe, simple, and easily conducted. (See Figure 7.) Furthermore, chemical hydrolysis, which can take place in the wash, is a major route for the dissipation of many pesticides.[32] The laundering process need only contend with any problems with dissolution, suspension, and transport of pesticide both within and without the substrate.

An organoleptic indicator of residual contamination can be useful. Most pesticides have characteristic and persistent odors. If apparel or protective item is discolored, it is likely not resistant to the pesticide. Other operating practices to minimize pesticide exposure due to contaminated items are to periodically discard any apparel used in pesticide work and to designate specific PPE for use only when applying pesticides. Lloyd states, "Until effective decontamination procedures are available for the total removal of surface and adsorbed [ed. does the author mean absorbed?] residues

of pesticides from protective gloves, boots, and garments, disposal of items grossly contaminated by pesticide concentrates must be considered. In general if more than ten percent of the surface of protective clothing, worn next to the skin, is contaminated by a toxic agent then it should be destroyed."[26]

9.5 Practical Considerations

Decontamination in an agricultural setting requires several practical considerations, as follows:

9.5.1 Water use

Since laundering is essentially a dilution and removal process, the more copious the pre- and postwash rinse, and the more times the wash-cycle is repeated, the more complete will be the decontamination. In some parts of the country, however, water is scarce. Application of water to the growing crop or animals is likely to be of more concern to the farmer than the decontamination of PPE, especially if the farmer does not recognize the potential hazards. Water may not be available to satisfy a theoretically "best" wash procedure. Farm pumps and water supplies may not be able to keep up with water demand, especially in a large operation where much or frequent washing is required.

9.5.2 Water temperature

Laundering efficiency increases with water temperature. Hot water is energy-intensive and may not be available in all circumstances. Cold water will probably be most widely used. In these cases, detergents specifically formulated for cold water applications should be used.

9.5.3 Dry cleaning

Use of organic solvents and disposal of contaminated material is a matter of current industrial and environmental concern. Obviously, dry cleaning solvents and dry cleaning process sludges contaminated with removed pesticides would constitute hazardous waste. Standards of performance for petroleum dry cleaners are found in 40 CFR Subpart JJJ, Sections 60.620. State and local ordinances pertaining to dry-cleaning and use of solvents are also in effect.

9.5.4 Waste disposal

Laundry waste is an effluent that is usually discharged to ground or surface waters. Rinse and wash water from pesticide decontamination will contain the pesticide. Farms may not be setup to handle such wastewater in a way that is safe for people and animals and environmentally acceptable. Waste disposal problems are not unique to laundering; they exist for all decontamination processes.

9.5.5 Cost

Many agricultural operations are financially marginal. Increasing use of water and energy will drive up the operational cost.

9.6 Recommendations

Alternatives for reducing the problems associated with decontamination include:

- Reduce the use of pesticides.
- Reduce the toxicity of the pesticides that are used.
- Use work practices or engineering controls that minimize worker contact with pesticides.
- Select garments and other PPE that minimize absorption, entrapment, and adsorption of contaminants.
- Use pesticides or forms of pesticides that are more easily removed by conventional laundering procedures.
- Use garments and other PPE that are disposable.

References

[1] Obendorf, S.K. and C.M. Solbrig, "Distribution of Malathion and Methyl Parathion on Cotton/Polyester Unfinished and Durable Press Fabrics Before and After Laundering as Determined by Electron Microscopy," *Performance of Protective Clothing, ASTM STP 900*, R.L. Barker and G.C. Coletta, Eds., American Society for Testing and Materials, Philadelphia, PA, 1986, pp. 187-204.

[2] Sharpe, D.C. and R.R. Reich, "Ethox Challenges Aeration Times for IOLs," Medical Devices and Diagnostic Industry, **10**, No. 6, 1988, pp. 142–146.

[3] Vink, P. and K. Pleijsier, "Aeration of Ethylene Oxide Sterilized Polymers," Biomaterials I, May 1988, pp. 225–230.

[4] Anon, "Ethylene Oxide Sterilization – A Guide for Hospital Personnel," revised July 1976, Subcommittee on Ethylene Oxide Sterilization, Association for the Advancement of Medical Instrumentation.

[5] Nelson, C.N. and J.R. Fleeker, Eds., "Limiting Pesticide Exposure Through Textile Cleaning Procedures," North Central Cooperative Series #314, North Dakota State University at Fargo, March 1988.

[6] Laughlin, J. and R.E. Gold, "Cleaning Protective Apparel to Reduce Pesticide Exposure," in *Reviews of Environmental Contamination and Toxicology*, Vol. 101, Springer Verlag New York, Inc., 1988, pp. 93–119.

[7] Soap and Detergent Association Handbook of Industry Terms, New York, 1978.

[8] Keaschall, J.L., J.M. Laughlin, and R.E. Gold, "Effect of Laundering Procedures and Functional finishes on Removal of Insecticides Selected from Three Chemical Classes," *Performance of Protective Clothing, ASTM STP 900*, R.L. Barker and G.C. Coletta, Eds., American Society for Testing and Materials, Philadelphia, PA, 1986, pp. 162–176.

[9] Fleeker, J.R., C. Nelson, M.F. Wazir, and M.M. Olsen, "Effect of Formulation on Removal of Carbaryl and Chlorothalonil from Apparel fabrics by Dry Cleaning, Aqueous Extraction, and Vaporization," *Performance of Protective Clothing: Second Symposium, ASTM STP 989*, S.Z. Mansdorf, R.Sager, and A.P. Nielsen, Eds., American Society for Testing and Materials, Philadelphia, PA, 1988, pp. 715–726.

[10] Finley, E.L., J.B. Graves, T.A. Summers, P.E. Schilling, and H.F. Morris, "Some Facts about Methyl Parathion Contamination of Clothing in Cotton Fields and its Removal by Home Laundering," Louisiana State University Agricultural Experimental Station, Circular No. 104, 1974.

[11] Easley, C.B., J.M. Laughlin, R.E. Gold, and K. Schmidt, "Detergents and Water Temperature as Factors in Methyl Parathion Removal from Denim Fabrics," Bull. Envirnm. Contam. Toxicol., **28,** 1982, pp. 239–244.

[12] Easley, C.B., J.M. Laughlin, R.E. Gold, and R.M. Hill, "Laundry Factors Influencing Methyl Parathion Removal from Contaminated Denim Fabric," Bull. Environm. Contam. Toxicol., **29,** 1982, pp. 461–468.

[13] Coffman, C., adapted from Cooperative Extension information at North Dakota State University and research conducted at the University of Nebraska and Oregon State University, Department of Textiles and Apparel, Cornell University, Ithaca, NY, 1986.

[14] Olsen, M.J., C. Janecek, and J.R. Fleeker, "Removal of Paraquat from Contaminated Fabrics," Bull. Environ. Contam. Toxicol., 37, 19??, pp.___ ___.

[15] Raheel, M., "Laundering Variables in Removing Carbaryl and Atrazine Residues from Contaminated Fabrics," Bull. Environ. Contam. Toxicol., 39, 1987, pp. 671–679.

[16] Laughlin, J., and R.E. Gold, "Impact of Water Hardness and Surfactant on Refurbishment of Protective Apparel Fabrics Contaminated with Methyl Parathion," Proceedings of the Third Scandinavian Symposium On Protective Clothing Against Chemical and Other Health Risks, Ed., J. Eggestad, Norwegian Defence Research Establishment, Division for Environmental Toxicology, 1989, pp. 101–105.

[17] Goodman, C.J., J. Laughlin, and R.E. Gold, "Strategies for Laundering Protective Apparel Fabrics Sequentially Contaminated with Methyl Parathion," *Performance of Protective Clothing: Second Symposium, ASTM STP 989,* S.Z. Mansdorf, R. Sager, and A.P. Nielsen, Eds., American Society for Testing and Materials, Philadelphia, PA, 1988, pp. 671–679.

[18] Kim, C.J., J.F. Stone, and C.E. Sizer, "Removal of Pesticide Residues as Affected by Laundering Variables," Bull. Environm. Contam. Toxicol., **29,** 1982, pp. 95–100.

[19] Obendorf, S.K., and N.A. Klemash, "Electron Microscopical Analysis and Polyester/cotton fabrics," Text. Res. J., **52,** 1982, pp. 434–442.

[20] Easter, E., "Removal of Pesticide Residues from Fabrics by Laundering," Text. Chem. & Colorist, **15,** No. 3, 1983, pp. 29–33.

[21] Easter, E.P. and J.O. DeJonge, "The Efficacy of Laundering Captan and Guthion contaminated Fabrics," Arch. Envrin. Contam. Toxicol., **14,** 1985, pp. 281–287.

[22] Laughlin, J.M., C.B. Easley, R.E. Gold, and R.M. Hill, "Fabric Parameters and Pesticide Characteristics that Impact on Dermal Exposure of Applicators," *Performance of Protective Clothing, ASTM STP 900*, R.L. Barker and G.C. Coletta, Eds., American Society for Testing and Materials, Philadelphia, PA, 1986, pp. 136–150.

[23] Obendorf, S.K., J. Borsa, V. Ravichandran, R. Sagan, D. Ghandi, A. Lone, and C.W. Coffaman. Starch as a Renewable Finish to Improve Pesticide Protective Properties in Conventional Work Clothing, manuscript in preparation, Dept. Textiles and Apparel, Cornell University, Ithaca, NY.

[24] Laughlin, J.M., J. Lamplot, and R.E. Gold, "Chlorpyrifos Residues in Protective Apparel Fabrics Following Commercial or Consumer Refurbishment," *Performance of Protective Clothing: Second Symposium, ASTM STP 989*, S.Z. Mansdorf, R. Sager, and A.P. Nielsen, Eds., American Society For Testing and Materials, Philadelphia, 1988, pp. 705–714.

[25] Laughlin, J.M., C.B. Easley, R.E. Gold, and D.R. Tupy, "Methyl Parathion Transfer from contaminated Fabrics to Subsequent Laundry and to Laundry Equipment," Bull. Environm. Contam. Toxicol. **27**, 1981, pp. 518–523.

[26] Lloyd, G.A., "Procedures for the Decontamination of Protective Gloves and Clothing Used by Operators of Pesticide Spraying Equipment," Operator Protection Group Information Sheet No. 16, Ministry of Agriculture, Fisheries, and Food, Harpenden Laboratory, Hatching Green, UK, 1985.

[27] Reich, D.A., "Dry Cleaning," Kirk Othmer Encyclopedia of Chemical Technology, 3rd Ed., 8, Wiley & Sons, New York, 1979, pp. 50–68.

[28] Ringenberg, K.P., J.M. Laughlin, and R.E. Gold, "Chlorpyrifos Residue Removal from Protective Apparel Through Solvent-Based Refurbishment Procedures," *Performance of Protective Clothing: Second Symposium, ASTM STP 989*, S.Z. Mansdorf, R. Sager, and A.P. Nielsen, Eds., American Society for Testing and Materials, Philadelphia, PA, 1988, pp. 697–704.

[29] International Fabricare Institute, "How Dry Cleaners Keep Solvents Clean," PC Report Bull. PCR–40, Silver Spring, MD, 1984.

[30] Fleeker, J.R., C. Nelson, M.F. Wazir, and M.M. Olsen, "Effect of Formulation on Removal of Carbaryl and Chlorothalonil from Apparel Fabrics by Dry Cleaning, Aqueous Extraction, and Vaporization," *Performance of Protective Clothing: Second Symposium, ASTM STP 989*, S.Z. Mansdorf, R. Sager, and A.P. Nielsen, Eds., American Society for Testing and Materials, Philadelphia, 1988, pp. 715–726.

[31] Laughlin, J. and R.E. Gold, "Evaporative Dissipation of Methyl Parathion from Laundered Protective Apparel Fabrics," Bull. Envrin. Contam. Toxicol., **42**, 1989, pp. 566–573.

[32] Stone, J.F., K.J. Koehler, C.J. Kim, and S.J. Kadolph, "Laundering Pesticide Soiled Clothing: A Survey of Iowa Farm Families," J. Environ. Health, 48, No.5, 1986, pp. 259–264.

[33] Farmer, W.J. and Y. Aochi, "Chemical Conversion of Pesticides in the Soil Water Environment," Publication 3320, Fate of Pesticides in the Environment, University of California, Div. of Agriculture and Natural Resources, Oakland, CA, 1987, pp. 69–74.

Appendices

A Appendix

Gloves

Appendix A – Gloves

Vendor	Style	Thickness Mil (cm)	Sizes	Length (in)	Liner Material	Cuff	Grip
Butyl Rubber Glove, Solvent Dipped, Unsupported							
MSA	38552	17 (0.044)	10	14		Straight	Smooth
North Hand	B131	13 (0.033)	7,8,9,10,11	11		Rolled	Smooth,Rough
North Hand	B161	16 (0.043)	7,8,9,10,11	11		Rolled	Smooth,Rough
North Hand	B174	17 (0.044)	8,9,10,11	14		Rolled	Smooth,Rough
North Hand	B324	32 (0.081)	8,9,10,11	14		Rolled	Smooth,Rough
Rex	Erista–BX	19.7 (0.050)	7,7.5–10	12		Rolled	Smooth
Rex	Erista–BX	19.7 (0.050)	9,10,11	14		Rolled	Smooth
Chloroprene Milled/ Chloroprene Latex Glove, Supported							
Boss	Neoprene	NA*	L	11	Cotton Knit	Pinked	Rough
Pioneer	Stanzoil Temp–Tec	NA	Jumbo	12	Knit/Jersey	Sealed	Rough
Pioneer	Stanzoil Duplex NL–34	NA	S,M,L,XL	12	Cotton Knit	Pinked	Rough
Pioneer	Stanzoil Duplex NL–32	NA	S,M,L,XL	12	Cotton Knit	Pinked	Rough
Pioneer	Stanzoil Duplex NL–52	NA	8,9,10,11	14	Cotton Knit	Pinked	Rough
Pioneer	Stanzoil Duplex W–39	NA	S,M,L,XL	12	Cotton Knit	Pinked	Rough
Chloroprene Milled/ Chloroprene Latex Glove, Unsupported							
Pioneer	Stanzoil N–35	15 (0.038)	7,8,9,10,11	10.5		Rolled	Rough
Pioneer	Stanzoil N–36	18 (0.046)	9,10,11	11		Rolled	Rough
Pioneer	Stanzoil N–44	22 (0.056)	9,10,11	12		Rolled	Rough
Pioneer	Stanzoil N–54	30 (0.076)	9,10,11,12	14		Rolled	Smooth,Rough
Pioneer	Stanzoil N–73	22 (0.056)	8,9,10,11	18		Rolled	Rough
Pioneer	Stanzoil N–74	30 (0.076)	9,10,11	18		Rolled	Smooth,Rough
Pioneer	Stanzoil GF–N–8152	15 (0.038)	8.5,9.75,10.5,11.5	32		Rolled	Smooth
Pioneer	Stanzoil GF–N–8302	30 (0.076)	9.75,10.5,11.5	32		Rolled	Smooth
Chloroprene Milled/Chloroprene Milled, Unsupported							
Boss	3 Ply Stanzoil	15 (0.038)	9,10	10.5		Rolled	Rough
Boss	3 Ply Stanzoil	30 (0.076)	10,11	14		Rolled	Rough
Chloroprene Rubber Latex Glove, Supported							
Allied	Neoprene	NA	Men's	12	Knit	Straight	Smooth
Ansell Edmont	Neox	NA	Men's	W+,10,12,14,18,31	Fabric	KW#,Straight	Rough
Ansell Edmont	Neox Hi–Lo Temperature	NA	Men's	12	Fabric	Straight	Smooth
Ansell Edmont	Neox Lighter Weight	NA	Men's	W,12	Fabric	KW,Straight	Smooth
Ansell Edmont	Redmont	NA	Men's	10,12,14,18	Fabric	Straight	Rough
Ansell Edmont	Scorpio	NA	S,M,L,XL	12,14	Knit	Pinked	Rough
Best	Neoprene	NA	L	W,10,12,14,Elbow	Flannel	KW,Straight	Smooth,Rough

Vendor	Style	Thickness Mil (cm)	Sizes	Length (in)	Liner Material	Cuff	Grip
Best	Ultraflex Neoprene	NA	S	11	Knit	Scallop	Rough
Best	Ultraflex Neoprene	NA	M	12,14	Knit	Pink	Rough
Best	Ultraflex Neoprene	NA	L	14	Knit	Straight	Rough
Boss	Neoprene	NA	L	W,12,14,18	Fabric	KW,Straight	Smooth
Boss	Neoprene Heavyweight	NA	L	12,14,18	Fabric	Straight	Rough
Comasec	Astro–prene	NA	S,M,L,XL	11	Cotton Knit	Scalloped	Rough
Comasec	Astro–prene	NA	L,XL	14	Cotton Knit	Scalloped	Rough
Granet	Neoprene 7 Series	NA	L	12,14,18,31	Flannel	Straight	Smooth
Granet	Neoprene 7 Series	NA	L	W	Jersey	KW	Smooth
Granet	Neoprene 27 Series	NA	L	12,14,18	Flannel	Straight	Rough
Granet	Neoprene 27 Series	NA	L	W	Jersey	KW	Rough
MSA	Neoprene	NA	Men's	W,10,12,14,18	Flannel	KW,Pinked	Smooth
MSA	Python Neoprene	NA	Men's	W,12,14	Flannel	KW,Pinked	Smooth
Monte	Group 26	NA	Men's	W,10,12,14,16	Knit	KW,Straight	Smooth,Rough
Wheeler	Neoprene	NA	Men's	W,14	Fabric	KW,Straight	Rough
Chloroprene Rubber Latex Glove, Unsupported							
Allied	Neoprene	18 (0.046)	S,M,L,XL	11	Flocked	Rolled	Embossed
Allied	Neoprene	18 (0.046)	7,8,9,10,11	12		Rolled	Embossed
Allied	Neoprene	18 (0.046)	10,11	12		Rolled	Embossed
Ansell Edmont	Neoprene	15 (0.038)	8–10(by 0.5),11	11			
Ansell Edmont	Neoprene	17 (0.043)	7–10(by 0.5),11	12			
Ansell Edmont	Neoprene	18 (0.046)	7–10(by 0.5),11	11			
Ansell Edmont	Neoprene	19 (0.048)	8–10(by 0.5),11	12			
Ansell Edmont	Neoprene Soft–Lined	18 (0.046)	7–10(by 0.5),11	13	Flocked		
Best	Neoprene	18 (0.046)	S,M,L,XL		Flocked	Scalloped	Embossed
Boss	Neoprene	18 (0.046)	9,10			Rolled	Embossed
Boss	Neoprene	18 (0.046)	M,L	11	Flocked	Rolled	Embossed
Boss	Neoprene	35 (0.089)	10	14		Rolled	Embossed
Granet	2915	15 (0.038)	6,7,8,9,10,11	12		Rolled	Smooth
Granet	2915	15 (0.038)	6,7,8,9,10,11	13.5		Straight	Smooth
Granet	2917	17 (0.043)	6,7,8,9,10,11	12		Rolled	Rough
Granet	2917	17 (0.043)	6,7,8,9,10,11	13.5		Straight	Rough
Granet	2918	18 (0.046)	6,7,8,9,10,11	12		Rolled	Smooth
Granet	2918	18 (0.046)	6,7,8,9,10,11	13.5		Straight	Smooth
Granet	2918	18 (0.046)	6,7,8,9,10,11	14	Flocked	Straight	Rough
Granet	2919	19 (0.048)	6,7,8,9,10,11	12		Rolled	Rough
Granet	2919	19 (0.048)	6,7,8,9,10,11	13.5		Straight	Rough
Memphis	Neoprene	20 (0.051)	7,8,9,10	12		Straight	Embossed
Memphis	Neoprene	30 (0.076)	7,8,9,10	12		Straight	Embossed
MSA	Bayprene	28 (0.071)	6–10.5 (by0.5)	12.5,16.5	Flocked	Straight	Rough
Monte	Group 33 Neoprene	15 (0.038)	Men's	12		Straight	Smooth

Vendor	Style	Thickness Mil (cm)	Sizes	Length (in)	Liner Material	Cuff	Grip
Monte	Group 33 Neoprene	18 (0.046)	Men's	12	Flocked	Straight	Smooth
Monte	Group 33 Neoprene	35 (0.089)	Men's	12	Flocked	Straight	Smooth
Pioneer	Stanzoil N-30	15 (0.038)	S,M,L,XL	11		Rolled	Embossed
Pioneer	Stanzoil NS-35	18 (0.046)	S,M,L,XL	11	Flocked	Rolled	Embossed
Pioneer	Stanzoil N-15	15 (0.038)	S,M,L,XL	11		Rolled	Embossed
Pioneer	Stanzoil NS-28	18 (0.046)	S,M,L,XL	11	Flocked	Rolled	Embossed
Pro-Guard	5022K	25 (0.063)	S,M,L,XL	12.5		Rolled	Embossed
Rex	Rex-Neoprene	19.7 (0.050)	M,L,XL	12	Flocked	Straight	Embossed
Chloroprene + Natural Rubber/ Chloroprene + Natural Rubber Glove, Unsupported							
Playtex	Heavy Duty 103	36 (0.091)	7,8,9,10	13	Flocked	Straight	Rough
Playtex	834	20 (0.051)	7,8,9,10	14	Flocked	Straight	Embossed
Playtex	Argus 123	36 (0.091)	7,8,9,9W,10	13	Flocked	Straight	Rough
Chloroprene + Natural Rubber Latex Glove, Unsupported							
Ansell Edmont	Omni	22 (0.056)	7,8,9,10	12	Flocked	Pinked	Embossed
Ansell Edmont	Technicians	17 (0.043)	7–10 (by 0.5),11	12		Pinked	Rough
Boss	Neoprene/Latex	22 (0.059)	S,M,L,XL	12	Flocked	Pinked	Rough
Boss	Neoprene/Latex	17 (0.043)	S,M,L,XL	12		Rolled	Embossed
Marigold	414	17 (0.043)	S,M,L,XL	12		Rolled	Embossed
MSA	Batex	20 (0.051)	6–10.5 (by 0.5)	12.25	Flocked	Straight	Rough
Playtex	Clean Room 827	18 (0.046)	7,8,9,10	14		Straight	Embossed
Playtex	Utility Glove 834	20 (0.051)	7,8,9,10	11.5	Flocked		
Playtex	Utility Glove 835	18 (0.046)	7,8,9,10	11.5	Flocked	Straight	Embossed
Chloroprene/Natural Rubber Latex Glove							
Ansell Edmont	Chemi-Pro	28 (0.071)	7,8,9,10	13	Flocked	Pinked	Embossed
Memphis	Neoprene on Latex	30 (0.076)	7,8,9,10	13	Flocked	Straight	Embossed
Pro-Guard	Neotex	30 (0.076)	S,M,L,XL	13	Flocked	Straight	Embossed
Flexible Plastic Laminate							
North Hand	Silver Shield	3 (0.008)	S,M,L	15.25		Straight	Smooth
Safety 4	4H Glove	2.6 (0.065)	S,M,L,XL			Straight	Smooth
Fluoroelastomer Glove, Solvent Dipped							
MSA	Viton	12 (0.030)	10	14		Straight	Smooth
North Hand	Viton	10 (0.025)	8,9,10	11		Straight	Smooth
North Hand	Viton	12 (0.030)	8,9,10,11	14		Straight	Smooth
REX	Erista-Vitric	19.7 (0.050)	7,7.5–10	12		Rolled	Smooth
REX	Erista-Vitric	19.7 (0.050)	9,10,11	14,15.5		Rolled	Smooth

Vendor	Style	Thickness Mil (cm)	Sizes	Length (in)	Liner Material	Cuff	Grip
Natural Rubber Latex Glove, Supported							
Allied	Knit Cuff	NA	7,8,9,10	W	Fabric	KW	Rough
Allied	Band Cuff	NA	7,8,9,10	10	Fabric	Pinked	Rough
Allied	Gauntlet Cuff	NA	7,8,9,10	12,14	Fabric	Pinked	Rough
Ansell Edmont	Grab–it	NA	Men's	W,10,12	Jersey	KW,Straight	Very rough
Best	Nitty Gritty	NA	Men's	W,10,14	Flannel	KW,Pinked,Band	Rough
Best	Nitty Gritty	NA	Ladies	W	Flannel	KW	Rough
Comasec	Astro–Flex	NA	S,M,L,XL	11	Cotton Knit	Scalloped	Rough
Comasec	Astro–Flex	NA	L,XL	14	Cotton Knit	Scalloped	Rough
Comasec	Astro–Lite	NA	S,M,L,XL	11	Cotton Knit	Scalloped	Very rough
Comasec	Flexirex	NA	S,M,L	W	Cotton		Rough
Monte	Group 28	NA	Men's	W,12	Knit	KW,Band,Straight	Very Rough
Pioneer	Sure–grip	NA	M,L,XL	12	Cotton Knit	Pinked	Rough
Natural Rubber Latex Glove, Unsupported							
Allied	Latex	20 (0.051)	7–7.5 8–9,9.5–10	12	Flocked	Pinked	Rough,Embossed
Allied	Latex	20 (0.051)	7,8,9,10	14	Flocked	Pinked	Rough
Allied	Latex	18 (0.046)	7,8,9,10,11	13	Flocked	Pinked	Rough
Allied	Latex 390 Series	19 (0.048)	6.5–10 (by 0.5),11	12		Straight	Rough
Allied	Latex 390 Series	19 (0.048)	7,7.5,8,9,10	12		Straight	Embossed
Allied	790	45 (0.114)	9,10,11	18		Pinked	Smooth
Allied	799	65 (0.165)	9,10,11	18		Pinked	Smooth
Ansell Edmont	Sterile Surgical	9 (0.023)	6–8.5 (by 0.5)	12		Straight	Rough
Ansell Edmont	Premium White	9 (0.023)	6–10 (by 0.5)	11.5		Rolled	Smooth,Rough
Ansell Edmont	Premium White	7.5 (0.019)	6–9.5 (by 0.5)	11.5		Straight	Smooth
Ansell Edmont	Prem Wh Case Hardened	17 (0.043)	7–10 (by 0.5)	11		Straight	Smooth,Rough
Ansell Edmont	No Powder	9 (0.023)	6–8.5 (by 0.5)	12		Straight	Rough
Ansell Edmont	Conform,Kleen Ambi	5 (0.013)	S/M,M/L	9.5		Rolled	Smooth
Ansell Edmont	Conform Extra	5 (0.013)	S/M,M/L,XL	11		Rolled	Smooth
Ansell Edmont	Conform Plus	7 (0.018)	S/M,M/L	9.5		Rolled	Smooth
Ansell Edmont	Canners & Handlers RBC	19 (0.048)	7,8,9,10,11	12		Rolled	Embossed
Ansell Edmont	Canners & Handlers	19 (0.048)	7,8,9,10	12,14		Pinked	Embossed
Ansell Edmont	Canners & Handlers	19 (0.048)	6.5–10 (by 0.5),11	12		Pinked	Rough
Ansell Edmont	Natural Blue	17 (0.043)	7,8,9,10	12		Pinked	Embossed
Ansell Edmont	FL 200/FL 400	20 (0.051)	7,8,9,10	12,14	Flocked	Pinked	Embossed,Rough
Ansell Edmont	Orange Heavyweight	30 (0.076)	7,8,9,10	13	Flocked	Pinked	Embossed
Ansell Edmont	PVL	18 (0.046)	7,8,9,10,11	12		Rolled	Embossed
Ansell Edmont	PVL	21 (0.053)	7,8,9,10,11	12,15		Rolled	Embossed
Ansell Edmont	Tan Rubber	15 (0.038)	7–10(by 0.5),11	11		Rolled,Straight	Smooth,Rough
Ansell Edmont	Tan Rubber	18 (0.046)	7–10(by 0.5),11	11		Rolled	Smooth,Rough
Ansell Edmont	Tan Rubber	21 (0.053)	8–10(by 0.5),11	11		Rolled	Smooth,Rough
Ansell Edmont	Tan Rubber Soft–Lined	18 (0.046)	7–10(by 0.5),11	13	Flocked	Straight	Embossed

Vendor	Style	Thickness Mil (cm)	Sizes	Length (in)	Liner Material	Cuff	Grip
Best	Latex HD	50 (0.127)	10,11	15,18		Rolled	Smooth
Best	Tuff Guard	50 (0.127)	10,11	23		Straight	Smooth
Best	Derma Thin	5 (0.013)	5–6.5,7–8,8.5–10			Rolled	Smooth
Best	700	21 (0.053)	S,M,L,XL		Flocked	Straight	Rough
Best	702	18 (0.046)	S,M,L,XL		Flocked	Scalloped	Embossed
Best	709	15 (0.038)	S,M,L,XL			Straight	Embossed
Best	VMU	18 (0.046)	S,M,L,XL			Straight	Embossed
Best	VM	18 (0.046)	XS,S,M,L,XL		Flocked	Scalloped	Embossed
Best	VMP	18 (0.046)	S,M,L,XL		Flocked	Scalloped	Embossed
Boss	Latex	5 (0.013)	M,L	9.5		Rolled	Smooth
Boss	Latex	18 (0.046)	S,M,L,XL	12		Rolled	Embossed
Boss	Latex	18 (0.046)	7–10 (by 0.5)	11		Rolled,Pinked	Rough,Embossed
Boss	Latex	19 (0.048)	7–9.5 (by 0.5)	12		Pinked	Rough
Boss	Latex	19 (0.048)	7,8,9,10,11	12		Rolled	Embossed
Boss	Latex	20 (0.051)	S,M,L,XL	12	Flocked	Pinked	Embossed
Boss	Latex	20 (0.051)	M,L	13	Flocked	Straight	Rough
Boss	Latex	23 (0.058)	S,M,L,XL	12	Flocked	Rolled	Embossed
Boss	Latex	25 (0.063)	M,L	12		Rolled	Rough
Boss	Latex	35 (0.089)	S,M,L,XL	12		Rolled	Rough
Boss	Latex	40 (0.102)	9,10,11	14		Rolled	Rough
Boss	Latex	40 (0.102)	9,10	13		Straight	Rough
Comasec	Natural Rubber	33 (0.084)	9,10,11	12,14		Rolled	Smooth
Comasec	Natural Rubber	36 (0.090)	9,10,11	18		Rolled	Smooth
Comasec	Natural Rubber	43 (0.109)	9,10,11	12,14,18,24		Rolled	Smooth
Comasec	Natural Rubber	53 (0.135)	9,10,11	12,14,24		Rolled	Smooth
Comasec	Natural Rubber	58 (0.147)	9,10,11	18,24		Rolled	Smooth
Defense Apparel	Mil–Spec Anti–C	18 (0.046)	8,9,10,11	12		Rolled,Pinked	Embossed
Defense Apparel	DefensAp Anti–C	18 (0.046)	8,9,10,11	12		Rolled	Embossed
Defense Apparel	Rubber Work Glove	18 (0.046)	7,8–10 (by 0.5),11	12		Pinked	Rough
Defense Apparel	Surgeon Glove	7 (0.018)	8–10 (by 0.5)	11		Straight	Smooth
Glover	G25	25 (0.063)	8,9,10,11	12		Rolled	Rough
Glover	T32	35 (0.089)	8,9,10,11	12		Rolled	Rough
Glover	T40	40 (0.102)	9,10,11,12	14		Rolled	Rough
Glover	T50	50 (0.127)	9,10,11,12	14		Rolled	Rough
Glover	E50	50 (0.127)	9,10,11	18		Rolled	Rough
Glover	E60	60 (0.152)	9,10,11	18		Rolled	Rough
Glover	AR340	40 (0.102)	8,9,10,11	13		Straight	Rough
Glover	AR840	40 (0.102)	9,10,11	18		Straight	Rough
Glover	AR855	55 (0.014)	9,10,11	18		Straight	Rough
Glover	Y18	21 (0.053)	7–10 (by 0.5),10,11	12		Straight	Embossed
Glover	SL866	21 (0.053)	7–10 (by 0.5),10,11	12		Straight	Embossed
Glover	SL868	21 (0.053)	7,8,9,XL	13		Straight	Embossed
Glover	L38B	40 (0.102)	10,11	14		Rolled	Embossed

Vendor	Style	Thickness Mil (cm)	Sizes	Length (in)	Liner Material	Cuff	Grip
Glover	E2145	21 (0.053)	7–9 (by 0.5),10,11	12,14		Rolled	Smooth
Gloves, Inc	500		S,M,L,XL	13	Flocked	Pinked	Embossed
Gloves, Inc	505		S,M,L,XL	13		Pinked	Embossed
Granet	2615	15 (0.038)	6,7,8,9,10,11	12		Rolled	Smooth,Rough
Granet	2615	15 (0.038)	6,7,8,9,10,11	13.5		Straight	Smooth,Rough
Granet	2618	18 (0.046)	6,7,8,9,10,11	12		Rolled	Smooth,Rough
Granet	2618	18 (0.046)	6,7,8,9,10,11	14	Flocked	Straight	Rough
Granet	2621	21 (0.053)	6,7,8,9,10,11	12		Rolled	Smooth,Rough
Granet	3020	20 (0.051)	6,7,8,9,10,11	14		Straight	Rough
Granet	3618	18 (0.046)	6,7,8,9,10,11	14		Straight	Rough
Granet	3630	30 (0.076)	9,10,11	14		Rolled	Smooth,Rough
Granet	3640	40 (0.102)	10,11	14		Straight	Embossed
Granet	4607	7 (0.018)	6,7,8,9,10	11.5		Straight	Smooth
Granet	4609	9 (0.023)	6,7,8,9,10	11.5		Rolled	Smooth
Granet	4609	9 (0.023)	6,7,8,9,10,11	12		Rolled	Rough
Granet	4617	17 (0.043)	6,7,8,9,10,11	13.5		Straight	Smooth,Rough
Marigold	2J	30 (0.076)	S,M,L,XL	12.75	Flocked	Rolled	Rough
Marigold	G12	17 (0.043)	S,M,L,XL	12	Flocked	Rolled	Embossed
Marigold	41CB,40Y	17 (0.043)	S,M,L,XL	12		Rolled	Embossed
Marigold	173	28 (0.071)	S,M,L,XL	11.5	Flocked	Rolled	Embossed
Marigold	242	17 (0.043)	7,8,9,10,11	13		Straight	Embossed
Marigold	326	21 (0.053)	S,M,L,XL	12	Flocked	Rolled	Embossed
Marigold	440,790	45 (0.114)	9,10,11	14,18		Straight	Embossed
Marigold	744	45 (0.114)	8,9,10,11	14		Straight	Smooth
Marigold	799	65 (0.165)	9,10,11	18		Straight	Embossed
Memphis	Disposable Latex	5 (0.013)	S,M,L,XL			Straight	Smooth
Memphis	Heavy Gauge Latex	50 (0.127)	L	13		Straight	Smooth
Memphis	Canners	18 (0.046)	7,8,9,10	12		Rolled	Embossed
Memphis	Economy Canners	16 (0.041)	7,8,9,10	12		Rolled	Embossed
Memphis	Flock Lined	18 (0.046)	7,8,9,10	12	Flocked	Straight	Embossed
MSA	Natural Latex	20 (0.051)	6–10.5 (by 0.5)	12.5	Flocked	Straight	Rough
MSA	Natural Latex	18 (0.046)	6–9.5 (by 0.5)	12.5		Straight	Rough
Monte	Group 32	5 (0.013)	Men's,Women's	10		Straight	Smooth
Monte	Group 33 Latex	15 (0.038)	Men's	12		Straight	Smooth
Monte	Group 33 Latex	18 (0.046)	Men's	12	Flocked	Straight	Smooth
Monte	Group 33 Latex	40 (0.102)	Men's	12		Straight	Smooth
North Hand	RI23	23 (0.058)	9–11(by 0.5),12	11		Rolled	Smooth
North Hand	RI50	50 (0.127)	9–11(by 0.5),12	14,16,18		Rolled	Smooth
North Hand	RI60	60 (0.152)	9–11(by 0.5),12	14,16,18		Rolled	Smooth
Pioneer	Ivory Whites L–118	18 (0.046)	7,8,9,10,11	12		Cuff	Embossed
Pioneer	Sure–Grip LF–118	20 (0.051)	7,8,9,10,11	12	Flocked	Cuff	Embossed
Pioneer	Sheer Grip 7014	5 (0.013)	Reg, Lrg	10		Rolled	Smooth
Pioneer	Rollpruf 0716,0726	8 (0.020)	6–9 (by 0.5),10	11		Cuff	Smooth

Vendor	Style	Thickness Mil (cm)	Sizes	Length (in)	Liner Material	Cuff	Grip
Pro–Guard	1040Y	18 (0.046)	S,M,L,XL	12.5	Flocked	Pinked	Embossed
Pro–Guard	1050K	18 (0.046)	S,M,L,XL	12.5	Flocked	Rolled	Embossed
Pro–Guard	1070M	19 (0.048)	S,M,L,XL	12.5		Pinked	Embossed
Pro–Guard	1060K	18 (0.046)	S,M,L,XL	12.5		Straight	Embossed
Pro–Guard	3022K	34 (0.086)	S,M,L,XL	12.5	Flocked	Straight	Embossed
Pro–Guard	DLX	6 (0.015)	S,M,L	10		Rolled	Smooth
Pro–Guard	6028	50 (0.127)	XXL	18		Rolled	Smooth
Renco	Heavy Duty Latex	21 (0.053)	7,8,9,10,11	13		Rolled	Embossed
Renco	Heavy Duty Latex	40 (0.102)	10–11 (by 0.5)	14		Rolled	Embossed
Renco	Heavy Duty Latex	50 (0.127)	10,11	18		Rolled	Embossed
Renco	Static Dissipative	7 (0.018)	6,7,8,9	11		Straight	Smooth
Renco	Natural Latex	21 (0.053)	7–9 (by 0.5),10	12		Straight	Embossed
Renco	Natural Latex	21 (0.053)	7,8,9,XL	13	Flocked	Straight	Embossed
Rex	Surgical Gloves	7.9 (0.020)	6.5–9	11		Straight	Smooth
Rex	Post–Mortem gloves	15.7 (0.040)	6.5–9	10.5		Straight	Smooth
Rex	Rex–Latex	15.7 (0.040)	6.5–10.5	11		Rolled	Smooth
Rex	Rex–Kristall	19.7 (0.050)	7,8,9,10	11.5		Rolled	Rough
Rex	Rexi–Diamant	23.6 (0.060)	7,8,9,10	11.5	Flocked	Rolled	Rough
Rex	Rex–Saphir	23.6 (0.060)	7,8,9,10	11.5	Flocked	Rolled	Embossed
Rex	Rex–Primeros	15.7 (0.040)	6.5–10.5	11		Rolled	Very Rough
Rex	Rex–Brillant	13.8 (0.035)	6.5–10.5	10.5		Rolled	Rough
Rex	Rex–Velour	23.6 (0.060)	6.5–11	11.5	Flocked	Rolled	Rough
Rex	Rex–Industrie	15.7 (0.040)	6.5–10.5	11		Rolled	Very Rough
Rex	Rex–Industrie	37.4 (0.095)	9,10,11	12,14,16,18,24		Straight	Smooth
Rex	Rex–Industrie	53.1 (0.135)	9,10,11	12,14,16,18,24		Straight	Smooth
Rex	Rex–Sandjet	53.1 (0.135)	9,10,11	12,14,15,18		Straight	Very Rough
Natural Rubber + Chloroprene + Nitrile Glove, Unsupported							
Pioneer	TRIonic E–194	19 (0.048)	7,8,9,10,11	14		Cuff	Embossed
Natural Rubber + Synthetic Rubber, Unsupported							
Rex	Rex–Europa	23.6 (0.060)	7,8,9,10,11	11.5	Flocked	Pinked	Rough
Rex	Rex–Europa	23.6 (0.060)	7,8,9,10	11.5	Flocked	Pinked	Embossed
Rex	Rex–Europa	23.6 (0.060)	6.5–10,10.5–11	12.5	Flocked	Pinked	Rough
Nitrile Rubber Latex Glove, Supported							
Allied	Nitrile		7,8,9,10	12,14	Fabric	Pinked	Smooth
Best	Ultraflex Nitrile	NA	S	11	Knit	Scalloped	Rough
Best	Ultraflex Nitrile	NA	M	12	Knit	Pinked	Rough
Best	Ultraflex Nitrile	NA	L	12	Knit	Straight	Smooth
Best	Nitri–pro	NA	L	W	Jersey	KW,Band	Smooth,Rough

Vendor	Style	Thickness Mil (cm)	Sizes	Length (in)	Liner Material	Cuff	Grip
Best	Nitri–pro	NA	Ladies	W	Jersey	KW	Smooth
Boss	Nitrile	NA	8,9,10,11	12	Cotton Knit	Straight	Embossed
Comasec	NBR Nitrile	NA	S,M,L,XL	11,14	Cotton Knit	Pinked	Embossed
Jomac	Nitrile	NA	L	W	Terrycloth	Band	Rough
Memphis	Nitrile	NA	L		Jersey	Cuff	Smooth
Monte	Group 27	NA	Men's	W	Jersey	KW	Smooth
Pioneer	Stansolv Gator–Hide	NA	8,9,10,11	12	Cotton Knit	Pinked	Embossed
Nitrile Rubber Latex Glove, Unsupported							
Allied	Nitrile	22 (0.056)	7,8,9,10,11	14		Straight	Smooth
Allied	Nitrile	22 (0.056)	9,10,11	18		Straight	Smooth
Allied	Nitrile	15 (0.038)	7,8,9,10,11	12		Straight	Smooth
Allied	Nitrile	25 (0.064)	8,9,10,11	14		Straight	Smooth
Allied	Nitrile	18 (0.046)	7,8,9,10,11	13	Flocked	Straight	Smooth
Allied	Nitrile	22 (0.056)	9,10,11	13	Flocked	Straight	Smooth
Ansell Edmont	Sol–Vex	11 (0.028)	6–10(by 0.5),11	13		Straight	Embossed
Ansell Edmont	Sol–Vex	15 (0.038)	7–10(by 0.5),11	13		Straight	Embossed
Ansell Edmont	Sol–Vex	22 (0.056)	7–10(by 0.5),11	15,18		Straight	Embossed
Ansell Edmont	Sol–Vex Soft–Lined	15 (0.038)	6–10(by 0.5),11	13	Flocked	Straight	Embossed
Best	717	11 (0.028)	7,8,9,10,11	13		Straight	Rough
Best	727	15 (0.038)	7,8,9,10,11	13		Straight	Rough
Best	730	15 (0.038)	7,8,9,10,11	13	Flocked	Straight	Rough
Best	737	15 (0.038)	9,10,11	15		Straight	Embossed
Best	747	25 (0.064)	9,10,11	18		Straight	Embossed
Boss	Nitrile	11 (0.028)	9,10	13		Straight	Embossed
Boss	Nitrile	15 (0.038)	8,9,10,11	13		Straight	Embossed
Boss	Nitrile	18 (0.046)	8,9,10,11	13	Flocked	Straight	Embossed
Boss	Nitrile	25 (0.064)	9,10	18		Straight	Embossed
Glover	Nitrile	15 (0.038)	7,8,9,10,11	11,13		Straight	Rough
Glover	Nitrile	25 (0.064)	9,10,11	14,18		Straight	Rough
Granet	1711	11 (0.028)	6,7,8,9,10,11	13.5		Straight	Embossed
Granet	1715	15 (0.038)	6,7,8,9,10,11	13.5		Straight	Embossed
Granet	1715	15 (0.038)	6,7,8,9,10,11	13.5	Flocked	Straight	Embossed
Granet	1722	22 (0.056)	9,10,11	15,19		Straight	Embossed
Granet	4909	9 (0.023)	6,7,8,9,10,11	13.5		Straight	Rough
Granet	4915	15 (0.038)	6,7,8,9,10,11	13.5		Straight	Rough
Marigold	Maxi–Guard	14 (0.036)	S,M,L,XL	12.75		Straight	Embossed
Marigold	Maxi–Guard	16 (0.041)	S,M,L,XL	12.75	Flocked	Straight	Embossed
Marigold	116	15 (0.038)	7,8,9,10,11	12.5	Flocked	Straight	Embossed
Marigold	129	20 (0.051)	8,9,10,11	12.5		Straight	Embossed
Marigold	146R	25 (0.064)	9,10,11	15		Straight	Embossed
Marigold	146T	25 (0.064)	8,9,10,11	15		Straight	Smooth

Vendor	Style	Thickness Mil (cm)	Sizes	Length (in)	Liner Material	Cuff	Grip
Marigold	310	10 (0.025)	7,8,9,10,11	13		Straight	Rough
Marigold	315,316	15 (0.038)	7,8,9,10,11	13		Straight	Rough
Marigold	315	15 (0.038)	7,8,9,10,11	13	Flocked	Straight	Rough
Marigold	317	18 (0.046)	7,8,9,10,11	13	Flocked	Straight	Embossed
Marigold	346	25 (0.064)	9,10,11	15		Straight	Embossed
Marigold	366	25 (0.064)	9,10,11	18		Straight	Embossed
Marigold	166	25 (0.064)	9,10,11	18		Straight	Embossed
Memphis	Nitrile	18 (0.046)	7,8,9,10		Flocked	Straight	Embossed
Memphis	Nitrile	12 (0.030)	7,8,9,10			Straight	Embossed
MSA	Nitrile	15 (0.038)	6–10.5 (by 0.5)	12.5	Flocked	Straight	Embossed
MSA	Nitrile	15 (0.038)	6–10.5 (by 0.5)	12.5		Straight	Embossed
MSA	Nitrile	25 (0.064)	6–10.5 (by 0.5)	15.25	Flocked	Straight	Embossed
Monte	Group 33 Nitrile	16 (0.041)	Men's	12		Straight	Smooth
Monte	Group 33 Nitrile	18 (0.046)	Men's	12	Flocked	Straight	Smooth
North Hand	LA102	10 (0.025)	7,8,9,10,11	12		Straight	Rough
North Hand	LA111	11 (0.028)	7,8,9,10,11	12		Straight	Rough
North Hand	LA132	13 (0.033)	7,8,9,10,11	12	Flocked	Straight	Rough
North Hand	LA142	14 (0.036)	7,8,9,10,11	12	Flocked	Straight	Rough
North Hand	LA172	17 (0.043)	7,8,9,10,11	12	Flocked	Straight	Rough
North Hand	LA254	25 (0.064)	9,10,11	14,18		Straight	Rough
Pioneer	Stansolv A–10	11 (0.028)	7,8,9,10,11	13		Flat cuff	Embossed
Pioneer	Stansolv A–10 CR	11 (0.028)	7,8,9,10,11	13		Flat cuff	Embossed
Pioneer	Stansolv A–14	22 (0.056)	7,8,9,10,11	14		Flat cuff	Embossed
Pioneer	Stansolv A–15	15 (0.038)	7,8,9,10,11	13		Flat cuff	Embossed
Pioneer	Stansolv A–18	22 (0.056)	9,10,11	18		Flat cuff	Embossed
Pioneer	Stansolv AF–18	18 (0.046)	7,8,9,10,11	13	Flocked	Flat cuff	Embossed
Pioneer	Stansolv AF–28	22 (0.056)	9,10,11	13	Flocked	Flat cuff	Embossed
Pro–Guard	4022K	17 (0.043)	S,M,L,XL	12.5	Flocked	Rolled	Embossed
Pro–Guard	4062K	16 (0.041)	S,M,L,XL	12.5		Pinked	Embossed
Pro–Guard	4072K	13 (0.033)	S,M,L,XL	12.5		Pinked	Embossed
Pro–Guard	4082K	22 (0.056)	M,L,XL	24		Straight	Smooth
Renco	NBR	15 (0.038)	7,8,9,10,11	12		Straight	Rough
Renco	NBR	18 (0.046)	7,8,9,10,11	12	Flocked	Straight	Rough
Renco	NBR	22 (0.056)	9,10,11	14		Straight	Rough
Rex	Erista–Special	15.7 (0.040)	7,7.5–10	11		Rolled	Very Rough
Rex	Erista–LP	15.7 (0.040)	7,7.5–10	11		Rolled	Smooth
Rex	Erista–P	29.5 (0.075)	9,10,11	12,14,15.5,18		Rolled	Smooth
Rex	Erista–P	39.4 (0.100)	9,10,11	12,14,15.5,18		Rolled	Smooth

Vendor	Style	Thickness Mil (cm)	Sizes	Length (in)	Liner Material	Cuff	Grip
Nitrile/Latex, Supported							
Best	Nitri–Seal	NA	S	11	Knit	Scalloped	Rough
Best	Nitri–Seal	NA	M	12,14	Knit	Pinked	Rough
Best	Nitri–Seal	NA	L	14	Knit	Straight	Rough
Nitrile/Latex, Unsupported							
Pro–Guard	Nitrex	24 (0.061)	S,M,L,XL	12.5	Flocked	Rolled	Embossed
Nitrile/Pvc, Supported							
Barry	Petrochief	NA	Men's	12	Jersey	Pinked	Rough
Nitrile + Pvc Glove Supported							
Ansell Edmont	Snorkel	NA	Men's,Women's	W	Jersey	KW	Rough
Ansell Edmont	Snorkel	NA	M,L	10,12,14	Jersey	Straight	Rough
Ansell Edmont	Snorkel	NA	M,L	12,14	Knit	Straight	Rough
Comasec	Multplus	NA	S,M,L	10,12,14,16	Cotton Knit	Pinked	Rough
Comasec	Multplus	NA	XL	12,14	Cotton Knit	Pinked	Rough
Polyethylene, Unsupported							
Ansell Edmont	Poly–D	1.25 (0.003)	S,M,L			Straight	Smooth
Ansell Edmont	Poly–D	1.25 (0.003)	L	22		Straight	Smooth
Ansell Edmont	Poly–D	1.75 (0.004)	S,M,L			Straight	Smooth
Armin Poly–version							
Handgards	Embossed Poly	1.25 (0.003)	S,M,L			Straight	Embossed
Handgards	Embossed Poly	1.25 (0.003)	L	Elbow		Straight	Embossed
Handgards	Clear Poly	1.25 (0.003)	S,M,L			Straight	Smooth
Handgards	Clear Poly	1.25 (0.003)	L	Elbow		Straight	Smooth
Pro–Guard	GSM	1.25 (0.003)	S/M,M/L	11.5		Straight	Embossed
Renco	Polyethylene	1.25 (0.003)	M/L			Straight	Smooth
Polyurethane, Supported							
Colonial	Sensi Glove	NA	S,M,L		Nylon	Straight	Smooth
Polyvinyl Alcohol Glove, Supported							
Ansell Edmont	PVA	NA	Men's,Women's	12	Knit	Straight	Smooth
Ansell Edmont	PVA	NA	Men's	14	Knit	Straight	Smooth

Vendor	Style	Thickness Mil (cm)	Sizes	Length (in)	Liner Material	Cuff	Grip
Polyvinyl Chloride Glove, Supported							
Abel	PVC	NA	L	W,10,12,14	Jersey	KW,Straight	Rough
Allied	KP100	NA	7,8,9,10	W	Cotton,Jersey	KW	Smooth,Rough
Allied	BP100	NA	7,8,9,10	W	Cotton,Jersey	Band	Smooth,Rough
Allied	GP100 Series	NA	7,8,9,10	12	Cotton	Pinked	Smooth,Rough
Allied	GP100 Series	NA	7,8,9,10	14,18	Cotton	Pinked	Rough
Allied	GP100 Economy Series	NA	7,8,9,10	W,12,14	Cotton	Pinked	Smooth
Ansell Edmont	Ever–Flex Fireball	NA	Men's	W	Fabric	KW	Smooth
Ansell Edmont	Ever–Flex Fireball	NA	Men's M,L	12	Fabric	Straight	Smooth
Ansell Edmont	Ever–Flex Monkey Grip	NA	Men's	W	Fabric	KW	Smooth
Ansell Edmont	Ever–Flex Monkey Grip	NA	Men's M,L	12	Fabric	Straight	Smooth
Ansell Edmont	Grappler	NA	Men's	W,12,14	Jersey	Straight,KW	Rough
Ansell Edmont	Monkey Grip Standard	NA	Men's	W,10,12,14,18	Fabric	Straight	Smooth
Ansell Edmont	Petroflex	NA	Men's	W,10,12,14	Jersey	Straight	Smooth
Ansell Edmont	Petroflex	NA	Men's	12,14	Knit	Straight	Rough
Barry	Bargain Charlie's	NA	Men's	W,10,12,14	Knit	KW,Pinked	Rough
Barry	Bemac Black	NA	Men's	W,10,12,14	Knit,Jersey	KW,Pinked	Rough
Barry	Flexi–Mac	NA	Men's	W,10.5,12,14,18	Jersey	KW,Pinked	Rough
Barry	Flexi–Mac	NA	Ladies 7,8,8.5	W,11	Jersey	KW,Pinked	Rough
Barry	Claws Fishermen's	NA	Men's	W,10.5,14	Knit	KW,Pinked	Very Rough
Barry	Summer Flambeau	NA	Men's	W,10.5,12,14	Jersey	Pinked	Rough
Barry	Summer Polarflex	NA	Men's	W,10.5,12	Jersey	KW,Pinked	Rough
Best	Neo Hyde	NA	Men's	W,10,14	Jersey	KW,Band,Straight	Rough
Best	Besyellow	NA	Men's	W,10,14,Elbow	Fabric	KW,Band,Straight	Smooth
Best	Besyellow	NA	Ladies	W,11	Fabric	KW,Straight	Smooth
Best	Cannonball	NA	L	W,10,12,14	Jersey	Straight,KW	Rough
Best	Cannonball	NA	Women's	W,11	Jersey	Straight,KW	Rough
Best	Black Knight	NA	L	W,10,12,14	Jersey,Knit	Straight,KW	Smooth,Rough
Best	Hustler	NA	L	W,10,12,14	Knit	Straight,KW	Rough
Best	Hustler	NA	L	Elbow	Jersey	Straight	Rough
Best	Red Dog	NA	L	W,10,12	Jersey	Straight,KW	Smooth
Best	Rough & Tough	NA	L	W,10,12	Jersey	Straight,KW	Rough
Best	Super Flex	NA	L	W,10,12	Jersey	Straight,KW	Smooth
Boss	PVC	NA	L	W,10,12,14	Jersey	KW,Straight,Cuff	Smooth,Rough
Boss	PVC	NA	L	W	Cotton,Jersey	KW	Smooth,Rough
Boss	Slip–on	NA	S,M,L	W	Knit	Pinked	Smooth
Comasec	Blockbuster	NA	L	B,W,12	Jersey	Straight,KW,Band	Very Rough
Comasec	Thermoplus	NA	L	W,10,16	Terry Cloth	Hemmed	Smooth
Comasec	PVC	NA	L	W,10,12,14	Jersey Fleece	Straight,KW,Band	Smooth,Rough
Comasec	PVC	NA	L	W,10,12,14	Mesh	Straight,KW	Smooth,Rough
Comasec	Presti–PVC	NA	S,M,L	W,10,12,14,22,28	Cotton	Pinked,KW	Smooth,Rough
Comasec	Presti–PVC	NA	M,L	22,28	Cotton	Flat	Smooth

Vendor	Style	Thickness Mil (cm)	Sizes	Length (in)	Liner Material	Cuff	Grip
Defense Apparel	PVC Work Glove	NA	L	W	Cotton	KW	Smooth
Granet	Dynagrip 5 Series	NA	M,L	10,12,14	Jersey	Straight	Rough
Granet	Dynagrip 5 Series	NA	L	W,18	Jersey	KW,Straight	Rough
Granet	Dynagrip 5 Series	NA	Women's L	W	Jersey	KW	Rough
Granet	Extraflex 38 Series	NA	M,L	10,12,14	Jersey	Straight	Smooth
Granet	Extraflex 38 Series	NA	L	W,18	Jersey	KW,Straight	Smooth
Granet	Glo Gluv 10 Series	NA	L	W,12	Jersey	KW,Straight	Smooth
Granet	Golden Nugget 85 Series	NA	M,L	10,12,14	Jersey	Straight	Rough
Granet	Golden Nugget 85 Series	NA	L	W	Jersey	KW	Rough
Granet	Granflex 9 Series	NA	L	W,10,12,14	Knit	KW,Straight	Rough
Granet	Granflex 9 Series	NA	Women's L	W,10	Knit	KW,Straight	Rough
Granet	Hippohide 55 Series	NA	M,L	10,12,14	Jersey	Straight	Smooth
Granet	Hippohide 55 Series	NA	L	W,18	Jersey	Straight	Smooth
Granet	Panther 3 Series	NA	L	W,10,12,14	Jersey	KW,straight	Rough
Granet	Panther 13 Series	NA	L	W,10,12,14	Knit	KW,straight	Rough
Jomac	200 Series	NA	L	10,12,14	Jersey	Pinked	Smooth
Jomac	1000 Series	NA	Women's M	W,10	Cotton Knit	KW,Pinked	Smooth
Jomac	1000 Series	NA	M,L	W,10,12,14	Cotton Knit	KW,Pinked	Smooth
Jomac	3100 Series	NA	L	10,12,14	Cotton Knit	Pinked	Rough
Jomac	3200 Series	NA	M/L	10,12	Jersey	Pinked	Rough
Jomac	3200 Series	NA	L	14	Jersey	Pinked	Rough
Jomac	4000 Series	NA	L	W,10,12 14	Jersey,Knit	KW,Band,Pinked	Rough
Jomac	6000 Series	NA	L	10,12,14	Cotton Knit	Pinked	Rough
Jomac	9000 Series	NA	L	18	Cotton Knit	Pinked	Smooth
Jomac	S22–120	NA	L	31	Fabric	Straight	Smooth
Magid	Economy PVC	NA	Men's	W,10,12,14	Fabric	KW,Straight	Smooth,Rough
Magid	Regular Duty PVC	NA	Men's	W,10,12,14,17	Jersey	KW,Straight,Band	Rough
Magid	Regular Duty PVC	NA	Women's	W,12	Jersey	KW,Straight,Band	Rough
Magid	Super Comfort PVC	NA	Men's	W,10,12,14	Jersey	KW,Straight	Rough
Magid	Heavy Duty PVC	NA	Men's	W,12	Fabric	KW,Straight	Rough
Magid	Food Processing	NA	Men's	W,12,14	Fabric	KW,Straight	Smooth
Memphis	Double Dipped	NA	L	W,10,12,14	Jersey	KW,Pinked	Rough
Memphis	Double Dipped	NA	L	W,10,12,14	Knit	KW,Pinked	Rough
Memphis	Economy PVC	NA	L	W,11,12,14,18	Knit	KW,Pinked	Smooth
Memphis	Economy PVC	NA	L	12	Knit	Pinked	Rough
MSA	Multi–purpose	NA	Men's	W,10,12,14	Jersey	KW,Band,Pinked	Smooth
MSA	Multi–purpose	NA	Ladies	W	Jersey	KW	Smooth
MSA	Utility	NA	Men's	W,12,14	Jersey	KW,Band,Pinked	Smooth
MSA	Flexible Vinyl	NA	Men's	W,11,12,14	Knit	KW,Pinked	Smooth
MSA	Super Flexible Vinyl	NA	Men's	W,12	Jersey	KW,Pinked	Smooth
MSA	Glow Glove	NA	Men's	W,12	Jersey	KW,Pinked	Smooth
Monte	Group 25	NA	Men's	W,10,12,14	Knit	KW,Band,Straight	Smooth,Rough
Monte	Group 25	NA	Men's	16	Knit	Straight	Smooth

Vendor	Style	Thickness Mil (cm)	Sizes	Length (in)	Liner Material	Cuff	Grip
Monte	Group 25	NA	Women's	W,12	Knit	KW,Straight	Smooth,Rough
Monte	Group 30	NA	M,L,Women's	W	Knit	Straight	Smooth
North Hand	SNI72	NA	L	10.5,12,14	Jersey	Pinked	Smooth
Wheeler	Vinyl	NA	Men's	W,14	Fabric	KW,Straight	Rough
Polyvinyl Chloride Glove, Unsupported							
Ansell Edmont	DuraTouch Sheer	5 (0.013)	S,M,L,XL			Rolled	Smooth
Ansell Edmont	DuraTouch Ambi	6.5 (0.017)	M,L,XL			Rolled	Smooth
Boss	Powdered Vinyl	5 (0.013)	S,M,L,XL	10		Rolled	Smooth
Boss	Powder free Vinyl	5 (0.013)	S,M,L	10		Rolled	Smooth
Defense Apparel	Pylox Quixams	5 (0.013)	S,M,L	10.5		Pinked	Smooth
Defense Apparel	Lightweight Vinyl	6.5 (0.017)	L,XL			Rolled	Smooth
Handgards	Seamless vinyl	5 (0.013)	S,M,L			Straight	Smooth
Marigold	V–1000	5 (0.013)	S,M,L,XL	9		Rolled	Smooth
Memphis	Disposable Vinyl	5 (0.013)	S,M,L,XL			Straight	Smooth
Oak	Long Length	4 (0.010)	S,M,L/XL			Rolled	Smooth
Oak	Clean Room	4 (0.010)	S,M,L/XL			Rolled	Smooth
Oak	Disposable Vinyl	4 (0.010)	S,M,L/XL			Rolled	Smooth
Oak	Low Powder	4 (0.010)	S,M,L			Rolled	Smooth
Oak	Heavyweight	6.5 (0.017)	S,M,L/XL			Rolled	Smooth
Oak	Super Heavyweight	10 (0.025)	S,M,L/XL	14		Rolled	Smooth
Oak	Maximum Length	4 (0.010)	S/M,L/XL			Rolled	Smooth
Pioneer	Stanflex V–20	20 (0.051)	S,M,L,XL	10.5		Pinked	Smooth,Rough
Pioneer	Quixam V–5	5 (0.013)	S,M,L	10.5		Pinked	Smooth,Rough
Pioneer	Nimble Fingers V–10	10 (0.025)	S,M,L,XL	10.5		Pinked	Smooth,Rough
Pro–Guard	DV–Prepowdered	6 (0.015)	S,M,L,XL	9.9		Rolled	Smooth
Pro–Guard	PF/DV–Powder Free	6 (0.015)	S,M,L,XL	9.9		Rolled	Smooth
Renco	Powder free vinyl	5 (0.013)	S,M,L,XL	10		Rolled	Smooth
Renco	Powdered vinyl	5 (0.013)	S,M,L,XL	10		Rolled	Smooth
Teflon, Unsupported							
CRP	E3400	2 (0.005)	Men's	11,18,24,36		Straight	Smooth

* NA=information not available or applicable
+ W=wrist length
# KW=knit wrist

B Appendix

Sleeves

Appendix B – Sleeves

	Vendor	Model #	Length (inches)	Comments
Chemrel, Plastic Laminate – Polyester	Chemron	C604	full arm	
Chloroprene	CPP	YNS–18C	18	14 oz.; elastic cuff
Chloroprene–cotton–chloroprene	Kishigo	NSY–18	18	18 oz.
	Sawyer Tower	55–00	18	
Chloroprene – Nylon	PGI	NN–145–18	18	
	Rainfair	2300–1212		
Chloroprene – Nylon – Chloroprene	Marathon	492		
Encase III Polyethylene – Nonwoven PP	Abandaco	EB2502	18	
		EY2509	18	
		EY6509	18	Bound seams
Nitrile	Charkate	250	18	
		750L	23	Snap wrist
Nitrile – Cotton	PGI	1518	18	Various end options
Nitrile – Cotton – Nitrile	Kishigo	HS–18	18	18 oz.
		HSB–27	27	18 oz.; Ties at shoulder
	North	H1716	16	
		H1718	18	
	PGI	4518	18	Various end options
		4527–SL	27	Ties at shoulder
	Rainfair	2300–1030		
Nitrile – Cotton + Polyester – Nitrile	Ronco	504D,E,& C	18	Elastic Cuff
Nitrile + Polyvinyl Chloride + Polyurethane – Polyester	PGI	ARM–18	18	
Polyethylene – Polyester	Ronco	504EC	18	7 oz., elastic cuff
Polyethylene – Nonwoven Polyproplylene	Magid	SL9P	18	
	Melco	1806		

	Vendor	Model #	Length (inches)	Comments
Polyethylene – Nylon – Polyethylene	Scooba			
Polyethylene – Tyvek	Abandaco	2509	18	
		6509	18	Bound seams
	Charkate	8010	18	
	Daffin	1890	18	
	Durafab	2190	14	Bottom cuff
		2191	20	Bottom cuff
	Kappler	5502	20	
	Mar–Mac	PC760 BS	18	
		PC760 XL BS	22	
	Melco	1808		
Polypropylene, Nonwoven	Abandaco	RB2502	18	
	Scooba			
Polyurethane –	CPP	YUS–18	18	Elastic cuff
Polyvinyl Chloride	Ansell Edmont	54–103	18	elastic ties
	Charkate	1108	16	8 mil
		1109	18	8 mil
	CPP	8–HS18, 24		8 mil, heat sealed
		4–HS	18	4 mil, heat sealed
	Expendables	589	18	
	Kishigo	P1808		
	Magid	190–18	18	
	Melco	SL/18		
	North	C612	12	6 mil
		C616	16	6 mil
		C618	18	6 mil
	Plastimayd			8 mil

	Vendor	Model #	Length (inches)	Comments
	PGI	418	18	4 mil
		818	18	8 mil
		827–SL	27	8 mil; ties at shoulder
	Pulmosan	60351 K318		8 mil
	Ronco	504K	18	8 mil, elastic cuff
	Tracies	PS–10–6	18	6 mil; various types of seaming
		PS–20–6	25	6 mil; ties at shoulder
	Scooba			
Polyvinyl Chloride – Polyester – Polyvinyl Chloride	Frommelt	933	14	
		934	18	
		935	23	
	Wheeler	55036	12	16 oz
		55236	18	16 oz
		55336	24	16 oz
Saranex (Single Ply) – Tyvek	Abandaco	2513	18	
	Charkate	8210	18	
	Expendables	789	18	
	Kappler	77502	20	
	Mar–Mac	760 BS	18	
		760 XL BS	22	
Sontara	Mar–Mac	FRS760 BS	18	
		FRS760 XL	22	
Styrenebutadiene Rubber – Cotton	Rainfair	2300–1070		
Tyvek, Nonwoven Polyethylene Fabric	Abandaco	2502	18	
	Charkate	6010	18	
	Chicago Prot.	901	18	
	Cleanroom Prod.	E4100		

Vendor	Model #	Length (inches)	Comments
Daffin	1090	18	
Durafab	2191	20	Elastic cuff
Expendables	185	18	
Kappler	2501	18	
	2502	20	
Magid	SL28	18	
Mar–Mac7	60 BS	18	
	760 XL BS	22	
Melco1807			

C Appendix

Footwear

Appendix C – Footwear

Vendor	Style	Sizes	Height (inches)	Toe	Comments
Butyl Rubber					
Chem–Tex	SC	One size	16	P	
MSA	SC	One size	10	P	
Tingley	SC	S–XL	10	P	
Chemrel, Plastic Laminate Polyester					
Chemron	SC	One size	10,16	P	
Chemrel Max, Plastic Laminate – Polyester – Plastic Laminate					
Chemron	SC	One size	10,16	P	
Chloroprene					
Allied	B	6–13M	6,10,12,16	S	
Boss	B	6–13M	12,16	P,S	
Iron Age	SC	S–XL	10,16	P	
LaCrosse	B	6–14M	12,16	P,S	
Magid	B	6–13M	12,16	P,S	
Lehigh	B	6–13M	12,16	S	
Ranger	B	6–13M	7,12,15	S	
RICO	B	6–13M	6	S	
RICO	SC	S–XL	4	P	
Rainfair	B	6–13M	12,16	P,S	
Standard Safety	B	7–13M	12	P	
Standard Safety	SC	S–XL	16	P	
Tingley	B	6–13M	6,12,16	P,S	Net lining
Tingley	SC	S–XL	10,17	P	
Kleenguard, Nonwoven PP SMS Fabric					
Kimberly–Clark	SC	One size	10	P	
Natural Rubber					
Abel	B	7–16M	14,17	P	
Allied	B	6–13M	16	P,S	
Allied	SC	S–XL	6.16	P	
Bata	B	4–13M	6,12,16	P,S	
Bata	B	4–11W	14	P,S	

Vendor	Style	Sizes	Height (inches)	Toe	Comments
Bata	SC	S–XL	6,9,17	P	
Boss	B	5–13M	6,10,15,16	P,S	
Boss	B	4–10W	13	S	
Boss	SC	6–14M	6,10,12,17	P	
Gloves, Inc.	B	7–16M	17	P	
Iron Age	B	6–13M	6,10,12	S	
Iron Age	SC	S–XL	10,16	P	
LaCrosse	B	5–16M	7,12,14,16,18	P,S	P,S midsole
LaCrosse	B	5–11W	12	S	
LaCrosse	SC	6–15M	6,12,14,16	P	
LaCrosse	SC	5–11W	6,10	P	
Lehigh	B	5–14M	6,11,12,15,16	S	P,S midsole
Lehigh	B	4–11W	10,12	S	P,S midsole
Lehigh	SC	6–14M	11,14	P	
Magid	B	6–13M	6,16	P,S	
Magid	SC	S–XL	6,11,16,17	P	
Rainfair	B	6–13M	12,14,16	P,S	
Ranger	B	6–13M	6,10,12,15,16	P,S	P,S midsole
Ranger	SC	6–13	4,6,10,13,14, 15,16,17,18	P	
Renco	SC	M–XL	17	P	
RICO	B	6–13M	6,12,16	S	
RICO	SC	S–XL/M	10,17	P	
RICO	SC	S–XL/W	11	P	
Steele	SC	S–XL	20	P	
Tingley	B	6–13M	6,12,16,17	P,S	P,S midsole
Tingley	SC	S–XL	10,11,14,17	P	
Nitrile Rubber					
Bata	B	6–14M	12,16	P	
Magid	B	6–13M	12,16	P,S	
Rainfair	B	6–13M	16	S	
Nitrile – PVC					
Bata	B	4–13M	16	P,S	
Bata	B	4–11W	14	P	
Jordan David	B	3–13M	16	P,S	
Lehigh	B	6–13M	6,15	P,S	

Vendor	Style	Sizes	Height (inches)	Toe	Comments
Ranger	B	3–13M	6,16	P,S	
Tingley	B	5–13M	12,15	P,S	
Tingley	B	5–10W	14	S	
Polyethylene					
Granet	SC	One size	12	P	
Magid	SC	One size	10	P	
Polyethylene – Encase					
Abandco	SC	one size	6,14,16	P	
Polyethylene – Tyvek					
Abandco	SC	One size	6,14	P	
Charkate	SC	One size	16	P	
CRP	SC	One size	6,12	P	
Daffin	SC	One size	,18	P	
Durafab	SC	One size	6,10	P	
Expendables	SC	One size	6	P	
Kappler	SC	One size	6	P	
Mar–Mac	SC	One size	12,18	P	
Melco	SC	S–XL	6,18	P	
MSA	SC	One size	10	P	
Pro/Control	SC	One size	6,17	P	
Polyethylene – Nylon – Polyethylene					
Scooba	SC	One size	10	P	
Polyurethane					
Rainfair	B	6–13M	16	S	
Polyurethane – Natural Rubber					
Iron Age	B	6–13M	12,15,16	S	P,S midsole;Ureth. coated
Polyurethane – Polyvinylchloride					
Bata	B	4–13M	6,12,16	P,S	
Bata	B	4–11W	14	P,S	
Iron Age	B	6–13M	6,16	S	

Vendor	Style	Sizes	Height (inches)	Toe	Comments
LaCrosse	B	3–13M	7,14	P,S	
Lehigh	B	4–13M	16	S	
Lehigh	B	4–10W	14	S	
Magid	B	4–13M	16	P,S	
Rainfair	B	6–13M	16	P,S	
Ranger	B	3–13M	6,16	P,S	
RICO	B	6–13M	6	S	
Polyvinylchloride					
Allied	B	4–13M	6,16	S	
Allied	SC	S–XL	11,16	P	
Bata	B	4–13M	12,16	P,S	
Bata	B	4–11W	14	P,S	
Boss	B	6–13M	12,16	P,S	
CPP	SC	One size	10	P	
CRSI	B	6–13M	12	P	
Defense Apparel	SC	S–XL	6,8,10,17	P	
Defense Apparel	B	7–17	10	P	
Expendables	SC	One size	6	P	
Iron Age	B	4–13M	6,16	P,S	
Jordan David	SC	S–XL	6,10,17	P	
Jordan David	B	3–13M	6,16	P,S	
LaCrosse	B	3–13M	6,11,16	P,S	
LaCrosse	SC	6–15M	11,16	P	
Lehigh	B	6–13	12,15	P,S	
M.L. Kishigo	SC	One size	10	P	
Magid	SC	One size	17	P	
Magid	B	6–13M	12,16	P,S	
Melco	SC	S–XL	6,10	P	
MSA	SC	One size	10	P	
Plastex	SC	One size	10	P	
Protexall	SC	One size	12	P	
Rainfair	B	5–13M	11,16	P,S	
Ranger	SC	3–13M	6,12,16	P,S	
RICO	B	6–13M	12,16	S	
RICO	SC	S–XL	4,10,16	P	
Standard Safety	SC	M,L	10	P	
Tingley	B	5–13M	15	P,S	

Vendor	Style	Sizes	Height (inches)	Toe	Comments
Tingley	B	5–10W	14	P,S	P,S midsole
Tracies	SC	M–XL	6,12	P	
Trelleborg	B	6–13	16	P	
Polyvinylchloride – Nylon – Polyvinylchloride					
Colonial	SC	S–XL	8	P	
Saranex – Tyvek					
Abandco	SC	one size	16	P	
Charkate	SC	One size	16	P	
Daffin	SC	One size	6,18	P	
Expendables	SC	One size	6	P	
Kappler	SC	One size	6,12	P	
Mar–Mac	SC	One size	6,12,18	P	
MSA	SC	One size	10	P	
Pro/Control	SC	One size	6,17	P	
Tyvek, Nonwoven Polyethylene Fabric					
Abandco	SC	One size	6,14,16	P	
Allied	SC	One size	6,12	P	
Charkate	SC	One size	16	P	
CRSI	SC	One size	12	P	
Daffin	SC	One size	6,18	P	
Durafab	SC	One size	6,10	P	
Expendables	SC	One size	6	P	
Kappler	SC	One size	6,12,16	P	
Mar–Mac	SC	One size	6,12,16	P	
Melco	SC	One size	6,18	P	
MSA	SC	One size	10	P	
Pro/Control	SC	One size	6,17	P	
Superior Surgical	SC	One size	6,16	P	

Style: SC=shoe cover; B=boot
Size: S=small; M=medium; XL=extra large; M following a number=men's; W=women's
Height: Shoe=6"; Halfs=12"; Knee=16"
Toe and Comments: P=plain; S=steel

D Appendix

Hats

Appendix D – Hats

Vendor	Model #	Style	Sizes (inches)	Seams	Comments
Chloroprene – Nylon					
Boss	3NN0551	Sou'wester			
Neese	12	Sou'wester		S & S	
Chloroprene + Sbr – Nylon					
Sawyer–Tower	N–333	Sou'wester	6–3/4 —> 7–1/2	S & S	8 oz.; unlined
Chloroprene – Cotton					
Sawyer–Tower	N–333	Sou'wester	6–3/4 —> 7–1/2	S & S	11 oz.; unlined
Chloroprene – Cotton – Chloroprene					
Marathon	70	Sou'wester	6–1/2 —> 7–3/4		
	72	Nor'easter	6–1/2 —> 7–3/4		
Sawyer–Tower	N–15	Sou'wester	6–3/4 —> 7–1/2	S & S	14.5 oz.; lined
Chloroprene – Nylon – Chloroprene					
Sawyer–Tower	N–15	Sou'wester	6–3/4 —> 7–1/2	S & S	8.5 oz.; lined
Polyurethane – Nylon					
Neese	3			S & S	
Polyvinylchloride – Rayon					
Jomac		Sou'wester			
Polyvinylchloride – Nylon					
Neese	18–H	Sou'wester			
	16	Sou'wester			
	14	Sou'wester			

Vendor	Model #	Style	Sizes (inches)	Seams	Comments
Polyvinylchloride – Nylon – Polyvinylchloride					
Ansell–Edmont	65–609	Sou'wester	M, L		
Magid	S7819	Sou'wester			
Neese	10	Sou'wester		S & S	
Plastex	10–454	Sou'wester	one size		
Sawyer–Tower	V–333	Sou'wester	6–3/4 —> 7–1/2	HS	
Styrenebutadiene Rubber – Cotton					
Rainfair	2505–1197	Sou'wester	6–3/4 —> 7–3/4		
	2505–1174	Storm Hat	6–3/4 —> 7–3/4		chin strap

S & S = sewn and sealed
HS = Heat seal

E Appendix

Hoods
(without face shields)

Appendix E – Hoods (without face shields)

Vendor	Model #	Coverage	Pieces	Sizes	Closure	Seams	Comments
Butyl – Nylon – Butyl							
Sawyer–Tower	B–800	H	3	S, M, L, XL	DS	S & S	11 oz.; unlined
Chemrel, Plastic Laminate – Polyester							
Chemron	Pullover	H & S	2	one size	Face Elastic		
Chloroprene – Cotton							
Sawyer–Tower	NU–82	H	2	S, M, L, XL	DS	S & S	11 oz.; unlined
Chloroprene – Cotton – Chloroprene							
Marathon	DH–20	H		one size	DS		13.5 oz
Marathon	DH–40	H		one size	DS		15.5 oz
Sawyer–Tower	NL–83	H	3	S, M, L, XL	DS	S & S	14.5 oz.; lined
Chloroprene – Nylon							
Boss	3NN0541	H	2	one size	DS	Bonded	
Jomac	H–70–501	H		one size	DS		
Neese	17	H		one size	DS	S & S	
Rainfair	2800–2286	H		one size	DS		
Chloroprene – Nylon – Chloroprene							
Bata	91060	H		one size	DS	Sealed	12.5 oz.
Marathon	DH–40	H		two sizes	DS		
Neese	24	H		one size	DS	S & S	
Sawyer–Tower	NU–83	H	3	S, M, L, XL	DS	S & S	8.5 oz.; unlined
Chloroprene + SBR – Nylon							
Sawyer–Tower	NN–82	H	2	S, M, L, XL	DS	S & S	8 oz.; unlined
Kleenguard, Nonwoven PP SMS Fabric							
Kimberly–Clark	36890			one size	Face elastic		
Nylon – Polyurethane							
Rainfair	2800–2597	H		one size	DS		
Rainfair	2800–2594	H		one size	DS		
Sawyer–Tower	98–00	H	3	S, M, L, XL	DS	S & S	11 oz.

Vendor	Model #	Coverage	Pieces	Sizes	Closure	Seams	Comments
Polyethylene – Tyvek							
Charkate	8011	H & S	3	one size	snap front		
Expendables	692	H & S		one size	DS		
Mar Mac	PC757 EFH WS	H & S		one size	Face elastic		
Mar Mac	PC757 EFH BS	H & S		one size	Face elastic		
Mar Mac	PC757 EFH WS	H		one size	Face elastic		
Mar Mac	PC757 EFH BS	H		one size	Face elastic		
MSA	696057	H & S		one size	DS		
Polyurethane – Nylon							
Bata	96060	H		one size	DS		
Bata	96560	H		one size	DS	S & Taped	
Jomac	H–707–501	H		one size	DS		
Neese	4	H		one size	DS	S & S	
Neese	1	H		one size	DS		
Polyvinylchloride – Nylon							
Ansell–Edmont	65–561	H		one size	DS		
Jomac	H–606–501	H		one size	DS		
Jomac	H–607–501	H		one size	DS		
Neese	19–HO	H		one size			
Neese	15	H		one size	DS	Heat sealed	
Polyviniychloride – Nylon – Polyvinylchloride							
Ansell–Edmont	65–411	H		one size	DS		
Ansell–Edmont	65–611	H		one size	DS		
Bata	93060	H		one size	DS	Welded	
Bata	91560	H		one size	DS	S & S	7.5 oz.
Boss	3PN0778	H	2	one size	DS	S & S	
Magid	H7819	H			DS		
Neese	11	H		one size	DS	S & S; Welded	
Rainfair	2870–2509	H		one size	DS		
Sawyer–Tower	VU–82	H	2	S, M, L, XL	DS		7.5 oz.; unlined
Sawyer–Tower	SV–82	H	2	S, M, L, XL			7.5 oz.; unlined

Vendor	Model #	Coverage	Pieces	Sizes	Closure	Seams	Comments
Polyvinylchloride – Nylon+Polyester							
Bata	94060	H		one size	DS	S & S	
Boss	3PN0776	H	2	one size	DS	S & S	
Polyvinylchloride – Nylon+Polyester – Polyvinylchloride							
Boss	3PN0777	H	2	one size	DS	S & S	
Sawer–Tower	48–380	H	2	S, M, L, XL			
Polyvinylchloride – Polyester							
Bata	92060	H		one size	DS	Dielectric	
Bata	92560	H		one size	DS	Dielectric	
Neese	96–HO	H		one size	DS	Welded	
Polyvinylchloride – Polyester – Polyvinylchloride							
Rainfair	2870–6009	H		one size	DS		Three weights
Polyvinylchloride – Rayon – Polyvinylchloride							
Jomac	H–19–501	H		one size	DS	S & S	
Jomac	H–22–501	H		one size	DS	S & S	
Saranex (Single Ply) – Tyvek							
Charkate	8211PE	H & S	2	one size	Face elastic		
Expendables	792	H & S		one size	DS		
Mar Mac	SRN757 EFH WS	H & S		one size	Face elastic		
Mar Mac	SRN757 EFH BS	H & S		one size	Face elastic		
Mar Mac	SRN757 EFH WS	H		one size	Face elastic		
Mar Mac	SRN757 EFH BS	H		one size	Face elastic		
MSA	696056	H & S		one size	DS		
Sontara							
Mar Mac	FRS 756	H & S		one size			
Mar Mac	FRS 757	H & S		one size			
Styrenebutadiene Rubber – Cotton							
Rainfair	2800–1309	H		one size	DS		

Vendor	Model #	Coverage	Pieces	Sizes	Closure	Seams	Comments
Tyvek, Nonwoven Polyethylene Fabric							
Charkate	several	H & S		one size	Face elastic		
Clean Room Prod.	E2100	H & S	3	one size	Snap		
Clean Room Prod.	E2200	H & S	2	one size	Snap		Eyes only
Daffin	1065	H		one size			
Daffin	1066	H & S		one size			
Daffin	1067	H & S		one size	snaps		
Durafab	2194	H		one size			
Durafab	2196	H & S		one size	DS		
Expendables	19	H & S		one size	snaps		
Expendables	193	H & S		one size	Face elastic		
Holcomb	2601	H		one size	DS		
Mar Mac	757 EFH WS	H & S		one size	Face elastic	Welded	
Mar Mac	757 EFH BS	H & S		one size	Face elastic	S & S	
Mar Mac	757 EFH WS	H		one size	Face elastic	Welded	
Mar Mac	757 EFH BS	H		one size	Face elastic	S & S	
Melco	900	H & S		one size	snap		
Melco	901	H		one size			
MSA	696005	H & S		one size	DS		
Superior Surg.	8622	H & S		one size			

Coverage: H=head only (this is a detachable hood); H & S=head and shoulders
Pieces: Number of pieces of fabric composing hood
Sizes: S=small; M=medium, L=large, XL=extra large
Seams: S & S=stitched and sealed
Closure: DS=drawstring

F Appendix

Aprons

Appendix F – Aprons

Vendor	Thick (mils) or Weight (oz.)	Edges	Neck Straps	Comments
Chemrel, Plastic Laminate – Polyester				
Chemron		F	T	extra long length
Chloroprene Rubber				
Magid	L & H		T	
Chloroprene Rubber – Cotton				
CPP	19 & 12.5 ozs.	F	T	
Chloroprene Rubber – Nylon				
PGI	L	F	T,F,AS	D
Rainfair		F	AS	
Tingley		F	T	
Chloroprene – Cotton – Chloroprene				
Kishigo		F	T	
Marathon	13.5, 15.5	F	A	
Rainfair		F	AS	
Sawyer–Tower		F	T,A	BP
Tingley		F	T	
Chloroprene – Nylon – Chloroprene				
Marathon	4.5, 15.5	F	A	
Sawyer–Tower	L, H	F	T,AS	BP
Hypalon				
Frommelt	M, H		A	
Natural Rubber – Cotton				
Rainfair		F	AS	
Nitrile Rubber				
Charkate	24 & 13 oz.	F	T	BP
PGI	H, XH	P	AS	

Vendor	Thick (mils) or Weight (oz.)	Edges	Neck Straps	Comments
Nitrile Rubber – Cotton				
CPP	14,18 & 22 ozs.	F	T	
Rainfair		F	AS	BP
Sawyer–Tower	M,H	F	T	
Nitrile Rubber – Nylon				
Sawyer–Tower		F	T,AS	
Nitrile – Cotton – Nitrile				
Ansell Edmont	H		AS	
Kishigo	18 & 26 ozs.	F	T	BP
PGI	M,H,XH	F	T,F,AS	
Nitrile – Cotton + Polyester				
Ronco	H	F	A	BP
Nitrile + Pvc – Cotton				
Tingley		F	AS	BP
Nitrile + Pvc – Polyester				
Tingley		F	AS	BP
Nitrile + Pvc + Polyurethane – Polyester				
PGI		F	T	
Nitrile – Nylon – Nitrile				
Edmont			F,AS	
North Hand	L,H	F,P	T,A	
PGI	M,H,XH	F	T,F,AS	D
Nitrile + Pvc – Polyyester – Nitrile + Pvc				
PGI	XH	P	T,F,AS	D

Vendor	Thick (mils) or Weight (oz.)	Edges	Neck Straps	Comments
Polyethylene, Density Unknown, Film				
Ansell Edmont	1,1.25,1.75	P	F	
Charkate	1.5,2,4	P	F	
Melco		P	T	D
Pro–guard	1,2 mils.	P	F	
PGI	1.25,1.75 mils.	P	F	
Polyethylene – Encase II				
Abandco	L	F	T	
Polyethylene – Nylon – Polyethylene				
Scooba	1.54 oz		F	
Polyethylene – Polyester – Polyethylene				
PGI	10 mils.	F	T,F,AS	DT
Polyethylene – Polyester				
Ronco	L	P	T	
Polyethylene – Tyvek				
Abandco	L	F	T	
Charkate	L	P	T	
Daffin	L	P	F	
Durafab	L	P	F	
Expendables	L		F	
Kappler	L	P	F	long & short lengths
Melco	L	P	T	
Polypropylene, Nonwoven				
Abandco			T	
Scooba			T	
Kleenguard Nonwoven PP SMS Fabric (Kimberly–clark)				
Kimberly–Clark	L	F	T	
Polyurethane – Nylon				
CPP	L	F	T	

Vendor	Thick (mils) or Weight (oz.)	Edges	Neck Straps	Comments
Polyvinyl Chloride				
Ansell Edmont	7.5 & 20 mils.	F,P	F,T	
Charkate	6,8,12 & 20 mils.	F,P	T	
CPP	4,6,8,12 & 20 mils.	F,P	T,F	BP
Cleanroom	trim to fit	P	F	conductive
Gloves	6,8 mils.	F	T	
Holcomb	8 mils.	F		
Kishigo	4,8,12 & 15 mils.	F,P	F,T	
Magid	8,12 mils.		T	
Melco		P	T	
North Hand	6 mils.	F	T,A	
Plastimayd	8,20 mils.		F	
PGI	4,8,12,15,20 mils	F,P	T	BP,D
Pulmosan	8 mils		T	
Ronco	8,20 mils.	F	T	
Scooba			T	
Tracies	4,6,8 mils		F,T	long and short
Polyvinyl Chloride – Cotton				
Jomac	M,H, XH	F	T	
Polyvinyl Chloride – Nylon				
CPP		F	T	BP
Polyvinyl Chloride – Polyester				
Holcomb	14 ozs.			
Rainfair		F	AS	
Standard	19–30 mils.		T	
Polyvinyl Chloride – Rayon				
Jomac	M,H,XH	F	T	with or without ties
Polyvinylchloride – Nylon – Polyvinylchloride				
Sawyer–Tower		F	T	

Vendor	Thick (mils) or Weight (oz.)	Edges	Neck Straps	Comments
Polyvinylchloride – Polyester – Polyvinylchloride				
Frommelt	M,H		A	
Rainfair				
Standard	19–30 mils.		T	
Wheeler	H	F	A	
Saranex (Single–ply) – Tyvek				
Abandco	L		T	
Charkate	L	P	T	
Kappler	L	F	F	long length
Mar–Mac	L	F	F	
Styrenebutadiene Rubber – Cotton – Sbr				
Tingley		P	T	
Styrenebutadiene Rubber – Nylon				
PGI	L	F	T,F,AS	D
Styrenebutadiene Rubber – Nylon – Sbr				
PGI	XH	F	T,F,AS	D
Tyvek, Nonwoven Polyethylene Fabric (Dupont)				
Abandco	L	P	T	
Charkate	L	P	T	
Cleanroom	L	P	F	one size fits all
Daffin	L	P	F	
Durafab	L	P	F	avail. half aprons
Expendables	L	P	F	
Holcomb	L		T	
Kappler	L	P	F	long & short lengths
Melco	L		T	half apron also

G Appendix

Aprons with Sleeves

Appendix G – Aprons With Sleeves

Vendor	Thick (mils) or Weight (oz.)	Edges	Neck Straps	Comments
Chemrel, Plastic Laminate – Polyester				
Chemron		F	T	hook & loop closure, ankle length, one size
Chloroprene – Nylon				
PGI		F	T	
Nitrile + Pvc + Polyurethane – Polyester				
PGI	L	F	T	tape tie back closure
Polyethylene – Nonwoven Polypropylene				
Melco	L	P	T	
Polyethylene – Tyvek				
Kappler	L	P	T	
Mar–Mac		F	F	
Polyvinyl Chloride				
Ansell Edmont	7.5 mils	P		elastic waist
Expendables	L,XL	F		hook & loop fastener, elastics at wrists
PGI	8 mil	F	T	
Rainfair	7.5 mils S,XL		T	
Polyvinylchloride – Polyester				
Standard	19–30 mils	P	A	
Saranex (Single–ply)– Tyvek				
Mar–Mac	L	F	F	neck tie, elastic at wrists

Thickness/Weight: L=light, M=medium, H=heavy, XH=extra heavy
Edges: F=finished, P=Plain
Neck Straps: F=fixed, A=adjustable, AS=adjustable with safety release, T=ties
Features: D=drip trough, BP=belly patch

H Appendix

Clothing Based on Porous or Microporous Fabrics

Appendix H – Clothing Based on Porous or Microporous Fabrics

Vendor	Style	Garment Type	Sizes	Attached Closure	Hood	Boot	Ankle	Interfaces Wrist	Seam Types	Comments
Cellulosic, Reinforced										
Durafab	K4120Z	Coverall	S,M,L,XL	Z	N	N	O	O	S,B,U,S/B,S/T,SN	
Durafab	K4140	Lab Coat	S,M,L,XL	S	N			O	S,B,U,S/B,S/T,SN	
Durafab	K4150	Pants	S,M,L,XL			N	O		S,B,U,S/B,S/T,SN	
Durafab	K4160	Shirt	S,M,L,XL	S				O	S,B,U,S/B,S/T,SN	
Kleenguard, Nonwoven PP SMS Fabric										
Kimberly-Clark		Coverall	S,M,L,XL,XXL	Z	N	N	O	E		Elastic Back
Kimberly-Clark		Lab Coat	M,L,XL	S	N			O		
Kimberly-Clark	Hooded	Coverall	M,L,XL,XXL	Z	E	N	E	E		Elastic Back
Kimberly-Clark	Hooded	Coverall	M,L,XL,XXL	Z	E	Y		E		Elastic Back
Kimberly-Clark	Limited Use	Coverall	S,M,L,XL,XXL	Z	N	N	O	O		
Kimberly-Clark	Limited Use Hood	Coverall	XL,XXL	Z	E	N	O	O		
Kimberly-Clark	Limited Use Hood	Coverall	XL,XXL	Z	E	Y		O		
Polypropylene, Nonwoven										
Abandaco	1212	Lab Coat	S,M,L,XL,XXL,XXXL	S	N	N		O		
Abandaco	1612	Shirt	S,M,L,XL,XXL,XXXL	S	N	N		O		
Abandaco	1812	Pants	S,M,L,XL,XXL,XXXL			N	O			
Abandaco	1412	Coverall	S,M,L,XL,XXL,XXXL	Z	N	N	O	O		
Abandaco	1414	Coverall	S,M,L,XL,XXL,XXXL	Z	D	Y		E		
Abandaco	1427	Coverall	S,M,L,XL,XXL,XXXL	Z	D	N	O	O		
Abandaco	1417	Coverall	S,M,L,XL,XXL,XXXL	Z	N	N	E	E		
Expendables	40*	Coverall	S,M,L,XL,XXL,XXXL	Z						
Kappler	6412	Coverall	S,M,L,XL	Z	N	N	O	O	S	
Kappler	6612	Shirt	S,M,L,XL	S	N			O	S	
Kappler	6812	Pants	S,M,L,XL			N	O		S	
Kappler	61412	Coverall	S,M,L,XL	Z	N	N	O	O	S	
Kappler	61414	Coverall	S,M,L,XL	Z	E	Y		E	S	
Melco	3317	Lab Coat	S,M,L,XL,XXL	S				E		1 Pocket
Melco	3302	Lab Coat	S,M,L,XL,XXL	S				E		
Melco	55802	Coverall	S,M,L,XL,XXL	Z	N	N	O	O		Yoke
Melco	55840	Coverall	S,M,L,XL,XXL	Z	N	N	E	E		Yoke
Melco	55819	Coverall	S,M,L,XL,XXL	Z	E	N	O	E		Yoke
Pro/Control	200–2PW	Coverall	M,L,XL,XXL,GT	Z	N	N	O	O		
Pro/Control	210–2PW	Coverall	M,L,XL,XXL,GT	Z	N	N	E	E		
Pro/Control	211–2PW	Coverall	M,L,XL,XXL,GT	Z	E	N	O	O		
Pro/Control	212–2PW	Coverall	M,L,XL,XXL,GT	Z	E	N	E	E		
Pro/Control	213–2PW	Coverall	M,L,XL,XXL,GT	Z	E	Y		E		
Pro/Control	A–D06–520	Lab Coat	M,L,XL,XXL,GT	S				O		2 Pockets

Vendor	Style	Garment Type	Sizes	Attached Closure	Hood	Boot	Ankle	Interfaces Wrist	Seam Types	Comments
Pro/Control	A–D06–499	Lab Coat	M,L,XL,XXL,GT	S				O		
Pro/Control	A–D05–180	Sack Suit	M,L,XL,XXL,GT	D			O	O		
Pro/Control	A–D16–200	Shirt	M,L,XL,XXL,GT	S				O		
Pro/Control	A–D15–700	Pants	M,L,XL,XXL,GT				O			
Scooba		Coverall	S,M,L,XL,XXL,XXXL	Z	N	N	O	O	S	
Scooba		Coverall	S,M,L,XL,XXL,XXXL	Z	E	Y		E	S	
Scooba		Coverall	S,M,L,XL,XXL,XXXL	Z	O	Y		O	S	
Scooba		Lab Coat	S,M,L,XL,XXL,XXXL	S				O	S	
Scooba		Shirt	S,M,L,XL,XXL,XXXL	S				O	S	
Scooba		Pants	S,M,L,XL,XXL,XXXL				O		S	
Sontara										
Abandaco	1409	Coverall	S,M,L,XL,XXL,XXXL	Z	N	N	E	E		
Abandaco	1451	Coverall	S,M,L,XL,XXL,XXXL	Z	D	N	E	E		
Abandaco	1410	Coverall	S,M,L,XL,XXL,XXXL	Z	N	N	O	O		
Abandaco	1457	Coverall	S,M,L,XL,XXL,XXXL	Z	D	N	O	O		
Abandaco	0955	Lab Coat	S,M,L,XL,XXL,XXXL	S				O		
Mar–Mac	1412	Coverall	S,M,L,XL	Z	N	N	O	O		
Mar–Mac	1414 EFH	Coverall	S,M,L,XL	Z	E	Y		E		
Mar–Mac	1414 NEW	Coverall	S,M,L,XL	Z	E	Y		O		
Mar–Mac	1417	Coverall	S,M,L,XL	Z	N	N	E	E		
Mar–Mac	1427 EFH	Coverall	S,M,L,XL	Z	E	N	O	O		
Mar–Mac	1428 EFH	Coverall	S,M,L,XL	Z	E	N	E	E		
Mar–Mac	1428 NEW	Coverall	S,M,L,XL	Z	E	N	E	O		
Mar–Mac	720	Lab Coat	S,M,L,XL	S				O		
Mar–Mac	721	Lab Coat	S,M,L,XL	S				O		2 Pockets, Extra Full
Mar–Mac	730	Pants	S,M,L,XL				O			
Mar–Mac	735	Shirt	S,M,L,XL	S			O			
Melco	3401	Lab Coat	S,M,L,XL,XXL	S				O		2 Pocket
Tyvek, Nonwoven Polyethylene Fabric										
Abandaco	1236	Lab Coat	S,M,L,XL,XXL,XXXL	S				O		
Abandaco	1426	Coverall	S,M,L,XL,XXL,XXXL	Z	N	N	O	O		
Abandaco	1470	Coverall	S,M,L,XL,XXL,XXXL	Z	N	N	O	O		Elast Back,Side Slit,Pockets
Abandaco	1523	Coverall	S,M,L,XL,XXL,XXXL	Z	N	N	E	E		
Abandaco	1616	Shirt	S,M,L,XL,XXL,XXXL	S				O		
Abandaco	1861	Pants	S,M,L,XL,XXL,XXXL					O		
Ansell Edmont	55–530	Coverall	M,L,XL	Z	N	N	O	O		
Ansell Edmont	55–533	Coverall	M,L,XL	Z	E	N	E	E		
Ansell Edmont	55–430	Lab Coat	S,M,L,XL	B				O		
Ansell Edmont	55–510	Coverall	S,M,L,XL	Z	N	N	O	O		Heavy Duty, Mandarin Collar
Charkate	6001	Coverall	S,M,L,XL,XXL,XXXL	Z	N	N	O	O		

Vendor	Style	Garment Type	Sizes	Attached Closure	Hood	Boot	Ankle	Interfaces Wrist	Seam Types	Comments
Charkate	6001–0	Coverall	S,M,L,XL,XXL,XXXL	Z	N	N	O	O		
Charkate	9001	Coverall	S,M,L,XL,XXL,XXXL	Z	N	N	O	O		
Charkate	6001EWA	Coverall	S,M,L,XL,XXL,XXXL	Z	N	N	E	E		
Charkate	6001HEWA	Coverall	S,M,L,XL,XXL,XXXL	Z	D	N	E	E		
Charkate	6001H	Coverall	S,M,L,XL,XXL,XXXL	Z	D	N	O	O		
Charkate	6001B	Coverall	S,M,L,XL,XXL,XXXL	Z	D	Y		E		
Charkate	6003	Lab Coat	S,M,L,XL,XXL,XXXL	S				O		
Charkate	6003/2P	Lab Coat	S,M,L,XL,XXL,XXXL	S				O		2 Pockets
Charkate	6003/3P	Lab Coat	S,M,L,XL,XXL,XXXL	S				O		3 Pockets
Charkate	6005	Shirt	S,M,L,XL,XXL,XXXL	S				O		
Charkate	6007	Pants	S,M,L,XL,XXL,XXXL				O			
CRP	E1300	Lab Coat	S,M,L,XL	S				E		2 Pockets
CRP	E4100	Smock	S,M,L,XL	T				O		
CRP	E1500	Coverall	S,M,L,XL	Z	N	N	E	E		
CRP	E1600	Coverall	S,M,L,XL	Z	D	Y		E		
CRSI		Coverall	S,M,L,XL,XXL	Z	N	N	O	O		
CRSI		Coverall	S,M,L,XL,XXL	Z	N	N	E	E		
CRSI		Coverall	S,M,L,XL,XXL	Z	D	N	O	O		
CRSI		Coverall	S,M,L,XL,XXL	Z	D	Y	E	E		
Daffin	1010	Coverall	S,M,L,XL,XXL,XXXL	Z	N	N	O	O		
Daffin	1011	Coverall	S,M,L,XL,XXL,XXXL	S	N	N	O	O		
Daffin	1012	Coverall	S,M,L,XL,XXL,XXXL	Z	E	Y	E	E		
Daffin	1013	Coverall	S,M,L,XL,XXL,XXXL	Z	N	N	E	E		
Daffin	1014	Coverall	S,M,L,XL,XXL,XXXL	Z	O	N	O	O		
Daffin	1110	Coverall	S,M,L,XL,XXL,XXXL	Z	N	N	O	O		
Daffin	1020	Lab Coat	S,M,L,XL,XXL,XXXL	S				O		2 Pockets
Daffin	1021	Lab Coat	S,M,L,XL,XXL,XXXL	S				O		
Daffin	1121	Lab Coat	S,M,L,XL,XXL,XXXL	S				O		
Daffin	1030	Smock	S,M,L,XL,XXL,XXXL	T				O		
Daffin	1040	Pants	S,M,L,XL,XXL,XXXL				O			
Daffin	1050	Shirt	S,M,L,XL,XXL,XXXL	S				O		
Durafab	2120	Coverall	S,M,L,XL	S	N	N	O	O	S,B,U,S/B,S/T,SN	
Durafab	2120Z	Coverall	S,M,L,XL	Z	N	N	O	O	S,B,U,S/B,S/T,SN	
Durafab	2125	Coverall	S,M,L,XL	P					S,B,U,S/B,S/T,SN	
Durafab	2127Z	Coverall	S,M,L	Z	O	N	E	E	S,B,U,S/B,S/T,SN	
Durafab	2126	Sack Suit	S,M,L	D	N	N	E	E	S,B,U,S/B,S/T,SN	
Durafab	2126S	Sack Suit	S,M,L	D	N	Y		E	S,B,U,S/B,S/T,SN	
Durafab	3120	Coverall	S,M,L	S	N	N	O	O	S,B,U,S/B,S/T,SN	
Durafab	3120Z	Coverall	S,M,L	Z	N	N	O	O	S,B,U,S/B,S/T,SN	
Durafab	2129	Coverall	S,M,L	Z	N	N	O	O	S,B,U,S/B,S/T,SN	
Expendables	10*	Coverall	S,M,L,XL,XXL,XXXL	Z						
Expendables	21*	Lab Coat	S,M,L,XL,XXL,XXXL	S						
Expendables	100+	Coverall	S,M,L,XL,XXL,XXXL	Z	N	N	O	O		

Vendor	Style	Garment Type	Sizes	Attached Closure	Hood	Boot	Ankle	Interfaces Wrist	Seam Types	Comments
Expendables	107+	Coverall	S,M,L,XL,XXL,XXXL	Z	D	N	O	O		
Expendables	117+	Coverall	S,M,L,XL,XXL,XXXL	Z	D	Y		O		
Expendables	108+	Sack Suit	S,M,L,XL,XXL,XXXL	D	N	N	O	O		
Expendables	110+	Lab Coat	S,M,L,XL,XXL,XXXL	V				O		
Expendables	120+	Pants	S,M,L,XL,XXL,XXXL			N	O			
Expendables	130+	Shirt	S,M,L,XL,XXL,XXXL	V				O		
Expendables	140+	Smock	S,M,L,XL,XXL,XXXL	T			O			
Holcomb	0101	Coverall	S,M,L,XL	Z	N	N	O	O		
Holcomb	6101	Coverall	S,M,L,XL	Z	Y	Y		O		
Holcomb	0201	Smock	S,M,L,XL	T	N			O		
Holcomb	0301	Lab Coat	S,M,L,XL	S	N			O		
Holcomb	0401	Shirt	S,M,L,XL	S				O		
Holcomb	0501	Pants	S,M,L,XL			N	O			
Kappler	1412	Coverall	S,M,L,XL	Z	N	N	O	O	S,B	
Kappler	1414	Coverall	S,M,L,XL	Z	E	Y		E	S,B	
Kappler	1415	Coverall	S,M,L,XL	Z	N	Y		E	S,B	
Kappler	1417	Coverall	S,M,L,XL	Z	N	N	E	E	S,B	
Kappler	1423	Coverall	S,M,L,XL	S	N	N	O	O	S,B	
Kappler	1427	Coverall	S,M,L,XL	Z	E	N	O	O	S,B	
Kappler	1428	Coverall	S,M,L,XL	Z	E	N	E	E	S,B	
Kappler	9412	Coverall	S,M,L,XL	Z	N	N	O	O	S,B	
Kappler	9417	Coverall	S,M,L,XL	Z	N	N	E	E	S,B	
Kappler	1210	Lab Coat	S,M,L,XL	S	N	N		O	S,B	
Kappler	1212	Lab Coat	S,M,L,XL	S	N	N		O	S,B	
Kappler	1214	Lab Coat	S,M,L,XL	S	N	N		E	S,B	
Kappler	1349	Smock	S,M,L,XL	T	N	N		O	S,B	
Kappler	1612	Shirt	S,M,L,XL	S	N			O	S,B	
Kappler	9612	Shirt	S,M,L,XL	S	N			O	S,B	
Kappler	1812	Pants	S,M,L,XL			N		O	S,B	
Kappler	9812	Pants	S,M,L,XL			N		O	S,B	
Magid	CVS11	Coverall	S,M,L,XL	S	N	N	O	O		
Magid	CVZ11	Coverall	S,M,L,XL	Z	N	N	O	O		
Magid	CVC11	Coverall	S,M,L,XL	Z	N	N	E	E		
Magid	CVZ21	Coverall	S,M,L,XL	Z	N	N	O	O		Breathable
Magid	CVZH11	Coverall	S,M,L,XL	Z	O	N	O	O		
Magid	CVCH11	Coverall	S,M,L,XL	Z	O	N	E	E		
Magid	C111	Lab Coat	S,M,L,XL	S				O		Pocket Slits
Magid	C115	Lab Coat	S,M,L,XL	S				O		2 Pockets
Magid	C211	Lab Coat	S,M,L,XL	S				O		Breathable, Pocket Slits
Magid	SR13	Smock	S,M,L,XL	T				O		
Magid	SR23	Smock	S,M,L,XL	T				O		Breathable
Magid	J11	Shirt	S,M,L,XL	S				O		
Magid	J21	Shirt	S,M,L,XL	S				O		Breathable

Vendor	Style	Garment Type	Sizes	Attached Closure	Hood	Boot	Ankle	Interfaces Wrist	Seam Types	Comments
Magid	P11	Pants	S,M,L,XL				O			
Melco	500	Coverall	S,M,L,XL,XXL	Z	N	N	O	O		Raglan, 2 Pocket
Melco	510	Coverall	S,M,L,XL,XXL	Z	N	N	O	O		Raglan, 2 Pocket, High Porosity
Melco	501	Coverall	S,M,L,XL,XXL	S	N	N	O	O		Raglan
Melco	502	Coverall	S,M,L,XL,XXL	Z	N	N	O	O		Raglan
Melco	536	Coverall	S,M,L,XL,XXL	Z	N	N	O	O		Raglan, No Collar
Melco	540	Coverall	S,M,L,XL,XXL	Z	N	N	E	E		Raglan
Melco	534	Coverall	S,M,L,XL,XXL	Z	N	N				Raglan, High Porosity
Melco	520	Coverall	S,M,L,XL,XXL	Z	N	N	E	E		Raglan, Mandarin Collar
Melco	503	Coverall	S,M,L,XL,XXL	S	O	N	O	O		Raglan
Melco	504	Coverall	S,M,L,XL,XXL	Z	O	N	O	O		Raglan
Melco	505	Coverall	S,M,L,XL,XXL	Z	O	N	O	E		Raglan
Melco	508	Coverall	S,M,L,XL,XXL	Z	O	N	E	E		Raglan
Melco	538	Coverall	S,M,L,XL,XXL	Z	D	N	E	E		Raglan
Melco	526	Coverall	S,M,L,XL,XXL	Z	O	Y		O		Raglan
Melco	530	Coverall	S,M,L,XL,XXL	Z	O	Y		O		Raglan
Melco	539	Coverall	S,M,L,XL,XXL	Z	D	Y		E		Raglan
Melco	5802	Coverall	S,M,L,XL,XXL	Z	N	N	O	O		Yoke
Melco	5840	Coverall	S,M,L,XL,XXL	Z	N	N	E	E		Yoke
Melco	5823	Coverall	S,M,L,XL,XXL	Z	E	N	O	O		Yoke
Melco	5845	Coverall	S,M,L,XL,XXL	Z	E	N	E	E		Yoke
Melco	5819	Coverall	S,M,L,XL,XXL	Z	E	Y		E		Yoke
Melco	5102	Coverall	S,M,L,XL,XXL	Z	N	N	O	O		Yoke
Melco	5130	Coverall	S,M,L,XL,XXL	Z	O	Y		O		Yoke
Melco	600	Shirt	S,M,L,XL,XXL	S				O		
Melco	600E	Shirt	S,M,L,XL,XXL	S				E		
Melco	601	Shirt	S,M,L,XL,XXL					O		V–Neck Pullover
Melco	602	SS Shirt	S,M,L,XL,XXL					O		V–Neck Pullover
Melco	603	Shirt	S,M,L,XL,XXL					O		No Collar, High Porosity
Melco	605	SS Shirt	S,M,L,XL,XXL					O		No Collar, High Porosity
Melco	700	Pants	S,M,L,XL,XXL					O		
Melco	701	Pants	S,M,L,XL,XXL					O		High Porosity
Melco	703	Pants	S,M,L,XL,XXL					E		
Melco	300	Lab Coat	S,M,L,XL,XXL	S				O		3 Pocket
Melco	303	Lab Coat	S,M,L,XL,XXL	S				O		3 Pocket, High Porosity
Melco	301	Lab Coat	S,M,L,XL,XXL	S				O		2 Pocket
Melco	326	Lab Coat	S,M,L,XL,XXL	S				E		2 Pocket
Melco	314	Lab Coat	S,M,L,XL,XXL	S				O		1 Pocket, High Porosity
Melco	316	Lab Coat	S,M,L,XL,XXL	S				O		1 Pocket
Melco	302	Lab Coat	S,M,L,XL,XXL	S				O		
Melco	304	Lab Coat	S,M,L,XL,XXL	S				O		High Porosity
Melco	308	Lab Coat	S,M,L,XL,XXL	Z				O		
Melco	321	Lab Coat	S,M,L,XL,XXL	S				E		

Vendor	Style	Garment Type	Sizes	Attached Closure	Hood	Boot	Ankle	Interfaces Wrist	Seam Types	Comments
Melco	324	Lab Coat	S,M,L,XL,XXL	Z				E		Bound Neck, Safety Stitch
Melco	309	Lab Coat	S,M,L,XL,XXL	S				E		
Melco	320	Lab Coat	S,M,L,XL,XXL	S				E		1 Pocket
Melco	334	Lab Coat	S,M,L,XL,XXL	S				O		3 Pocket
Melco	335	Lab Coat	S,M,L,XL,XXL	S				O		1 Pocket
Superior Surg.	8607	Coverall	M,L,XL	Z	N	N	E	E		
Superior Surg.	8605	Coverall	S,M,L,XL	Z	N	N	O	O		
Superior Surg.	8646	Lab Coat	S,M,L,XL	S			O	O		2 Pockets
Superior Surg.	8648	Frock	S,M,L,XL	S				E		Mandarin Collar
Superior Surg.	8675	Smock	M,L,XL	T				O		
Pro/Control	200–2TW	Coverall	M,L,XL,XXL,GT	Z	N	N	O	O		
Pro/Control	210–2TW	Coverall	M,L,XL,XXL,GT	Z	N	N	E	E		
Pro/Control	211–2TW	Coverall	M,L,XL,XXL,GT	Z	E	N	O	O		
Pro/Control	212–2TW	Coverall	M,L,XL,XXL,GT	Z	E	N	E	E		
Pro/Control	213–2TW	Coverall	M,L,XL,XXL,GT	Z	E	Y		E		
Pro/Control	A–D06–520	Lab Coat	M,L,XL,XXL,GT	S			O			2 Pockets
Pro/Control	A–D06–499	Lab Coat	M,L,XL,XXL,GT	S			O			
Pro/Control	A–D05–180	Sack Suit	M,L,XL,XXL,GT	D			O	O		
Pro/Control	A–D16–200	Shirt	M,L,XL,XXL,GT	S			O			
Pro/Control	A–D15–700	Pants	M,L,XL,XXL,GT				O			

Size: S=small, M=medium, L=large, XL=extra large, XXL=double extra large, XXXL=triple extra large, GT=giant
Closure: S=snap, Z=zipper, V=hook and loop, T=ties
Hood: N=no; E=yes,elastic; D=yes, drawstring; O=open face
Boot: N=no, Y=yes
Interface: O=open, E=elastic
Seams: S=serge, B=bound, U=ultra, S/B=seal and bound, S/T=seal and tape, SN=single needle
* Options available include elastic or plain attached hood, attached boot covers, elastic wrists, elastic ankles, storm flap and boot flap.
+ Options available include elastic at wrists or ankles, attached hood, attached boot covers, and pockets.

Appendix

Splash Suits and Rainwear

Appendix I – Splash Suits and Rainwear

Vendor	Jacket	Coverall	Pant	Comment
Barricade, Plastic Laminate – Fabric				
Fyrepel		P,H,F		5.3 oz/sq yd
Kappler		P,H,F		
Butyl – Nylon – Butyl				
Chem–Tex	P	P,H	B	
Life–Guard	P	P,H	B	
Record	P		B	
Trelleborg		H,F		
Wheeler	P,H	P,H	B	
Chemrel, Plastic Laminate – Polyester				
Chemron	P	P	P	
Chemrel Max, Plastic Laminate – Polyester – Plastic Laminate				
Chemron	P		P	
Chemtuff, Plastic Laminate – Polyester				
Chemron	P	P,H	P	
Chlorinated Polyethylene				
Standard Safety	P,H	P,H	B	
Chloroprene (85%) + Styrenebutadiene Rubber (15%) – Nylon				
Sawyer–Tower	P,HD,H		B	11 oz
Chloroprene (35%) + Styrenebutadiene Rubber (65%) – Nylon				
Sawyer–Tower	P,HD,H		B	8 oz
Chloroprene – Cotton				
Goodyear	P		B	

Vendor	Jacket	Coverall	Pant	Comment
Chloroprene – Cotton – Chloroprene				
Marathon	P,HD,H		B	13.5, 15.5, 20 oz
Rainfair	HD		B	
Record	P		B	
Sawyer–Tower	P,HD,H	P,HD	B	14.5 oz
Tingley	P		B	
Chloroprene – Nylon				
Boss	P,HD,H		P,B	
Jomac	HD,H		B	
Neese	HD	P,H	B	
Rainfair	P,HD,H		P,B	
Tingley	HD,H		B	
Chloroprene – Nylon – Chloroprene				
Bata	HD		B	
Chem–Tex	P	P,H	B	
Life–Guard	P	P,H	B	
Marathon	P,HD,H		B	6.5 8, 15.5 oz
Neese	HD		B	
Rainfair	HD		B	
Sawyer–Tower	P,HD,H		B	8.5 oz
Tingley	HD,H		B	
Fluoroelastomer – Nylon – Fluoroelastomer				
Chem–Tex	P	P,H	B	
Hypalon – Polyester				
Trelleborg		H		
Nitrile + Pvc – Polyester				
Rainfair	P,HD,H	B		
Tingley	P		B	

Vendor	Jacket	Coverall	Pant	Comment
Nitrile + Pvc – Polyester + Nylon				
Ansell Edmont	HD,H		B	
Goodyear	P,HD		B	
Tingley	P		B	
Natural Rubber – Cotton				
Goodyear	P,H		B	
Record	P			
Natural Rubber – Polyester				
Plastex	H		B	
Nylon – Bion – Nylon				
Rainfair	H	P	P	
Nylon – Polyurethane				
Rainfair	P,HD,H	P,B		
Polyethylene – Encase II				
Abandaco	P	P,H,F	P	
Polyethylene – Nylon – Polyethylene				
Scooba	P,H	P,H,F	P	
Polyethylene – Polypropylene Nonwoven				
Expendables		P,H,F		
Pro/Control	P,H,F			

Vendor	Jacket	Coverall	Pant	Comment
Polyethylene – Tyvek				
Abandaco	P	P,H,F	P	
Charkate	P	P,H,F	P	
Daffin		P,H,F		
Durafab	P	P,H	P	
Expendables	P	P,H,F	P	
Kappler		P,H,F	P	
Magid	P	P,H	P	
Mar–Mac	P	P,H,F	P	
Melco	P	P,H,F	P	
MSA	P	P,H,F	P	
Pro/Control	P		P	
Polyurethane – Nylon				
Bata	HD,H		P,B	
Jomac	HD,H		B	
Neese	HD	P,H	B	
Rainfair	P,H		P,B	
PTFE – Nomex				
Trelleborg		P		180 gm.sq m
PVC Film, <10 Mil				
Ansell Edmont	HD		B	
Bata	HD		P	
Boss	HD		P	
Defense Apparel	HD	P,H	P	
Expendables		P		
Plastex	HD,H		P	
Plastimayd	P,H		P	
Sawyer–Tower	HD		P,B	8 Mil, 4 Mil

Vendor	Jacket	Coverall	Pant	Comment
PVC Film, >10 Mil				
Abel	HD,H		P,B	
Bata	HD		B	
Boss	H		P	
Durafab	P	P	P	
Expendables	P,H	P,H,F	P	
Magid	HD,H	P	P	
Monte	H		B	
Neese	P,HD,H	P,B	P,B	
Plastex	HD		B	
Plastimayd	H		P	
Tingley	H		P	
PVC – Cotton				
Bata	H		B	
Boss	H	B		
PVC – Nylon				
Boss	HD,H		B	
Chem–Tex	P	H	B	210 Denier Nylon
Jomac	HD,H		B	
Magid	HD,H		B	
Neese	HD		B	
Plastex	HD	P,H	B	
Record	HD		B	
Steiner	HD		B	
Trelleborg		H		
PVC – Nylon – PVC				
Abel	HD		B	
Ansell Edmont	P,HD,H		P,B	
Bata	HD,H		B	
Boss	HD,H	H	B	
Chem–Tex	P	P,H	B	
Goodyear	P,H	P	B	
Jomac	P	P	P,B	
Magid	HD,H		B	
Monte	HD		B	

Vendor	Jacket	Coverall	Pant	Comment
Neese	HD	P,HD,H	B	
Plastex	HD		B	
Rainfair	P,HD,H		B	
Sawyer–Tower	P,HD,H		B	7, 7.5 oz
Tingley	P,HD,H		B	
Trelleborg	P,H	H,F	P	
PVC – Nylon + Polyester				
Bata	HD,H		P,B	
Neese	HD		B	
Sawyer–Tower	P,HD,H		B	Non–woven
PVC – Nylon+Polyester – PVC				
Bata	HD	H	B	
PVC – Polyester				
Abel	HD,H		B	
Ansell Edmont	HD,H		P,B	Non–woven polyester
Bata	HD,H		B	Non–woven polyester
Boss	HD,H		B	
Gloves	HD		B	
Holcomb	P		B	14 oz
Monte	HD		B	
Neese	HD		B	
Standard Safety	P,H	P,H	B	
Tingley	P,HD,H		P,B	
PVC – Polyester – PVC				
Jomac	H		B	
Life–Guard	P	P,H	B	
Neese	HD,H	P,HD,H	B	
Rainfair	HD		B	
Standard Safety	P,H	P,H	B	
Wheeler	P,H	P,H	B	

Vendor	Jacket	Coverall	Pant	Comment
PVC – Rayon				
Goodyear	P,HD		B	
Sawyer–Tower	P,H		B	10 oz
PVC – Rayon – PVC				
Jomac	P,HD,H	P	P,B	
Responder				
Life–Guard		P,H		7.5 oz, 27 mils
Saranex (Single PLY) – Tyvek				
Abandaco		P,H,F		
Charkate		P,H,F		
Daffin		P,H,F		
Durafab		P		
Expendables	P	P,H,F	P	
Fyrepel		P,H,F		2.0 oz
Kappler		P,H,F		
Magid	P	P,H	P	
Mar–Mac	P	P,H,F	P	
Melco		P,H,F		
MSA	P	P,H,F	P	
Pro/Control	P		P	
Styrenebutadiene Rubber – Cotton				
Boss	P,H		B	
Rainfair	HD,H		B	
Tingley	P,H		B	
Styrenebutadiene Rubber – Cotton – Chloroprene				
Boss	P,H		B	
Rainfair	P,HD,H		P,B	
Tingley				

Vendor	Jacket	Coverall	Pant	Comment
Styrenebutadiene Rubber – Nylon				
Record	H		P	
Viton – Nomex – Chloroprene				
Life–Guard	P	P,H	B	
Viton – Nylon – Chlorobutyl				
Life–Guard	P	P,H	B	
Viton/Butyl – Nylon – Butyl				
Trelleborg		H,F		

Jacket: P=no hood, H=attached hood, HD=detachable hood
Coverall: P=no hood, H=attached hood, HD=detachable hood, F=attached booties
Pant: P=plain, B=bib style

J Appendix

PPE Vendor Directory

Appendix J – PPE Vendor Directory

Manufacturer	Address		City	State	Zip	Telephone
Abandco Inc.	14 Locust Street		Manhasset	NY	11030	516627-4554
Abel Products	530 Turnpike Street		Canton	MA	02021	617/821-2500
American Optical Safety Products	P.O. Box 1		Southbridge	MA	01550	800/225-6338
Ansell Edmont Industrial	1300 Walnut Street	Box 6000	Coshocton	OH	43812	614/622-4201
Armin Poly-Versin, Inc.	301 West Side Avenue		Jersey City	NJ	07305	201/451-0600
Arrowhead Products	4411 Katella Avenue		Los Alamitos	CA	90720	714/828-7770
Barry Manufacturing Co. Ltd.	920 Lakeshore Road East		Mississauga	ON	L5E1E1	416/274-3691
Bata Shoe Company, Inc.	Route 40	Industrial Products Division	Belcamp	MD	21017	301/272-2000
Bel-Art Products	Industrial Road		Pequannock	NJ	07440	201/694-0500
Best Manufacturing Company	Edison Street		Menlo	GA	30731	800/241-0323
Boss Manufacturing Company	221 W. First Street		Kewanee	IL	61443	309/852-2131
CPP, Inc.	1200 E. Sunrise Avenue	P.O. Box 2276	Thomasville	NC	27360	919/472-3400
Charkate	130 West 10th Street		Huntington Station	NY	11746	516/427-1802
Chem-Tex Corporation	550 West Ingham Ave.	P.O. Box 5878	Trenton	NJ	08638	609/392-6770
Chemical Fabrics Corporation	Daniel Webster Highway	P.O. Box 1137	Merrimack	NH	03054	603/424-9000
Chemron, Inc.	1455 Busch Parkway		Buffalo Grove	IL	60089	312/520-7300
Clean Room Products, Inc.	1800 Ocean Avenue		Ronkonkoma	NY	11779	516/588-7000
Colonial Grove & Garment Inc.	1800 Ocean Avenue		Ronkonkoma	NY	11779	516/588-6900
Comasec	Niblick Road	P.O. Drawer 10	Enfield	CT	06082	800/333-0219
Control Resource Systems, Inc.	670 Mariner Drive		Michigan City	IN	46360	291/872-5591
Daffin Disposables, Inc.	One Daffin Square		Secretary	MD	21664	301/943-8777
Defense Apparel	247 Addison Road		Windsor	CT	06095	800/243-3847
Durafab Disposables, Inc.	Box 658		Cleburne	TX	76031	817/645-8851
Eastern Safety Equipment Co., Inc.	59-20 56th Avenue		Maspeth	NY	11378	718/894-7900
Encon Manufacturing Co.	13333 Northwest Freeway	P.O. Box 3826	Houston	TX	77253	713/462-4723
Expendables, Inc.	2945 Congressman Lane		Dallas	TX	75220	214/350-6783
Franklin Disposables, Inc.	7100 Huntley Road		Columbus	OH	43229	614/436-1216
Frommelt Industries, Inc.	Safety Products Division	4343 Chavenelle Drive	Dubuque	IA	52004	800/553-5560
Fyrepel Products Inc.	Box 518		Newark	OH	43055	614/344-0391
Glover Latex, Inc.	514 S. Rose Street	P.O. Box 167	Anaheim	CA	92805	714/535-8920
Gloves, Inc.	85 Constitutional Drive	Myles Standish Industrial Park	Taunton	MA	02780	508/823-5200
Goodyear Rubber Products Corp.	329 McCarter Highway		Newark	NJ	07114	201/242-5550
Granet, Inc.	Rt. 258 South	P.O. Box 337	Snowhill	NC	28580	800/562-0600
Handgards Inc.	901 Hawkins Boulevard	P.O. Box 26669	El Paso	TX	79926	915/779-6606
Holcomb Safety Garment Co.	4925 W. Grand Avenue		Chicago	IL	60639	312/745-7088
Hy-Test, Inc.	130 South Canal Street		Chicago	IL	60606	312/559-7424
ILC Dover	P.O. Box 266		Frederica	DE	19946	302/355-3911
International Playtex, Inc.	Glove Division	700 Fairfield Avenue	Stamford	CT	06902	203/356-8000

Manufacturer	Address		City	State	Zip	Telephone
Iron Age Protective Company	2406 Woodmere Drive		Pittsburgh	PA	15205	412/922-7000
Island Poly. Plastic Bags & Disposables	Products Division	514 Grand Boulevard	Westbury	NY	11590	516/338-4433
Jomac Products Inc.	863 Easton Road		Warrington	PA	18976	215/343-0800
Kappler Disposables, Inc.	P.O. Box 218		Guntersville	AL	35976	800/633-2410
Kimberly-Clark Corp.	Industrial Garments & Fabrics	1400 Holcomb Bridge Road	Roswell	GA	3076	404/587-8000
LRC Safety Products Co.	Marigold Industrial	Rt. 46 West, P.O. Box 415	Little Falls	NJ	07424	201/256-4100
La Crosse Footwear, Inc.	P.O. Box 1328		La Crosse	WI	54602	608/782-3020
Lehigh Safety Shoe Co.	Division of Endicott Johnson	1100 E. Main Street	Endicott	NY	13760	607/754-7980
Life-Guard, Inc.	534 Gunter Avenue	P.O. Box 1039	Guntersville	AL	35976	800/323-2533
M.L. Kishigo Manufacturing Company	P.O. Box 1526		Costa Mesa	CA	92626	714/848-3443
Magid Glove and Safety Mfg. Co.	2060 N. Kolmar Ave.		Chicago	IL	60639	312/384-2070
Mar-Mac Manufacturing Co., Inc.	P.O. Box 278		McBee	SC	29101	803/335-8211
Marathon Rubber	510 Sherman Street		Wausau	WI	54401	715/845-6255
Melco, Inc.	6603 Governor Printz Blvd.		Wilmington	DE	19809	800/441-9749
Memphis Glove Company	Division of Shelby Group, Inc.	P.O. Box 171814	Memphis	TN	38187	800/238-6887
Mine Safety Appliances Co.	608 Penn Center Blvd.		Pittsburgh	PA	15235	800/672-2222
Molnlycke Tissue	2694 Bishop Drive	Suite 105	San Ramen	CA	94583	415/830-2970
Monte Glove Company	Monte Lane	P.O. Box 409	Maben	MI	39750	601/263-5353
National Draeger, Inc.	101 Technology Drive	P.O. Box 120	Pittsburgh	PA	15230	412/787-8383
Neese Industries Inc.	P.O. Box 628		Gonzales	LA	70707	504/647-6553
North Hand Protection	4090 Azalea Drive	P.O. Box 70729	Charleston	SC	29405	803/554-0660
Oak Technical, Inc.	218 Sycamore Street		Ravenna	OH	44266	216/296-3416
PPG Industries, Inc.	Optical Products	One PPG Place	Pittsburgh	PA	15272	412/434-3751
Pioneer Industrial Products Co.	512 East Tiffin Street		Willard	OH	44890	419/933-2211
Plastex Protective Products, Inc.	9 Grand Street	P.O. Box 57	Garfield	NJ	07026	201/779-4946
Plastimayd Corp.	2204 S.E. Seventh Avenue	P.O. Box 14217	Portland	OR	97214	503/232-5101
Pro-Guard	P.O. Box 1193		Fort Wayne	IN	46801	219/432-3533
Pro/Control Products, Inc.	9116 Virginia Road		Lake-In-The-Hills	IL	60102	815/455-3777
Protective Equipment	P.O. Box 622		Reading	PA	19603	212/939-3200
Protective Garments For Industry	P.O. Box 307		Green Lake	WI	54941	800/558-8290
Pyramid Industries, Inc.	P.O. Box 190	349 Highway 8	Pelzer	SC	29669	803/947-6762
Rainfair, Inc.	P.O. Box 1647		Racine	WI	53401	800/558-5990
Ranger	Division of Endicott Johnson	1100 E. Main Street	Endicott	NY	13760	607/757-4260
Record Industrial Co.	1020 Eighth Avenue	P.O. Box 407	King of Prussia	PA	19406	215/337-2500
Renco Corp.	2060 Fairfax Avenue		Cherry Hill	NJ	08003	609/424-5755
Rex-Gummiwarenfabrik	OstendstraBe 5	Postfach 1169	Pfungstadt	FRG	D6120	0615720572058
Ronco Textile Products, Inc.	1405 East Lake Avenue		Peoria Heights	IL	61614	309/685-7266
Safeguard America, Inc.	800 16th Ave. North	P.O. Box 1649	Clanton	AL	35045	205/755-7710
Safety 4 A/S	2920 Wolfe Street		Racine	WI	53404	414/632-8133
Sawyer-Tower	76 Stanley Avenue		Watertown	MA	02172	617/926-1200

Manufacturer	Address		City	State	Zip	Telephone
Scooba Mfg. Co., Inc.	P.O. Box 31		Shuqualak	MI	39361	601/793-4582
Standard Safety Equipment Co.	P.O. Box 188		Palatine	IL	60078	312/359-1400
Steele & Associates, Inc.	First & Washington	P.O. Box 7304	Seattle	WA	98346	206/324-9445
Steiner Industries	2265 West St. Paul		Chicago	IL	60647	800/621-4515
Superior Surgical Mfg. Co., Inc.	10099 Seminole Boulevard	P.O. Box 4002	Seminole	FL	34642	800/727-8643
Tingley Rubber Corp.	P.O. Box 100		South Plainfield	NJ	07080	201/757-7474
Trelleborg, Inc.	30700 Solon Industrial Parkway		Solon	OH	44139	216/248-8600
Wheeler Protective Apparel, Inc.	4330 W. Belmont Ave.		Chicago	IL	60641	312/685-5551
Wilson Safety Products	P.O. Box 622		Reading	PA	19603	215/376-6161

K Appendix

Neat Carrier Solvent Permeation Data

The information in this appendix summarizes the permeation data available for representative carrier solvents of solvent containing pesticide formulations. The data were extracted from the data base compiled in the development of the *Guidelines for the Selection of Chemical Protective Clothing*. The solvents are organized by principal functional group: acetate, alcohol, halogenated hydrocarbon, ketone, and petroleum distillates. Across the top of the following pages in this appendix are the twelve glove materials for which data are available.

Since there is enough space for only six glove materials per page, the data for any one chemical require two pages. The information begins with acetates and proceeds through petroleum distillates for the first six glove materials. Midway through the appendix, the information starts over with acetates for the second group of six glove materials.

In column four, the material is a neoprene coating over a natural rubber latex substrate [by convention a slash ("/") is used to designate a multi-layer glove]. In column five, the material is a blend of neoprene and natural rubber latex (by convention a "+" is used to designate a blend). Under each material heading is the breakthrough time (hours), the steady-state permeation rate (Äg/cm@-min), and the glove material thickness (cm). In some cases, typically those for a fabric supported glove, no thickness is given. The number under REF is the literature source for the data as reported in the *Guidelines* data base and are identified in the reference list at the end of the appendix.

Carrier Solvent	Butyl Rubber				Natural Rubber				Neoprene				Neoprene/Natural				Neoprene+Natural				Nitrile Rubber			
	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF
ACETATES																								
Amyl Acetate					0.20	60	--	118	0.25	66	--	118									0.67	30	--	118
																					1.00	90	0.06	147
Butyl Acetate	1.5	36	0.05	124	0.03	2906	0.02	296	0.06	321	0.07	296	0.07	72	--	48	0.07	72	0.04	48	0.25	301	0.04	124
	1.9	46	0.04	303	0.07	1403	0.03	296	0.09	220	0.08	296	0.15	641	0.05	296	0.07	72	0.05	48	0.26	--	0.04	278
					0.07	72	0.05	48	0.18	832	0.03	296					0.07	72	0.06	48	0.32	150	0.04	124
					0.07	72	0.05	48	0.21	--	0.06	278					0.11	641	0.05	296	0.33	351	0.03	296
					0.07	72	0.05	48	0.21	--	0.06	278									0.47	--	0.03	278
					0.07	72	0.05	48	0.23	--	0.04	278									0.48	327	0.04	303
					0.11	942	0.05	296	0.25	72	--	118									0.53	--	0.03	278
					0.13	216	--	118	0.32	210	0.06	124									0.53	217	0.05	124
					0.13	882	0.05	296	0.34	--	0.05	278									0.55	481	0.04	296
					0.23	511	0.06	296	0.48	321	0.05	296									0.64	--	0.03	278
									0.55	--	0.06	278									0.64	--	0.03	278
									0.87	319	0.06	316									0.66	--	0.04	278
									0.87	321	0.07	296									0.67	451	0.04	296
									>1.0	nd	0.05	296									0.74	--	0.03	278
									>1.0	nd	0.08	296									0.84	--	0.03	278
																					0.97	251	0.06	296
																					1.08	102	0.06	124
																					1.25	902	0.06	147
																					1.33	90	--	118
																					1.68	144	0.06	316
ALCOHOLS																								
Ethanol	>8.0	nd	0.04	303	0.20	14	0.02	296	1.5	9	0.04	147	>1.0	nd	0.05	296	0.37	>0.3	317		4.0	9	0.06	147
					0.47	4	0.03	296	1.6	--	0.06	278									6.0	0.02	--	118
					0.50	9	0.05	147	2.0	3	--	118									>1.0	nd	0.03	296
					1.50	6	--	118	2.0	--	0.06	278									>1.0	nd	0.04	296
					>1.0	nd	0.05	296	3.0	9	--	147									>1.0	nd	0.04	296
					>1.0	nd	0.05	296	8.8	--	0.05	278									>1.0	nd	0.06	296
					>1.0	nd	0.06	296	9.3	--	0.04	278									>8.0	nd	0.05	316
					>8.0	nd	0.05	316	12.6	--	0.06	278												

BT = Breakthrough time (hour); SSPR = Steady-state permeation rate (ug/cm^2-min); TH = Thickness (cm)
REF = Reference source, see reference list at end of Appendix.

(continued)

Carrier Solvent	Butyl Rubber				Natural Rubber				Neoprene				Neoprene/Natural				Neoprene+Natural				Nitrile Rubber			
	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF
Ethanol (continued)									>1.0	nd	0.03	296												
									>1.0	nd	0.05	296												
									>1.0	nd	0.05	296												
									>1.0	nd	0.07	296												
									>1.0	nd	0.07	296												
									>1.0	nd	0.08	296												
									>1.0	nd	0.08	296												
									>8.0	nd	0.07	316												
Isopropanol					0.12	<0.9	0.05	147	2.0	5	--	118	0.25	0.12	--	48	0.15	1	0.06	48	6.0	0.02	--	118
					0.17	2	0.05	48	>1.0	nd	--	316					0.23	1	0.04	48	>6.0	nd	0.06	147
					0.25	0.1	0.05	48	>6.0	nd	--	147					0.25	0.1	0.05	48	>8.0	nd	0.05	316
					0.25	0.1	0.05	48	>6.0	nd	0.04	147					0.52	6	0.05	317				
					0.37	1	0.05	48																
					1.50	13	--	118																
					2.50	1	0.06	76																
					>1.0	nd	--	316																
					>2.0	nd	0.02	83																
					>2.0	nd	0.05	83																
					>3.0	nd	0.02	83																
Methanol					0.22	<0.9	0.05	147	1.5	6	--	118									6.0	<0.02	--	118
					6.00	<0.02	--	118	2.5	<0.9	0.04	147									>6.0	<0.9	0.06	147
									>6.0	nd	--	147												
Propylene Glycol					>3.0	nd	0.05	124					>3.0	nd	0.06	124								
					>3.0	nd	0.06	124																
HALOGENATED HYDROCARBONS																								
Dichloromethane	0.17	698	0.04	372	0.01	13026	0.02	296	<.02	2687	0.05	139	0.03	>160	0.05	357	0.03	1275	0.05	317	--	4016	--	74
	0.17	696	0.04	139	0.02	8216	0.03	296	<.02	2689	0.05	372	0.07	3407	0.05	296	0.05	4609	0.05	296	<.02	5639	0.03	139
	0.40	800	0.04	303	0.03	>120	0.04	357	0.01	2806	0.07	296									<.02	5645	0.03	372
					0.03	4810	0.05	296	0.03	4810	0.03	296									0.03	1904	0.03	296
					0.03	>140	0.12	357	0.07	3507	0.05	296									0.03	>150	0.05	357

BT = Breakthrough time (hour); SSPR = Steady-state permeation rate (ug/cm^2-min); TH = Thickness (cm)
REF = Reference source, see reference list at end of Appendix.

(continued)

Carrier Solvent	Butyl Rubber				Natural Rubber				Neoprene				Neoprene/Natural				Neoprene+Natural				Nitrile Rubber			
	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF
Dichloromethane (continued)					0.05	4309	0.05	296	0.08	1804	--	118									0.03	2806	0.11	410
					0.05	3808	0.06	296	0.08	>140	0.06	357									0.04	13026	0.04	296
					0.10	1804	--	118	0.10	1437	--	316									0.04	12024	0.04	296
									0.10	3707	0.05	410									0.04	>125	0.05	357
									0.11	2806	0.05	296									0.07	4605	0.04	303
									0.13	1102	0.08	296									0.07	2204	0.11	410
									0.15	2605	0.07	296									0.10	5812	0.06	410
									0.21	>150	0.09	357									0.11	8216	0.06	296
									0.22	2004	0.08	296									3.00	5411	--	118
KETONES																								
Acetone	>4.0	nd	0.07	169	--	289	--	74	--	1557	--	74	0.13	5	--	48	0.05	126	0.05	317	0.05	1503	0.03	296
	>17.0	nd	0.04	303	0.04	210	0.02	296	0.04	311	0.07	296	0.13	46	0.05	296	0.08	13	0.04	48	0.07	802	0.03	296
	>18.0	nd	0.06	76	0.09	110	0.03	296	0.04	180	0.08	296	0.13	>150	0.05	357	0.08	100	0.05	296	0.08	<802	0.04	296
	>20.0	nd	0.08	421	0.10	60	--	118	0.08	902	0.04	147					0.12	8	0.06	48	0.08	>150	0.05	357
					0.10	4709	0.02	83	0.10	72	--	118					0.13	5	0.05	48	0.09	2004	0.04	296
					0.10	>140	0.04	357	0.17	902	--	147									0.10	>110	0.05	357
					0.10	82	0.05	296	0.20	210	0.06	316									0.17	962	0.06	76
					0.12	30	0.05	316	0.23	334	0.05	421									0.22	<802	0.06	296
					0.13	5	0.05	48	0.27	140	0.03	296									0.33	481	--	118
					0.13	5	0.05	48	0.30	34	--	243												
					0.15	7	0.05	48	0.32	140	0.05	296												
					0.17	9	0.05	48	0.37	150	0.05	76												
					0.17	902	0.05	147	0.43	120	0.06	357												
					0.23	35	0.12	357	0.55	90	0.05	296												
					0.25	66	0.05	296	0.95	86	0.08	296												
					0.28	34	0.06	76	>1.0	--	0.09	357												
					0.45	45	0.06	296																
					0.98	--	0.02	83																
					>3.0	nd	0.05	83																
Cyclohexanone	16.0	nd	0.04	303													0.28	132	0.05	317	0.48	519	0.03	303
	>16.0	nd	0.05	421																				

BT = Breakthrough time (hour); SSPR = Steady-state permeation rate (ug/cm^2-min); TH = Thickness (cm)
REF = Reference source, see reference list at end of Appendix.

(continued)

Carrier Solvent	Butyl Rubber				Natural Rubber				Neoprene				Neoprene/Natural				Neoprene+Natural				Nitrile Rubber			
	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF
Methyl Isobutyl Ketone	0.17	30	0.04	356	0.10	902	0.05	147	0.25	541	--	118									0.20	493	0.04	124
	0.83	70	0.04	356	0.25	421	--	118	0.33	304	0.04	356									0.32	1034	0.04	124
	1.50	36	0.04	356					0.33	284	0.04	356									0.35	848	0.05	124
	1.50	19	0.04	356					0.47	529	0.06	124									0.50	305	0.04	356
	2.17	41	0.04	356					0.50	299	0.06	356									0.50	290	0.04	356
	2.67	22	0.04	356					0.53	278	0.06	356									0.80	403	0.06	124
	3.00	17	0.06	356					0.62	277	0.06	124									1.17	290	0.06	356
	3.75	8	0.06	356																	1.17	257	0.06	356
	4.07	6	0.05	124																	1.67	842	--	118
	4.50	39	0.06	356																				
	5.00	5	0.06	356																				
	5.00	52	0.06	356																				
	5.67	1	0.06	356																				
PETROLEUM DISTILLATES, ALIPHATIC																								
Diesel Fuel	4.0	--	--	176	<4.0	--	--	176	>4.0	nd	--	176									>24.0	nd	--	176
Gasoline (C4-C12)	<4.0	--	--	176	<4.0	--	--	176	1.6	96	0.08	316					0.07	1076	0.05	317	>6.0	nd	0.06	147
									<4.0	--	--	176									>8.0	nd	0.05	316
																					>24.0	nd	--	176
Light Fuel Oil	<4.0	--	--	176	<4.0	--	--	176	<4.0	--	--	176									8.0	--	--	176
Kerosene	<4.0	--	--	176	0.5	9	0.05	147	<4.0	--	--	176					0.60	12	0.05	317	>6.0	nd	0.06	147
					<4.0	--	--	176	>6.0	nd	--	147									>8.0	nd	0.05	316
									>6.0	nd	0.04	147									>24.0	nd	--	176
									>8.0	nd	0.08	316												
Mineral Spirits									1.5	9	0.04	147					0.22	138	0.05	317	>6.0	nd	0.06	147
									>6.0	nd	--	147												

BT = Breakthrough time (hour); SSPR = Steady-state permeation rate (ug/cm^2-min); TH = Thickness (cm)
REF = Reference source, see reference list at end of Appendix.

(continued)

Carrier Solvent	Butyl Rubber				Natural Rubber				Neoprene				Neoprene/Natural				Neoprene+Natural				Nitrile Rubber			
	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF
Naphtha									0.25	902	0.04	147					0.07	96	0.05	317	>6.0	nd	0.06	147
									>6.0	nd	–	147												
PETROLEUM DISTILLATES, AROMATIC																								
Xylene					0.02	5812	0.02	296	–	30	–	74	0.07	30	–	48	0.07	30	0.06	48	–	84	–	74
					0.04	3407	0.03	296	0.05	601	0.07	296	0.12	2505	0.05	296	0.07	30	0.05	48	0.45	168	0.05	421
					0.08	3707	0.05	296	0.06	501	0.08	296									0.47	301	0.03	296
					0.08	2806	0.056	296	0.09	3407	0.03	296									0.80	100	0.04	296
					0.12	445	–	118	0.13	409	–	118									0.95	100	0.04	296
					0.13	2405	0.06	296	0.23	1303	0.05	296									1.25	902	0.06	147
									0.30	1403	0.07	296									1.53	22	0.04	316
									0.38	802	0.05	296									1.67	301	–	118
									0.38	800	0.06	316									>1.0	nd	0.06	296
									0.73	701	0.08	296												
m-Xylene	0.17	229	0.05	124					0.23	199	0.06	124									0.27	397	0.04	124
	0.65	88	0.04	303																	0.55	180	0.04	124
	0.65	88	0.06	421																	0.65	199	0.05	124
																					1.03	189	0.04	421
																					1.62	72	0.06	124
o-Xylene	0.87	117	0.04	303																	0.20	180	0.04	421
	0.87	117	0.07	421																				
p-Xylene	0.45	91	0.04	303																	0.19	–	0.04	278
	0.45	91	0.07	421																	0.41	–	0.03	278
																					0.46	–	0.03	278
																					0.48	–	0.04	278
																					0.56	–	0.03	278
																					0.56	–	0.03	278
																					0.87	86	0.04	421
																					0.91	–	0.03	278

BT = Breakthrough time (hour); SSPR = Steady-state permeation rate (ug/cm^2-min); TH = Thickness (cm)
REF = Reference source, see reference list at end of Appendix.

(continued)

Carrier Solvent	Nitrile+PVC				Polyethylene				Polyvinyl Alcohol				Polyvinyl Chloride				Silver Shield				Viton			
	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF
ACETATES																								
Amyl Acetate	0.83	42	--	118					>6.0	nd	--	147	0.50	48	--	118								
Butyl Acetate	0.67	60	--	118	0.03	20	0.01	296	>6.0	nd	--	147	0.01	--	0.01	296	>6.0	nd	0.01	303	0.23	319	0.04	124
					0.03	66	0.01	124					0.02	6012	0.01	296								
					0.20	6	0.01	296					0.02	6914	0.01	296								
													0.03	6413	0.01	296								
													0.03	4309	0.02	296								
													0.03	4108	0.02	296								
													0.04	3307	0.03	296								
													0.33	72	--	118								
ALCOHOLS																								
Ethanol	6.00	0.02	--	118	>1.0	nd	0.01	296	1.67	55	--	168	0.03	57	0.02	296	>8.0	nd	--	421				
									1.67	6	--	169	0.05	34	0.01	296								
													0.05	43	0.01	296								
													0.06	28	0.01	296								
													0.08	37	0.01	296								
													0.18	43	0.02	296								
													0.33	30	--	316								

BT = Breakthrough time (hour); SSP BT = Breakthrough time (hour); SSPR = Steady-state permeation rate (ug/cm^2-min); TH = Thickness (cm)
REF = Reference source, see referen REF = Reference source, see reference list at end of Appendix.

(continued)

Carrier Solvent	Nitrile+PVC				Polyethylene				Polyvinyl Alcohol				Polyvinyl Chloride				Silver Shield				Viton			
	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF
													0.33	28	0.03	296								
Ethanol (continued)													1.00	9	--	147								
													2.50	6	--	118								
													2.50	6	--	118								
													2.50	6	--	118								
Isopropanol	6.0	0.02	--	118	>2.0	nd	0.01	83					2.2	12	--	118								
													2.5	<1	--	147								
													>3.0	nd	0.02	83								
Methanol	6.00	0.02	--	118									1.50	9	--	147					17.0	5	0.04	312
													2.00	9	--	118								
Propylene Glycol																								
HALOGENATED HYDROCARBONS																								
Dichloromethane	0.2	2645	--	118	<.02	421	0.01	372	0.28	<0.9	--	147	--	2555	--	74	1.9	0.02	0.01	395	0.95	>10	0.03	357
					<.02	421	0.01	139	>1.0	nd	0.12	357	<.02	--	0.01	372					1.00	44	0.02	303
					0.01	301	0.01	296	>2.0	nd	0.14	410	<.02	--	0.01	139					1.33	19	0.04	312
					0.03	100	0.01	296	>6.0	nd	0.05	372	0.01	--	0.01	296					1.38	23	0.02	139
									>8.0	nd	0.04	421	0.01	>16700	0.01	296					1.38	23	0.02	372

BT = Breakthrough time (hour); SSP BT = Breakthrough time (hour); SSPR = Steady-state permeation rate (ug/cm^2-min); TH = Thickness (cm)
REF = Reference source, see referen REF = Reference source, see reference list at end of Appendix.

(continued)

Carrier Solvent	Nitrile+PVC				Polyethylene				Polyvinyl Alcohol				Polyvinyl Chloride				Silver Shield				Viton			
	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF
Ethanol (continued)													0.33	28	0.03	296								
													1.00	9	--	147								
													2.50	6	--	118								
													2.50	6	--	118								
													2.50	6	--	118								
Isopropanol	6.0	0.02	--	118	>2.0	nd	0.01	83					2.2	12	--	118								
													2.5	<1	--	147								
													>3.0	nd	0.02	83								
Methanol	6.00	0.02	--	118									1.50	9	--	147					17.0	5	0.04	312
													2.00	9	--	118								
Propylene Glycol																								
HALOGENATED HYDROCARBONS																								
Dichloromethane	0.2	2645	--	118	<.02	421	0.01	372	0.28	<0.9	--	147	--	2555	--	74	1.9	0.02	0.01	395	0.95	>10	0.03	357
					<.02	421	0.01	139	>1.0	nd	0.12	357	<.02	--	0.01	372					1.00	44	0.02	303
					0.01	301	0.01	296	>2.0	nd	0.14	410	<.02	--	0.01	139					1.33	19	0.04	312
					0.03	100	0.01	296	>6.0	nd	0.05	372	0.01	--	0.01	296					1.38	23	0.02	139
									>8.0	nd	0.04	421	0.01	>16700	0.01	296					1.38	23	0.02	372

BT = Breakthrough time (hour); SSP BT = Breakthrough time (hour); SSPR = Steady-state permeation rate (ug/cm^2-min); TH = Thickness (cm)
REF = Reference source, see referen REF = Reference source, see reference list at end of Appendix.

(continued)

Carrier Solvent	Nitrile+PVC				Polyethylene				Polyvinyl Alcohol				Polyvinyl Chloride				Silver Shield				Viton			
	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF
Dichloromethane (continued)									>8.0	nd	0.05	139	0.01	>16700	0.01	296								
													0.01	>16700	0.01	296								
													0.01	>16700	0.02	296								
													0.01	>16700	0.02	296								
													0.02	12024	0.03	296								
													0.10	3487	--	118								
													0.10	2405	0.14	410								
													0.13	2405	0.17	410								
													0.13	1253	0.18	410								
													0.17	>150	0.16	357								
KETONES																								
Acetone	0.25	313	--	118	0.07	2	0.01	296	>4.0	nd	--	169	<.02	--	0.05	316	>6.0	nd	0.01	303	<.01	4844	0.02	421
					>1.0	--	0.01	296					0.03	--	0.02	83	>8.0	nd	0.01	421	0.03	>150	0.03	357
					>2.0	--	0.01	83					0.15	>140	0.16	357					0.06	--	0.04	421
													0.30	541	--	118								
Cyclohexanone									>7.0	nd	0.03	303					>6.0	nd	0.01	303	0.48	519	0.03	421

BT = Breakthrough time (hour); SSP BT = Breakthrough time (hour); SSPR = Steady-state permeation rate (ug/cm^2-min); TH = Thickness (cm)
REF = Reference source, see referen REF = Reference source, see reference list at end of Appendix.

(continued)

Carrier Solvent	Nitrile+PVC				Polyethylene				Polyvinyl Alcohol				Polyvinyl Chloride				Silver Shield				Viton			
	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF
Methyl Isobutyl Ketone	0.3	782	--	118	0.01	60	0.01	124	>6.0	nd	--	147	0.5	992	--	118					0.2	1743	0.04	124
																					>11.0	nd	0.02	303
PETROLEUM DISTILLATES, ALIPHATIC																								
Diesel Fuel									>24.0	nd	--	176	24.0	nd	--	176					>24.0	nd	--	176
Gasoline (C4-C12)									>6.0	nd	--	147	4.00	--	--	176					>24.0	nd	--	176
									>24.0	nd	--	176												
Light Fuel Oil									>24.0	nd	--	176	8.0	--	--	176					>24.0	nd	--	176
Kerosene									>6.0	nd	--	147	3.0	90	--	147					>24.0	nd	--	176
									>24.0	nd	--	176	>6.0	nd	--	147								
													>24.0	nd	--	176								
Mineral Spirits									>6.0	nd	--	147	2.50	9	--	147								

BT = Breakthrough time (hour); SSP BT = Breakthrough time (hour); SSPR = Steady-state permeation rate (ug/cm^2-min); TH = Thickness (cm)
REF = Reference source, see referen REF = Reference source, see reference list at end of Appendix.

(continued)

Carrier Solvent	Nitrile+PVC				Polyethylene				Polyvinyl Alcohol				Polyvinyl Chloride				Silver Shield				Viton			
	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF	BT	SSPR	TH	REF
Naphtha									>7.0	nd	--	147	2.00	--	--	147								
PETROLEUM DISTILLATES, AROMATIC																								
Xylene	0.75	331	--	118	0.07	100	0.01	296	>6.0	nd	--	147	--	72	--	74	>6.0	nd	0.01	303	>8.0	nd	0.04	421
									>8.0	nd	0.09	421	0.01	4509	0.01	296					>8.0	nd	0.02	303
													0.01	3507	0.01	296								
													0.02	3507	0.01	296								
													0.02	192	0.02	421								
													0.03	3006	0.01	296								
													0.03	2104	0.02	296								
													0.07	1701	0.05	316								
													0.08	1703	0.02	296								
													0.66	389	--	118								
m-Xylene									>12.7	nd	0.03	421									8.0	--	0.04	124
																					>16.0	nd	0.02	303
																					>16.0	nd	0.03	421
o-Xylene									>12.7	nd	0.03	421									>8.0	nd	0.02	303
																					>8.0	nd	0.03	421
p-Xylene									>14.0	nd	0.03	421	<.01	185	0.02	421					>16.0	nd	0.02	303
																					>16.0	nd	0.03	421

BT = Breakthrough time (hour); SSP BT = Breakthrough time (hour); SSPR = Steady-state permeation rate (ug/cm^2-min); TH = Thickness (cm)
REF = Reference source, see referen REF = Reference source, see reference list at end of Appendix.

References

[48] Ansell Industrial Products, Catalogue, 1986.

[71] Berardinelli, S.P., and E.S. Moyer, Chemical Protective Clothing Breakthrough Time: Comparison of Several Test Systems, Dept. of Health and Human Services, Am. Ind. Hyg. Assoc. J., 49(3), pp. 89-94 (March 1988).

[74] Best Manufacturing Company, Catalogue, Permeation Resistance Guide, 1988.

[76] Bhown, A.S., E.F. Philpot, D.P Segers, G.D Sides, et al. Predicting the Effectiveness of Chemical-Protective Clothing: Mode and Test Method Development.

[83] Bryan, C.J. Permeability Testing with Isopropyl Alcohol, Acetone, Toluene, and 1,1,1-Trichloroethane, Report No. MTB-705-87, Engineering Development Directorate - NASA, pp. 1-4 (December 9, 1987).

[94] Chemron, Inc., Catalogue, Chemical Permeation Guide, 1988.

[118] Comasec, Inc., Catalogue, Permeation Resistance Guide, 1988.

[124] Cullinane, J. Evaluation of the Permeation Resistance of Polymer Gloves to an Organophosphorus Pesticide and Pesticide Carrier Solvents, IT Corporation, Report to EPA under Contract 68-03-3069, (May 1985).

[139] Dow Chemical Company, Selection of Gloves for Use with Chlorinated Solvents, Chlorinated Solvents Information, Midland, Michigan 48640.

[144] E.I. du Pont de Nemours & Co., Spunbonded Products Division, Permeation Guide for Fabrics of DuPont Tyvek, 1988, 1986.

[147] Edmont Division of Becton, Dickinson Co., Catalogue, Chemical Resistance Guide, 1988.

[168] Forsberg, K., and K.G. Olsson, Faststallande av riktlinjer for val av kemikalieskyddshandskar, ASF-dontrakt 83-0750.

[169] Forsberg, K., and S. Faniadis, The Permeation of Multi-Component Liquids Through New and Pre-Exposed Glove Materials, Am. Ind. Hyg. Assoc. J., 47(3), pp. 189-193 (March 1986).

[176] Gammage, R.B., T. Vo-Dinh, and D.A. White, Measurement by Room Temperature Phosphorescience of Polynuclear Aromatic Containing Hydrocarbon Fuels that Permeate Glove Materials, Health and Safety Research Division.

[243] Life-Guard, Inc., Catalogue, Chemical Permeation Guide, 1988.

[278] Mickelsen, R.L., and R.C. Hall, A Breakthrough Time Comparison of Nitrile and Neoprene, Glove Materials Produced by Different Glove Manufacturers, Dept. of Health and Human Services, Am. Ind. Hyg. Assoc. J., 48(11), pp. 941-947 (November 1987).

[284] Mine Safety Appliances Company, Data Sheets, 13-00-07, 13-00-17, 13-00-18, 1986.

[296] Nelson, G.O., B. Lum, G. Carlson, C. Wong, and J. Johnson, Glove Permeation by Organic Solvents, Am. Ind. Hyg. Assoc. J., 42(3), p. 217 (1981).

[303] North Hand Protection, Div. of Siebe North, Inc., Catalog, Chemical Permeation Guide, 1988.

[312] Perkins, J.L., M.C. Ridge, A.B. Holcombe, M.K. Wang, et al., Skin Protection, Viton, and Solubility Parameters, Am. Ind. Hyg. Assoc. J., 47(12), pp. 803-808 (December 1986).

[316] Pioneer Industrial Products, Division of Brunswick Corp., Catalogue, Chemical Resistance Guide, 1988.

[317] Plastex Protective Products, Inc., Catalogue, 1986.

[356] Schlatter, C.N., and D.J. Miller, Influence of Film Thickness on the Permeation Resistance, Properties of Unsupported Glove Films, Performance of Protective Clothing, ASTM STP 900, R.L. Barker, and G.C. Coletta, Eds., American Society for Testing and Materials, Philadelphia, PA, pp. 75-81 (1986).

[357] Schoch, D.J., L.K. Tersegno, J.E. Winter, D.G. Bush, and R.L. James, Testing of "Impervious" Gloves for Permeation by Organic Solvents, American Industrial Hygiene Conference, Cincinnati, OH (June 6-11, 1982).

[372] Spence, M.W., Glove Materials for Chlorinated Solvents: Permeation Resistance Comparison for Four Solvents, American Industrial Hygiene Conference, Detroit, MI (May 21-25, 1984).

[373] Spence, M.W., Streamlined Methodology for Permeation Testing Using the ASTM F-1001 Standard Test Chemical Battery, Presentation at the 1987 American Industrial Hygiene Conf., (May 31-June 5, 1987).

[389] Stull, J.O., The U.S. Coast Guard's Research and Development Program for Hazardous Chemical Personnel Protection, Office of Research and Development, pp. 1-14.

[395] Stull, J., Personal Communication, U.S. Dept. of Transportation, Coast Guard (August 1986).

[410] Vahdat, N., Permeation of Protective Clothing Materials by Methylene Chloride and Perchlorethylene, Tuskegee University, Chem. Engr. Dept., Am. Ind. Hyg. Assoc. J., 48(7), pp. 646-651 (July 1987).

[421] Walters, D., Personal Communication. National Toxicology Program National Institutes of Environmental Health and Sciences, Glove Performance Study, Contract No. NO1-ES-45059, Radian Corporation, Austin, TX (June 1988).

L Appendix

Harpenden Tracer Study Breakthrough Time Data

Appendix L – Harpenden Tracer Study Breakthrough Time Data

Carrier solvent and concentration	Tracer breakthrough time (hours)				
	Butyl rubber	Natural rubber	Neoprene	Nitrile rubber	Polyvinyl chloride
Alcohols					
Diacetone Alcohol (16%)	>6.0	2.0	2.5	–	>6.0
Diethanol Amine (31%)	>6.0	>6.0	>6.0	–	>6.0
Tetrahydrofurfuryl Alcohol (41%)	>6.0	>6.0	>6.0	–	>6.0
Methanol (15%) and Dichloromethane (65%)	–	–	1.2	0.5	0.1
Methanol (30%) and Xylene (25%)	–	–	3.0	0.7	0.7
Methanol (39%) and Xylene (35%)	–	–	2.0	0.6	0.5
Halogenated Hydrocarbons					
Chlorinated Hydrocarbons	3.0	0.2	0.4	–	0.4
Dichloromethane (65%) and Methanol (15%)	–	–	1.2	0.5	0.1
Ketones					
Cyclohexanone (19%)	–	–	>6.0	>6.0	6.0
Isophorone (80%)	–	–	>6.0	3.5	3.0
Cyclohexanone (20%) and Oil (75%)	3.0	0.6	5.5	–	3.0
Cyclohexanone (10%) and Xylene (60%)	–	–	2.0	0.7	0.6
Cyclohexanone (10%) and Xylene (70%)	1.0	0.2	0.3	–	0.3
Cyclohexanone (12%) and Xylene (37%)	–	–	1.5	0.8	0.8
Cyclohexanone (15%) and Xylene (20%)	–	–	3.0	2.0	1.0
Cyclohexanone (15%) and Xylene (20%)	–	–	3.0	2.0	1.0
Cyclohexanone (20%) and Xylene (50%)	–	–	2.0	0.6	0.5
Cyclohexanone (24%) and Xylene (43%)	–	–	1.5	0.7	0.6
Cyclohexanone (30%) and Xylene (37%)	–	–	0.8	0.5	0.6
Cyclohexanone (30%) and Xylene (37%)	–	–	0.8	0.5	0.6
Isophorone (30%) and Xylene (40%)	–	–	2.0	0.6	0.2
Petroleum Distillates, Aliphatic					
Paraffin Oil (27%)	–	–	>6.0	>6.0	>6.0
Paraffin Oil (34%)	–	–	–	>6.0	4.5
Paraffin Oil (68%)	>6.0	1.5	2.0	–	>6.0
Paraffin Oil (70%)	>6.0	0.6	>6.0	–	4.0

Carrier solvent and concentration	Tracer breakthrough time (hours)				
	Butyl rubber	Natural rubber	Neoprene	Nitrile rubber	Polyvinyl chloride
Paraffin Oil (70%)	2.0	0.6	>6.0	–	>6.0
Paraffin Oil (70%)	5.0	1.0	>6.0	–	3.0
Paraffin Oil (80%)	>6.0	1.0	>6.0	–	>6.0
Naphtha (42%)	>6.0	0.8	>6.0	–	4.5
Naphtha (50%)	3.5	0.7	>6.0	–	3.0
Naphtha (54%)	>6.0	3.0	>6.0	–	>6.0
Oil (75%) and Cyclohexanone (20%)	3.0	0.6	5.5	–	3.0
Naphtha (35%) and Xylene (35%)	>6.0	1.5	>6.0	–	>6.0
Petroleum Distillates, Aromatic					
Xylene (27%)	>6.0	3.0	>6.0	–	>6.0
Xylene (22%)	>6.0	1.6	>6.0	–	1.5
Xylene (23%)	–	–	3.0	2.5	2.5
Xylene (23%)	–	–	3.0	2.5	2.0
Xylene (28%)	–	–	3.0	2.0	1.0
Xylene (28%)	–	–	3.0	2.0	1.0
Xylene (33%)	3.5	0.9	>6.0	–	3.0
Xylene (35%)	–	–	>6.0	3.0	1.5
Xylene (39%)	>6.0	0.7	1.0	–	2.0
Xylene (45%)	1.5	0.2	0.4	–	1.0
Xylene (60%)	–	–	1.0	1.0	0.9
Xylene (70%)	–	–	0.5	0.4	0.3
Xylene (70%)	–	–	0.5	0.4	0.4
Xylene (70%)	–	–	0.5	0.4	0.3
Xylene (80%)	–	–	0.6	0.5	0.4
Xylene (20%) and Cyclohexanone (15%)	–	–	3.0	2.0	1.0
Xylene (20%) and Cyclohexanone (15%)	–	–	3.0	2.0	1.0
Xylene (37%) and Cyclohexanone (12%)	–	–	1.5	0.8	0.8
Xylene (37%) and Cyclohexanone (30%)	–	–	0.8	0.5	0.6
Xylene (37%) and Cyclohexanone (30%)	–	–	0.8	0.5	0.6
Xylene (43%) and Cyclohexanone (24%)	–	–	1.5	0.7	0.6
Xylene (50%) and Cyclohexanone (20%)	–	–	2.0	0.6	0.5
Xylene (60%) and Cyclohexanone (10%)	–	–	2.0	0.7	0.6
Xylene (70%) and Cyclohexanone (10%)	1.0	0.2	0.3	–	0.3

Carrier solvent and concentration	Tracer breakthrough time (hours)				
	Butyl rubber	Natural rubber	Neoprene	Nitrile rubber	Polyvinyl chloride
Xylene (40%) and Isophorone (30%)	–	–	2.0	0.6	0.2
Xylene (25%) and Methanol (30%)	–	–	3.0	0.7	0.7
Xylene (35%) and Methanol (39%)	–	–	2.0	0.6	0.5
Xylene (35%) and Naphtha (35%)	>6.0	1.5	>6.0	–	>6.0

Reference Source: Lloyd, G.A., 1986.

M Appendix

29 CFR 1910.133

The following is the text (verbatim) of 29 CFR 1910.133. The footnotes reflect the recommendations and changes in the proposed revision.

1) Protective eye and face equipment shall be required where there is a reasonable probability of injury that can be prevented by such equipment. In such cases, employers shall make conveniently available a type of protector suitable for the work to be performed, and employees shall use such protectors. No unprotected person shall knowingly be subjected to a hazardous environmental condition. Suitable[1.] eye protectors shall be provided where machines or operations present the hazard of flying objects, glare, liquids[2.], injurious radiation, or a combination of these hazards.

2) Protectors shall meet the following minimum requirements: (i) They shall provide adequate protection against the particular hazards for which they are designed; (ii) They shall be reasonably comfortable when worn under the designated conditions; (iii) They shall fit snugly and shall not unduly interfere with the movements of the wearer; (iv) They shall be durable; (v) They shall be capable of being disinfected; (vi) They shall be easily cleanable; (vii) Protectors should be kept clean and in good repair.

3) Persons whose vision requires the use of corrective lenses in spectacles, and who are required by this standard to wear eye protection, shall wear goggles or spectacles of the following types: (i) Spectacles whose protective lenses provide optical correction; (ii) Goggles that can be worn over corrective spectacles without disturbing the adjustment of the spectacles; (iii) Goggles that incorporate corrective lenses mounted behind the protective lenses.[3.]

4) Every protector shall be distinctly marked to facilitate identification only of the manufacturer.[4.]

5) When limitations or precautions are indicated by the manufacturer, they shall be transmitted to the user and care taken to see that such limitations and precautions are strictly observed.[5]

6) Design, construction, testing, and use of devices for eye and face protection shall be in accordance with American National Standard for Occupational and Educational Eye and Face Protection, ANSI Z87.1 - 1968.[6]

As can be seen from the revisions mentioned in the footnotes, OSHA is attempting to keep the safety interests of the employee in mind by requiring more stringent provisions for personal protective equipment. It is anticipated that these changes combined with the publicity generated by the changes will heighten everyone's awareness of ocular safety and result in a decrease in the number of preventable ocular injuries.

References

[1]The proposed revisions will replace the word "suitable" with a requirement that "eye protection used by employees provide both front and side protection from flying objects."

[2]The revision will replace the word "liquid" with "molten metal and liquid chemicals." OSHA wanted to prevent confusion over whether or not molten metal is a "liquid."

[3]This section will be revised to address the issue of tinted lenses in that "workers who pass from well lit to dimly lit areas not wear protectors with tinted, or variable tinted lenses."

[4]This sentence will be dropped in the revision since it does not add or detract from the safety afforded by the protector. The ANSI standard will require a mark if the protector complies with the standard.

[5]A new provision will be added to this section requiring that "employees potentially exposed to injurious radiant energy, such as that produced by welding, use eye protection with filter lenses, which have a shade number appropriate for the work being performed."

[6]The OSHA standard will be updated to reflect the current ANSI Z87.1 1989 requirements.

N Appendix

Modification to ANSI Z87.1

Some of the new requirements of ANSI Z87.1 - 1989 are the ability of the eyewear to pass two types of impact tests:

1) A high-velocity impact test—a high-speed, low-mass test. This test is intended to ensure a level of protection from high velocity, low mass projectiles.

2) A high-mass impact test—a low-speed, high-mass test. This test is intended to ensure the level of mechanical integrity of a protective device and a level of protection from relatively heavy, pointed objects traveling at low speeds.

In addition, the standard still includes tests for flammability and corrosiveness; side shields are strongly recommended, but not required; one piece plano lenses are acceptable; photochromic lenses can be used indoors with a warning about transmission changes and require the "V" marking; and, special lenses must have a "S" mark and the manufacturer's stamp.

Employers should remember that the manufacturers of eye and face protection certify their own products. Manufacturers claim compliance to the ANSI standard by placing a visible Z87.1 - 1989 stamp on the item. OSHA and ANSI do not have inspectors to verify the certification. Fortunately, most manufacturers meet and exceed the requirements of the standard.

O Appendix

Manufacturers of Eye and Face Protective Devices

Appendix O – Manufacturers of Eye and Face Protective Devices*

Manufacturers	Spectacles	Cover Goggles**	Cup Goggles	Face Shields
ADEN 5801 SAFETY DRIVE N.E. BELMONT, MI 49806 616 784–6200		I		X
AMERICAN ALLSAFE COMPANY 99 WALES AVE. TONAWANDA, NY 14151–5104 716 695–8300 800 231–1332 (OUTSIDE NY)	Y	N, I		
AMERICAN OPTICAL CORPORATION SAFETY PRODUCTS DIVISION 14 MECHANICS ST. SOUTHBRIDGE, MA 01550 800 225–7768 800 252–8619 MA ONLY	Y	N, I		Y
BILSON INTERNATIONAL, INC. 109 CARPENTER DRIVE STERLING, VA 22170–9962 703 834–1070				
H.L. BOUTON COMPANY, INC. P.O. BOX G 320 MAIN ST. BUZZARDS BAY, MA 02532 508 759–8000 800 426–1881		N, I		
CREWS, INC. P.O. BOX 751255 MEMPHIS, TN 38175 800 821–6543		N, I		
EASTERN SAFETY EQUIPMENT CO. INC. 59–20 56TH AVE. MASPETH, NY 11378–2398 718 894–7900		N, I		

Manufacturers	Spectacles	Cover Goggles**	Cup Goggles	Face Shields
ENCON SAFETY PRODUCTS 412 NORTH EAST ST. P.O. BOX 272 COUDERSPORT, PA 16915 814 274–8581		I		
ERB SAFETY INC. 1 SAFETY WAY P.O. BOX 1237 WOODSTOCK, GA 30188–1237 404 926–7944		I		
FIBRE–METAL PRODUCTS COMPANY BOX 248 CONCORDVILLE, PA 19331 215 459–5300 800 523–7048		I		
JACKSON PRODUCTS INC. 5801 SAFETY DRIVE BELMONT, MI 49306 616 784–6200		I		
KEDMAN CO. HUNTSMAN PRODUCTS DIVISION P.O. BOX 25667 SALT LAKE CITY, UT 84125–0667 801 973–9112				
MORSAFE, INC. 5801 SAFETY DR. N.E. BELMONT, MI 49306 616 784–0839		I		
NORTH SAFETY EQUIPMENT A DIVISION OF SIEBE NORTH, INC. 2000 PLAINFIELD PIKE CRANSTON, RI 02920 401 943–4400		I		

Manufacturers	Spectacles	Cover Goggles**	Cup Goggles	Face Shields
OBERON COMPANY DIVISION OF PARAMOUNT CORP. 435 COGGESHALL ST. P.O. BOX N1008 NEW BEDFORD, MA 02746 800 322–3348 (OUTSIDE MASS.) 508 999–4442		N, I		
OHIO GOGGLES CO, INC. DIVISION OF MACK PRODUCTS CO. P.O. BOX 602 EDGEWATER BRANCH 1384 HIRD AVE. CLEVELAND, OH 44107 216 226–1220		I		
PAULSON MANUFACTURING CO. 46752 RAINBOW CANYON RD. TEMECULA, CA 92390 714 676–2451				
PULMOSAN PROTECTIVE EQUIPMENT A DIVISION OF WGM SAFETY CORP. P.O. BOX 622 READING, PA 19603–0622 800 345–3479 (OUTSIDE PA) 215 371–7720		I		
SELLSTROM MANUFACTURING CO. P.O. BOX 355 PALATINE, IL 60078 708 358–2000		N, I		
TITMUS OPTICAL, INC. 1015 COMMERCEE DRIVE PETERSBURG, VA 23803 800 446–1802				
US SAFETY 8101 LENEXA DRIVE LENEXA, KS 66214 (NEW ADDRESS FOR JUNE1, NO NEW PHONE)	X	N, I	X	X

Manufacturers	Spectacles	Cover Goggles**	Cup Goggles	Face Shields
UVEX WINTER OPTICAL INC. 10 THURBER BLVD. SMITHFIELD, RI 02917 401 232–1200 800 343–3411	X	N, I	X	
WILSON SAFETY PRODUCTS A DIVISION OF WGM SAFETY CORP P.O. BOX 622 READING, PA 19603–0622 215 376–6161	X	N, I	X	

* Cover Goggles: I = indirect ventilation, N = no ventilation
** X: device, blank: device not produced

P Appendix

Cover Goggle, Indirect Ventilation

Appendix P – Cover Goggle, Indirect Ventilation

Company Model	Lens Material*	UV Filter+	Fog Resistant	Tint Available	Scratch Resist.	ANSI Z87.1-1989	Notes
Aden							
XL20	POLYPROP	N	N	N	N	Y	
XL21	POLYPROP	N	Y	N	N	Y	
AS1146	POLYCARB	Y	N	N	N	Y	
AS1146FF	POLYCARB	Y	Y	N	N	Y	
American Allsafe							
211	POLYCARB	Y	Y	Y	N	Y	Respirator Fit Available
AO Safety Products							
40304	POLYCARB	N	N	N	N	1979	
40306	POLYCARB	N	Y	N	N	1979	
40305	POLYCARB	N	Y	N	N	1979	Anti Glare
40307	POLYCARB	N	Y	N	N	1979	Anti Glare
40815	POLYCARB	N	N	N	N	1979	
40906	POLYCARB	N	N	N	N	1979	
40816	POLYCARB	N	N	Y	N	1979	
40937	POLYCARB	N	N	Y	N	1979	
40832	POLYCARB	N	Y	N	Y	1979	
40934	POLYCARB	N	Y	N	Y	1979	
40833	POLYCARB	N	Y	Y	Y	1979	
40936	POLYCARB	N	Y	N	Y	1979	
40978	POLYCARB	N	N	N	N	1979	
40981	POLYCARB	N	N	Y	N	1979	
40889	POLYCARB	N	Y	N	Y	1979	
40990	POLYCARB	N	Y	Y	Y	1979	
40979	ACETATE	N	N	N	N	1979	

Company Model	Lens Material*	UV Filter+	Fog Resistant	Tint Available	Scratch Resist.	ANSI Z87.1-1989	Notes
Crews,Inc.							
230	POLYCARB	N	N	N	N	Y	
235	POLYCARB	N	Y	N	N	Y	
Eastern Safety Equipment Co. Inc.							
334	POLYCARB	N	N	N	N	1979	
438 Series	POLYCARB	N	Y	Y	N	1979	
038	ACETATE	N	N	N	N	1979	
Encon							
160 SERIES	POLYCARB	Y	Y	Y	Y	Y	Baffled Vent Design
500 SERIES	POLYCARB	Y	Y	Y	Y	Y	Labyrinth Vent System
Erb Safety Equipment							
117	POLYPROP	N	N	N	N	Y	
118	POLYPROP	N	Y	N	N	Y	
Fibre – Metal Products Co.							
VG–15	POLYCARB	N	N	N	N	Y	
VG–16	POLYCARB	N	N	Y	N	Y	
H.L. Bouton Co, Inc.							
551	POLYCARB	Y	Y	Y	N	Y	
560	POLYCARB	Y	Y	N	Y	Y	
Jackson Products Inc.							
JP4	ACETATE	N	N	Y	N	Y	
Morsafe, Inc.							
1146	POLYCARB	N	N	N	N	Y	
1146FF	POLYCARB	N	Y	N	N	Y	
1146G	POLYCARB	N	N	Y	N	Y	
North Safety Equipment							
1022	POLYPROP	N	Y	Y	N	Y	
1012	POLYPROP	N	N	Y	N	Y	

Company Model	Lens Material*	UV Filter+	Fog Resistant	Tint Available	Scratch Resist.	ANSI Z87.1-1989	Notes
Oberon Company							
7000	POLYCARB	N	N	N	N	Y	
7001	POLYCARB	N	N	N	Y	Y	
7002	POLYCARB	N	N	N	N	Y	Chemical Resistance
7003	POLYCARB	N	Y	N	N	Y	
7004	POLYCARB	N	Y	N	Y	Y	
7005	POLYCARB	N	Y	N	N	Y	Chemical Resist. Out / Antifog In
7006	POLYCARB	N	Y	N	N	Y	
7020	POLYCARB	Y	N	N	N	Y	
7021	POLYCARB	Y	N	N	Y	Y	
7023	POLYCARB	Y	Y	N	N	Y	
7024	POLYCARB	Y	Y	N	Y	Y	Scratch Resist. Out / Antifog In
7050	POLYPROP	N	N	Y	N	Y	
7091	POLYPROP	N	N	Y	N	Y	
9000	ACETATE	N	N	N	N	Y	Neoprene Rubber
Ohio Goggles Co., Inc.							
1530	POLYCARB	N	N	N	N	Y	
1540	POLYCARB	N	N	Y	N	Y	
1545	POLYCARB	N	N	Y	N	Y	
Pulmosan Protective Equipment							
40073P	POLYCARB	Y	N	N	N	1979	
40074P	POLYCARB	Y	N	N	N	1979	
40268P	POLYCARB	Y	N	N	N	1979	
Sellstrom							
88200	ACETATE	N	N	N	N	1979	
88210	ACETATE	N	Y	N	N	1979	
88220	ACETATE	N	N	Y	N	1979	
89201	ACETATE	N	N	N	N	1979	
89211	ACETATE	N	Y	N	N	1979	

Company Model	Lens Material*	UV Filter+	Fog Resistant	Tint Available	Scratch Resist.	ANSI Z87.1-1989	Notes
U.S. Safety							
283507	POLYCARB	Y	N	N	N	Y	
283547	POLYCARB	Y	Y	N	N	Y	
283157	POLYCARB	Y	Y	Y	N	Y	
292507	POLYCARB	Y	N	N	N	Y	
292547	POLYCARB	Y	Y	N	N	Y	
292557	POLYCARB	Y	Y	Y	N	Y	
283527	POLYCARB	Y	N	Y	N	Y	
293507	POLYCARB	Y	N	N	N	Y	
292527	POLYCARB	Y	N	Y	N	Y	
Uvex							
9400	POLYCARB	Y	Y	N	Y	Y	Anti-static,Adjust.Vent, 4C Option
9300	POLYCARB	Y	Y	N	Y	Y	Bottom Venting- 4C Lens Coating
9305	POLYCARB	Y	Y	N	Y	Y	Hood Splash Protection
Wilson Safety Products							
403	POLYCARB	N	N	N	N	1979	
403M	POLYCARB	N	Y	N	Y	1979	
405B	POLYCARB	N	N	N	N	1979	
X41	CR-39	N	N	N	N	1979	

* Lens Material: Polyprop = polypropionate; Polycarb = polycarbonate
+ N = No; Y = Yes

Q Appendix

Cover Goggle, No Ventilation

Appendix Q – Cover Goggle, No Ventilation

Company Model	Lens Material*	UV Filter+	Fog Resistant	Tint Available	Scratch Resist.	ANSI Z87.1-1989	Notes
AMERICAN ALLSAFE							
202	POLYCARB	Y	Y	Y	N	Y	Respirator Fit Available
AO SAFETY PRODUCTS							
40941	ACETATE	N	N	N	N	1979	
40942	ACETATE	N	N	Y	N	1979	
CREWS INC.							
237	POLYCARB	N	Y	N	N	Y	
EASTERN SAFETY EQUIPMENT							
039	ACETATE	N	N	N	N	1979	
H.L. BOUTON CO, INC.							
552	POLYCARB	N	Y	Y	N	Y	
451	ACETATE	N	Y	N	N	Y	
OBERON							
5000	POLYCARB	N	N	N	N	Y	
5001	POLYCARB	N	N	N	Y	Y	
5002	POLYCARB	N	N	N	N	Y	Chemical Resistant Lens
5003	POLYCARB	N	Y	N	N	Y	
5004	POLYCARB	N	Y	N	Y	Y	
5005	POLYCARB	N	Y	N	N	Y	Chemical Resistant Lens
5006	POLYCARB	N	Y	N	N	Y	
5020	POLYCARB	Y	N	N	N	Y	
5021	POLYCARB	Y	N	N	Y	Y	
5023	POLYCARB	Y	Y	N	N	Y	
5024	POLYCARB	Y	Y	N	Y	Y	
5050	POLYPROPIONATE	N	N	Y	N	Y	
5091	POLYCARB	N	N	Y	N	Y	

Company Model	Lens Material*	UV Filter+	Fog Resistant	Tint Available	Scratch Resist.	ANSI Z87.1–1989	Notes
SELLSTROM							
89001	ACETATE	N	N	N	N	Y	
89011	ACETATE	N	Y	N	N	Y	
U.S. SAFETY							
283540	POLYCARB	Y	Y	N	N	Y	
292540	POLYCARB	Y	Y	N	N	Y	
283550	POLYCARB	Y	Y	Y	N	Y	
292550	POLYCARB	Y	Y	Y	N	Y	
283510	POLYCARB	Y	Y	Y	N	Y	
UVEX							
9305	POLYCARB	Y	Y	N	Y	Y	
WILSON SAFETY PRODUCTS							
402	POLYCARB	N	N	N	N	1979	
402M	POLYCARB	N	Y	N	Y	1979	
X44	CR–39	N	N	N	N	1979	

* Lens Material: Polyprop = polypropionate; Polycarb = polycarbonate
+ N = No; Y = Yes

R Appendix

Cup Goggle, Indirect Ventilation

Appendix R – Cup Goggle, Indirect Ventilation

Company Model	Lens Material*	UV Filter+	Fog Resistant	Tint Available	Scratch Resist.	ANSI Z87.1-1989	Notes
Ohio Goggles, Inc.							
	POLYCARBNNN	N	N	N	N	Y	
U.S. Safety							
238860	POLYCARBYNN	Y	N	N	N	Y	

* Lens Material: Polyprop = polypropionate; Polycarb = polycarbonate
+ N = No; Y = Yes

S Appendix

Faceshields

Company	Lens Material
Aden	Acetate
American Allsafe	Polycarbonate Acetate Petg
American Optical	Polypropionate Polycarbonate
Bilson International Inc.	Polycarbonate Acetate
Crews, Inc.	Polycarbonate Acetate Petg
Eastern Safety Equipment Co., Inc.	Polycarbonate
ERB Safety Equipment	Polypropionate
The Fiber-metal Products Co.	Polypropionate
Huntsman	Acetate Polycarbonate
Jackson Products Inc.	Acetate Polycarbonate Polypropionate
Morsafe	Acetate
North	Polypropionate
Oberon	Polypropionate Polycarbonate
Paulson	Acetate Polypropionate Polycarbonate
Pulmosan Protective Equipment	Polycarbonate Polypropionate
Sellstrom	Acetate Polycarbonate
U.S. Safety	Acetate Polycarbonate
Uvex	Polycarbonate Acetate
Wilson Safety Products	Polycarbonate Polypropionate Acetate

T Appendix

Laundering Tyvek® Spunbonded Polyolefin

LAUNDERABILITY

The high wet strength of TYVEK® spunbonded olefin permits laundering and dry cleaning of soiled garments for re-use. Experience has shown that TYVEK can be cleaned satisfactorily with standard laundry equipment. Recommended procedures and materials are described below for optimum results with commercial, home and coin-operated laundry equipment, and for dry cleaning. Home laundry procedures are effective in reducing industrial (oil) and butcher (grease and blood) stains, but may not remove them completely. Commercial procedures, using caustic and organic solvents, remove such stains completely. The appendix lists materials and some supply sources.

The procedures are intended as a guide only and should be evaluated prior to routine use.

COMMERCIAL LAUNDRY PROCEDURES

Light to Medium Soils

Many water soluble substances can be removed from TYVEK with synthetic detergents. Cleaning conditions for light to medium soils are listed in Chart #1 for commercial laundry equipment.

Industrial Oil Stains

The oleophilic nature of TYVEK allows industrial oils to soak into its fibrous structure. These stains can be removed most efficiently by the proper non-ionic detergent, alkali, organic solvent, and water temperatures as outlined in the second soil category in Chart #1.

Butcher Grease and Blood Stains

Special cleaning procedures are outlined in a third category for heavily soiled garments, particularly those with blood, albumin, and animal fat. These garments should be segregated from other types of soils and cleaned separately. As with any fabric, processes for laundering this type of soil are more complicated. Heavy bleaching is required for stain removal and to kill bacteria. A hot sour step is required to remove residual iron stains from hemoglobin in the blood. TYVEK has been stabilized against oxidative degradation; souring and tinting are required to minimize discoloration of the antioxidant in the presence of strong alkalis and/or heat in drying.

The commercial operations shown on Chart #1 are listed in a sequence designed for optimum laundering results. First, select the vertical column describing the kind of soil to be removed from the garment. Across from each operation, the chart gives the wash wheel water level in inches, the temperature in °F., the cycle time in minutes, and the wash pH (when necessary). In addition, the chemicals to be added for the Break and the Suds operations are given in pounds of reagent per hundred pounds of dry garments.

Loading Wash Wheel

The wheel should be loaded at a factor of approximately 2.2 pounds/cubic foot of available space. As shown in the table below, this low loading factor is not a production penalty since the light weight of TYVEK will permit cleaning about twice the number of garments per load.

TYPICAL LOAD FOR GARMENTS OF DIFFERENT MATERIALS (42 x 84" Wheel)

Material	Pounds	Number of Garments
TYVEK	150	600
Polyester/Cotton	300	300
Cotton	400	300

Extraction

Garments of TYVEK® should not be pressure-extracted since this will set in wrinkles. Excess water can be removed by spinning the wash wheel "dry" for 3 to 5 minutes.

Drying and Finishing

The simplest method is drip drying on hangers overnight. The best mechanical means is tumbling at a temperature no higher than 170° F. in a steam heated or electric dryer. The garments and the dryer should be cooled down before tumbling is stopped to minimize wrinkles and avoid melts against hot spots. A vibrating steam box or tunnel will also remove most wrinkles. A tunnel dryer/finisher may be suitable with the proper temperature control. Gas-fired dryers may have hot spots which could melt TYVEK when dry. Substantial water savings can be realized with TYVEK since it absorbs very little water that must subsequently be removed in the dryer.

CAUTION

TYVEK begins to shrink at about 250° F. and melts around 275° F.

Static Protection

Cleaning operations remove the antistatic treatment from most synthetic materials. If it is necessary to reapply the antistat to TYVEK in order to meet static protection requirements of the National Fire Protection Association, the application is usually done in the final rinse.

Discoloration

Strong alkaline cleaning agents may discolor the anti-oxidant in TYVEK and result in yellow or a pink discoloration of the garment. Addition of a blue-green tint and souring to an acid pH will minimize this reaction and leave the resulting product white.

Printing Inks

Severe laundering at high temperature with caustic, non-ionic detergents and organic solvent may cause partial removal of printing inks and coatings. Therefore, the cleaning treatment should be tailored to the ink or the coating used and to the degree of cleanliness required.

HOME AND COIN-OPERATED LAUNDRY PROCEDURES

Home and coin-operated laundry procedures are described in Chart #2. Select the column for the soil to be removed. Supplies are listed in the appendix. Comments on elimination of wrinkles, temperatures and loading discussed under commercial laundering procedures are applicable to the smaller home and coin-operated equipment.

Avoid use of gas-fired dryers because of possible hot spots which can melt TYVEK. Always use a dryer with a cool-down cycle on the wash-and-wear setting (warm). Remove garments immediately and smooth by hand to reduce wrinkles. Do not fully dry heavy cotton zippers or cuffs — damp dry instead.

DRY CLEANING PROCEDURES

Garments of TYVEK® can be dry cleaned with perchloroethylene solvent. Cycles should be adjusted to accommodate soil level and maximize unit efficiency. Removal of water soluble soils is improved by addition of standard dry cleaning detergents. The best solvent recovery in a dry-to-dry machine is obtained by underloading garments by weight. For example, a 15 pound machine should be loaded with 5 to 7 pounds of TYVEK. Since the weight of a garment of TYVEK is about one fourth that of a conventional garment, there is no economic penalty.

Comments on temperatures and elimination of wrinkles discussed under commercial laundering are also applicable to dry cleaning.

For antistatic protection, antistat must be reapplied as a last rinse from a separate hold tank. Treatment with a 0.5-0.75 weight percent solution of Zelec® NK in perchloroethylene will enable garments to meet NFPA requirements. Cleaned garments may be finished on hangers in a vibrating box or tunnel steaming unit.

CAUTION

Solution containing Zelec® NK must not be passed through carbon or diatomaceous earth filters. It is absorbed, resulting in excessive pressure drop.

CHART #1
COMMERCIAL WASH PROCEDURES
GARMENTS OF TYVEK® SPUNBONDED OLEFIN

	Type of Soil											
	Light to Medium Soils				Industrial Oil Stains				Butcher Grease and Blood Stains			
Operation*	Level Inches	Temp. °F	Time Min.	pH	Level Inches	Temp. °F	Time Min.	pH	Level Inches	Temp. °F	Time Min.	pH
Finish									10	100	3	—
Break	6	140	15	—	6	190	20	12	6	140	5	12
Supplies (Lbs./100 lbs. garment)												
Non-ionic detergent[1]		1.0#				2.25#				2.25#		
Metasilicate[2]		1.5#				2.7#				2.7#		
Sodium tri-polyphosphate[3]		.5#				.8#				.8#		
Caustic[4]		.5#				1.0#				1.0#		
Solvent[5] (Add 3 minutes into break)						3.4#				3.4#		
Raise Temperature										190	15	
Flush					8	175-190	3	—	8	175-190	3	—
Suds					6	190	10	—	6	190	10	—
Supplies (Lbs./100 lbs. garments)												
Non-ionic detergent[1]						1.2#				1.2#		
Metasilicate[2]						1.4#				1.4#		
Sodium tri-polyphosphate[3]						.4#				.4#		
Caustic[4]						1.0#				1.0#		
Solvent[5] (Add 2 minutes into suds)						3.4#				3.4#		
Rinse					10	175	3	—	10	175	3	—
Rinse	10	140 (optional)	3	—	10	175	3	—	10	175	3	—
Bleach[6]	6	140 (optional)	5 2 qts.	—	6	160 2 qts.	5	10.5	6	160 3 qts.	10	10.5
Rinse	10	140	3	—	10	160	3	—	10	160	3	—
Rinse	10	140	3	—	10	160	3	—	10	160	3	—
Sour Sequence												
Tint[7] 2.3 ml/gal. water									6	160	3	—
Adjust pH to 5.0 with ammonium bi-fluoride[8]										160	5-10	5.0
Rinse	10	120	3	—	10	130	3	—	10	130	3	—
Rinse	10	100	3	—	10	100	3	—	10	100	3	—
Antistat Sequence	3 cold				3 cold				3 cold			
Tint[7] 2.3 ml/gal. water			3	—			3	—				
Adjust pH to 5.0 with ammonium bi-fluoride[8]			1	5.0/5.5			1	5.0/5.5			1	5.0/5.5
Antistat[9] (2.0% on wt. of water)			3	6.5			3	6.5			3	6.5
Brightener[10] (Optional, add with antistat)		1 oz.				1 oz.				1 oz.		

*See appendix for notes and supply sources of products known to be effective.

CHART 2
HOME AND COIN-OPERATED LAUNDRY PROCEDURE
TYVEK® SPUNBONDED OLEFIN

Operation*	Type of Soil: Light to Medium Soil	Food Stains	Butcher Grease and Blood Stains
Rinse — Cold Water			X
Pre Soak — Warm Water + Enzyme[12] overnight if possible			1/2 cup
Launder — Wash & Wear Cycle (Medium agitation, hot water & warm rinse)			
Detergent[11]	X	X	X
Enzyme[12]		1/2 cup	
Hypochlorite Bleach[13]	1 cup	1 cup (5 min. into Cycle)	1 cup
Rinse — Warm Water		X	X
Tumble Dry — Wash & Wear Cycle	X	X	X
Cool Down	X	X	X
Remove & Hang — Prevent Wrinkles	X	X	X

*See Appendix for notes and supply sources of products known to be effective

APPENDIX — NOTES AND CHEMICAL SUPPLY SOURCES*

1. Non-ionic biodegradable detergents:		
for use from 175-190° F. (Industrial oil and butcher, grease and blood stains)	"Tergitol" 15-S-12	Union Carbide Chemical Co. Div. of Union Carbide Corp. 270 Park Avenue New York, NY 10017
	"Surfonic" J-2	Jefferson Chemical Co. 3336 Richmond Avenue P.O. Box 53300 Houston, Texas 77052
for use up to 140° F. (Light to medium soils)	"Tergitol" 15-S-9	Union Carbide Chemical Co.
	"Surfonic" JN-70	Jefferson Chemical Co.
	"Kyro" EO-B	Procter & Gamble — Industrial Soap & Chemical Products Div. P.O. Box 599 Cincinnati, Ohio 45201
	"Igepal" CO-630	General Aniline & Film Corp. Chemical Division 140 W. 51st Street New York, NY 10020
2. Metasilicate	anhydrous sodium metasilicate — orthosilicate may be substituted for metasilicate and caustic.	
3. Sodium tri-polyphosphate	tri-sodium phosphate may be substituted with increased re-deposition.	
4. Caustic	sodium hydroxide.	
5. Organic solvents:	"ILF Solvent"	Industrial Laundry Formulations 10421 Franklin Avenue Franklin Park, IL 60131
	"Solvesso" 150	Humble Oil & Refining Co. P.O. Box 2180 Houston, Texas 77052
6. Bleach		
Commercial laundry	sodium hypochlorite — 1% solution	

*Undoubtedly there are other materials that will give satisfactory results.

7. Tint	**"Pontamine" Turquoise** 8GLS Blue 1% solution	E.I. du Pont de Nemours & Co. Organic Chemicals Department Dyes & Chemicals Division Wilmington, Delaware 19898
8. Ammonium bi-fluoride or equivalent		
9. Antistat:		
Laundering	**"G-2200"**	ICI United States
Dry cleaning (in perchloroethylene)	**"Zelec" NK**	E.I. du Pont de Nemours & Co.
10. Brighteners	**"Calcofluor" White BGT-PST**	American Cyanamid Co. Organic Chemicals Division Dyes & Chemicals Department Bound Brook, NJ 08805
	"Uvitex" EBF Conc. **"Tinopal" ET**	In-Tracolor Corporation (Formerly Ciba/Geigy Dyestuffs Div.) Route 208 Fair Lawn, NJ 07410
11. Commercially available powdered or liquid detergent — amount per manufacturer's instructions.		
12. Enzyme		
amount per manufacturer's instructions. (In soak tank use 2 tablespoons per gallon.)	**"Axion"** **"Biz"**	
13. Bleach		
Home and Coin — Laundry	hypochlorite (liquid) **"Purex"** **"Miracle White"** **"Clorox"** dry (maybe substituted for light to medium soil only) **"Snowy"** **"Miracle White"** **"Clorox II"**	

U Appendix

Appendix U - From The Farm Chemicals Handbook [1]

How to Care for Protective Clothing

Respirators—Discard cartridges, canisters, and filter pads when breathing becomes difficult, when you notice pesticide odor, or at the time interval specified by manufacturer. Write the date on the cartridge when it is first used. Wash the face piece with detergent and ..... area. Never use alcohol or other solvents for cleaning.

Rubber, Vinyl, or Plastic Boots and Gloves—Wash outside of boots and gloves with detergent and water before removing them. After you take them off, wash them inside and out with detergent and water, rinse thoroughly, and dry in a well-ventilated area.

Chemical-Resistant Clothing, Goggles, and Face Masks—Wash plastic or rubber clothing and equipment with detergent and water, rinse thoroughly, and dry in a well-ventilated area.

Fabric Clothing—Discard any fabric clothing that is saturated with a concentrated highly toxic pesticide. Remove clothing carefully and immediately place in a plastic trash bag. Close bag tightly and dispose of it along with your empty pesticide containers. Wear rubber, vinyl, or plastic gloves when handling severely contaminated clothing. Launder normally contaminated clothes at the end of the work.....

- Wash separately from other clothing.
- Pre-rinse clothing outdoors by spraying or hosing it, or presoak in a tub or large bucket, or use prewash cycle of an automatic washer, with detergent.
- Wash clothes using hot water, the highest water level, and a regular or super wash cycle. Use heavy-duty detergents; for emulsifiable concentrates or other oil-based formulations, use heavy-duty liquid detergent.
- Wash contaminated garments at least twice, then thoroughly rinse washer by running through another entire cycle using detergent.
- Line dry to avoid buildup of pesticide residues in the dryer.

References

[1]Farm Chemicals Handbook , Meister Publishing Co. Willoughby, OH, 1989.

V Appendix

Laundering Guidance from Agway Corp.[1]

PESTICIDE SAFETY

PROTECTION FROM PESTICIDE EXPOSURE

Protective Clothing and Equipment

Long sleeve shirts, long pants and sturdy footwear are the minimum acceptable gear when handling or applying pesticides. Additional protective equipment is required as the toxicity of products or risk of exposure increase. Full cover oilskins are essential when operating spray guns, airblast sprayers or where drift is likely. Operators should possess and maintain for their sole use adequate personal protective gear.

Clothing

Pesticide residues are picked up on clothing worn during application and handling. This can cause dermal absorption which is very dangerous because exposure is not obvious. Contamination may not be visible or apparent. Assume clothing has been contaminated and act accordingly.

- Wear fresh clothing daily.
- Always wash clothes after handling pesticides (Durafab or other lightweight disposable coveralls offer a comfortable option to protect personal clothing.)
- Do not reuse torn or threadbare clothing.

Washing Contaminated Clothing

- Clothes contaminated with highly toxic concentrate (undiluted) pesticide should be disposed of by burial.
- Remove contaminated clothing outdoors, empty pockets and hang it out to air.
- Use a prerinse cycle (or a hose).
- Wash separately from other clothing.
- Pretreat heavy contaminations.
- Wash only a few garments at a time.
- Use a full water level.
- Use hot water, 140° F or above.
- Use a normal 12 minute wash cycle.
- Use a heavy duty detergent.
- Use 2 full warm water rinses.
- Line dry outdoors in the sun (if feasible).
- Clean washer by running through a complete cycle with hot water and detergent but no clothing.

Gloves

Never handle pesticides without gloves. Never wear leather gloves; they absorb pesticides and cannot be decontaminated.

For most applications, plastic or plastic-coated gloves are suitable. Since parathion, methyl parathion and others can penetrate the ordinary plastic gloves, rubber or neoprene gloves are needed for these chemicals. Best protection for the hands is unlined rubber Gauntlet Gloves. The Gauntlet prevents exposure of the wrist and

Aprons

Aprons are generally used in manufacturing operations. They must be of rubber or plastic (rubber or neoprene if organophosphates are involved). For some jobs they give protection where it is most needed and are more comfortable than oilskins.

Boots

Wear a pair of rubber boots or overshoes when spraying or dusting. Ordinary leather or cloth-topped shoes quickly become contaminated from drift or from pesticide-laden grass or cover crop, and are difficult to decontaminate

Goggles

Whenever the manufacturer specifies that goggles are to be worn (assuming that a full face gas mask is not being worn), there is a risk of danger to the eyes. Be sure the goggles fit snugly but comfortably, and are non-fogging.

Hats

Dermal absorption of pesticides is very rapid on the neck, forehead and scalp. Hats should protect those areas from runoff and drift. Do not wear hats which can absorb pesticides.

Respirators

If there is any possibility that a moderately toxic to an extremely toxic pesticide may be inhaled, wear an appropriate respirator.

There are two basic types of respirators. These are the chemical cartridge respirator and the gas mask. Most respirators cover only the nose and mouth, some also protect the eyes. Most of them have two cartridges attached to the face-piece. The respirator facepieces have one-way valves, which allow the inhaled air to pass through the cartridge, but prevent exhaled moist breath from passing through the cartridge.

Gas Masks

Gas masks usually cover the entire face. Their face-pieces are made to hold a canister directly or to connect to the canister with a flexible hose. The hose-type canister is generally secured to the back or chest with straps.

Such a gas mask is absolutely necessary when fumigating buildings or working with aerosol sprays in enclosed areas such as greenhouses. Although not pleasant to wear, it is a life saver for a person exposed to a lethal concentration of poisonous gas. Pay attenion to proper adjustments, making certain that the face-piece fits tightly by holding the hand over the air intake. If the face piece collapses, the fit is satisfactory. If it does not collapse, adjust the straps until it does fit. Be sure that the type of canister is the one prescribed for the gas being used.

After relatively short exposures to certain odors, we lose the ability to detect these odors. If the gas or vapor which is being used can be detected by smell when wearing a full face respirator, the mask must be faulty and the operator should get into the fresh air at once and check the fit of the respirator. If the fit is faulty, correct it. If the fit is good, replace the canister.

Use only government approved respirators. Two approved respirators are listed in the pesticide price pages; the Agritox Full Face #162115 and the Agritox CP AT X-2. Read manufacturer's directions and follow carefully.

USE and CARE of RESPIRATORS

[illegible] when using respirators

Clean and disinfect respirators daily

1. Make sure valves, filters and cartridges are properly positioned and sealed.
2. Fit respirator on face with headbands snug enough to insure a tight but comfortable seal.
3. Test for leakage by placing the hand over the outside exhaust valve housing. Exhale to cause slight pressure inside face-piece. If no air escapes, respirator is properly fitted. if air escapes, readjust headbands and test again.
4. Change filters when breathing becomes difficult—usually twice a day or more under heavy usage.

References

[1]Agway Crop Protection and Fertility Guide, Agway Inc., Syracuse, NY, 1989.

W Appendix

Extension Service Information Pertinent to Decontamination

Farm bulletins represents information supplied by academic and agricultural support services. Although the bulletin that follows is from the University of Massachusetts-Amherst,[1] it in turn was reprinted from information from the University of Nebraska-Lincoln. Thus, it represents information supplied to farming communities in widely dispersed parts of the United States.

Cooperative Extension • University of Massachusetts

Laundering Pesticide Contaminated Clothing

Textile & Clothing Committee

The problem of how to launder pesticide contaminated clothing has puzzled many as pesticide use has become widespread. What is the best method? What water temperature should be used? Is there a difference in detergent performance? Must you be careful about washing contaminated clothes with other clothing?

Use the pesticide label as a guide for knowing which chemicals are most toxic. Key words on all pesticide labels identify the toxicity of the product *(Figure 1)*.

Key Word	*Toxicity*	*Examples**
DANGER POISON	Highly toxic/ concentrated	Counter Disyston Parathion Furadan Dyfonate
WARNING	Moderately toxic	Diazinon Treflan Chlordane
CAUTION	Slightly toxic	2,4-D Sevin

*Toxicity of the pesticide may vary depending upon the formulated product. Use the key word as an indication of the toxicity level.

Clothing contaminated with highly toxic and concentrated pesticides must be handled most carefully as these pesticides are easily absorbed through the skin. If the clothes have been completely saturated with concentrated pesticides, discard them. Clothing contaminated by moderately toxic pesticides do not warrant such drastic measures. Hazards are less pronounced in handling clothing exposed to low toxicity pesticides. But...the ease of pesticide removal through laundering does *not* depend on toxicity level — it depends on the formulation of the pesticide. For example, 2,4-D *amine* is easily removed through laundering because it is soluble in water; 2,4-D *ester* is much more difficult to remove through laundering.

Disposable clothing helps limit contamination of clothes because the disposable garments add an extra layer of protection. This is especially important when you are in direct contact with pesticides, such as when mixing and loading pesticides for application.

Laundering Recommendations

Wash contaminated clothing separately from the family wash. Research has shown that pesticide residues are transferred from contaminated clothing to other clothing when they are laundered together. Know when pesticides have been used so all clothing can be properly laundered!

Pre-rinsing contaminated clothing before washing will help remove pesticide particles from the fabric. Pre-rinsing can be done by:

2. pre-rinsing with agitation in an automatic washing machine;
3. spraying/hosing garment(s) outdoors.

Pre-rinsing is especially effective in dislodging the particles from clothing when a wettable powder pesticide formulation has been used.

Clothing worn while using slightly toxic pesticides may be effectively laundered in one machine washing. It is strongly recommended that *multiple washings* be used on clothing contaminated with *concentrated* pesticides to draw out excess residues. Always wear rubber gloves when handling highly contaminated clothing to prevent pesticide absorption into the body.

Washing in hot water removes more pesticide from the clothing than washing in other water temperatures. Remember...the hotter, the better. Avoid cold water washing! Although cold water washing might save energy, cold water temperatures are relatively ineffective in removing pesticides from clothing.

Laundry detergents, whether phosphate, carbonate, or heavy duty liquids, are similarly effective in removing pesticides from fabric. However, research has shown that heavy duty liquid detergents are more effective than other detergents in removing emulsifiable concentrate pesticide formulations. Emulsifiable concentrate formulations are oil-based and heavy duty liquid detergents are known for oil-removing ability.

Laundry additives, such as bleach or ammonia, do not contribute to removing pesticide residues. Either of these additives may be used, if desired, but caution must be used. *Bleach should never be added to or mixed with ammonia,* because they react together to form a fatal chlorine gas. Be careful — *don't mix ammonia and bleach!*

If several garments have become contaminated, wash only one or two garments in a single load. Wash garments contaminated by the same pesticide(s) together. Launder, using a full water level to allow the water to thoroughly flush the fabric.

During seasons when pesticides are being used daily, clothing exposed to pesticides should be laundered daily. This is especially true with highly toxic or concentrated pesticides. It is much easier to remove pesticides from clothing by daily laundering than attempting to remove residues that have accumulated over a period of time.

Pesticide carry-over to subsequent laundry loads is possible because the washing machine is likely to retain residues which are then released in following laundry loads. It is important to rinse the washing machine with an "empty load," using hot water and the same detergent, machine settings and cycles used for laundering the contaminated clothing.

Line drying is recommended for these items. Although heat from an automatic dryer might create additional chemical breakdown of pesticide residues, many pesticides break down when exposed to sunlight. This also eliminates the possibility of residues collecting in the dryer.

When Laundering Pesticide Contaminated Clothing...REMEMBER

- *READ* the pesticide *LABEL* for information.
- *DISPOSABLE PESTICIDE CLOTHING* provides extra protection.
- *PRE-RINSE* clothing by:
  * presoaking in a suitable container;
  * agitating in an automatic washing machine;
  * spraying/hosing the garment(s) outdoors.
- *WASHING* machine settings; *Hot* water temperature (140°F/60°C), *Full* water level, *Normal* (12 minutes) wash cycle.
- *RE-WASH* the contaminated clothing two or three times, if necessary.
- Wash *A FEW* contaminated garments at a time, using lots of water.
- Wash *SEPARATELY* from *FAMILY* laundry. *DISCARD* clothing if thoroughly saturated.
- *LAUNDER CLOTHING DAILY* when applying pesticide daily.
- *RINSE MACHINE* thoroughly after laundering contaminated clothing.
- *LINE DRY* to avoid contaminating the automatic dryer.
- *BE AWARE* of when pesticides are being used so that clothing can be appropriately laundered.

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References

[1] Laundering Pesticide Contaminated Clothing, Bulletin L 496, Cooperative Extension, University of Massachusetts, Amherst, MA, 1987.

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16. ABSTRACT

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and its amendments provide for the protection of the health and safety of farmers and farm workers who may be exposed to pesticides. Reduced contact with the active ingredients and other components of pesticides is particularly important for people who mix, load, and apply pesticides. Personal protective equipment is one means by which contact with potentially harmful pesticides can be minimized.

The Guidance Manual summarized here consolidates and extends literature information on the barrier effectiveness of protective materials to pesticides, the effect of personal protection equipment (PPE) on the productivity of pesticide handlers, heat stress associated with the use of PPE, and methods for decontamination of PPE. The Guidance Manual contains extensive appendices describing commercially available products.

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