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Currently available permeability and breakthrough data characterizing chemical warfare agents and their simulants in civilian protective clothing materials[1]

Mary Lou Daugherty, Annetta P. Watson and Tuan Vo-Dinh

Oak Ridge National Laboratory[2], P.O. Box 2001, MS 6050, Oak Ridge, TN 37831-6050 (USA)

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Abstract

The current analysis characterizes chemical protective clothing (CPC) that would be available to civilian emergency personnel responding to possible nerve or vesicant chemical warfare agent release with off-post consequences. Currently available commercial protective garments found in the public domain were identified through contacts with manufacturers, regulatory bodies, and distributors of protective clothing, as well as civilian emergency response personnel who use CPC. When appropriate data were available, individual protective clothing ensembles were further characterized by chemical resistance data for specific agents or their simulants. The literature analysis revealed a wide range of chemical protective garments that have been incompletely evaluated for use in a chemical agent environment.

Introduction

The Department of Defense Authorization Act of 1986 (PL 99-145) directed and authorized the Secretary of Defense to destroy the United States stockpile of lethal unitary chemical munitions and agents by September 30, 1994; the Act was amended in 1988 (PL 100-456) to permit operations testing of commercial scale incinerator design and to allow for unitary munitions disposal

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Correspondence to: Ms. M.L. Daugherty, Oak Ridge National Laboratory, P.O. Box 2001, MS 6050, Oak Ridge, TN 37831-6050 (USA). Phone (615) 576-2379, fax (615) 574-9888.

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completion by April, 1997. Note that unitary munitions are those that contain undilute chemical agent at the time the munition is loaded. A binary agent incorporates agent precursors in two separate compartments of the weapon; the precursors combine to form agent after the weapon is fired. The inventory of material to be destroyed includes the organophosphate nerve agents GA, GB, and VX as well as the vesicant (blister) agents H, HD, HT (various formulations of sulfur mustard) and Lewisite (an organic arsenical). The chemical, physical and toxicological properties of GB, VX and sulfur mustard, the subject agents of this report, have been described in Carnes [1], Carnes and Watson [2], Watson et al. [3,4], and Rogers et al. [5], and are briefly summarized in Table 1. The Chemical Stockpile Emergency Preparedness Program (CSEPP) has been established by the Department of the Army's Office of Program Manager for Chemical Demilitarization to carry out a portion of the Congressional mandates of 1986 and 1988. Additional interest in chemical warfare agents has been sparked by the Gulf War of 1991.

Chemical warfare agents are presently stored at eight separate locations on the continental United States as bombs, cartridges, mines, projectiles, rockets, spray tanks and ton containers (see map in Ref. [2]). The current method of choice for agent destruction is high-temperature (1130–1400°C) incineration at each stockpile installation. In the unlikely event of an unplanned release of chemical agents, the potential for agent contamination off-post exists, and civilian emergency personnel could be the first on the scene.

Because of the extreme toxicity of chemical agents, the highest quality of protection available is mandatory for first responders entering an exposure zone. The specialized and tested ensembles designed to protect military personnel from chemical hazards would not normally be available to a typical civilian community. Nevertheless, the general public does have access to many different types of protective clothing fabricated from a variety of commercially available materials. To date, very little data regarding the efficacy of any of these materials against chemical warfare agents have been published in the open literature.

The principal objective of the current analysis is to evaluate the degree of protection against chemical warfare agent exposure offered by materials used in garments normally available to civilian emergency response personnel. Assessment is on the basis of chemical permeation/breakthrough time data obtained from manufacturers' literature, the open literature, and other sources. In the absence of specific data for individual chemical warfare agents, data for their simulants and/or structural analogs are substituted when available (simulants: methyl salicylate and dimethyl methylphosphonate (DMMP) for VX; diisopropyl methylphosphonate (DIMP), diisopropyl fluorophosphonate (DFP) for GB; butyl sulfide and chloroethyl ethyl sulfide (CEES) for sulfur mustard [7,8]). Although the current investigation focuses on materials used in the construction of fully encapsulating garments, other items such as two-

TABLE 1

Characteristics of nerve and vesicant agents[a]

Characteristic	GB	VX	H, HD	HT
Common name	Sarin	-	Sulfur mustard	Sulfur mustard
CAS No.[b]	107-44-8	50782-69-9	505-60-2	Blend[d]
Chemical name	Methyl phosphonofluoridate, isopropyl ether	*S*-(2-diisopropylaminoethyl) methyl phosphonothiolate, *o*-ethyl ester	bis(2-chloroethyl) sulfide	60% HD and 40% T[d]
Chemical formula	$C_4H_{10}FO_2P$	$C_{11}H_{26}NO_2PS$	$C_4H_8Cl_2S$	Blend[d]
Vapor pressure (at 25 °C)	2.9 mmHg	0.0007 mmHg	0.08 mmHg[c] (H) 0.11 mmHg (HD)	0.104 mmHg
Liquid density (at 25 °C)	1.089 g/cm^3	1.008 g/cm^3	1.27 g/cm^3 (H)	1.27 g/cm^3
Freezing point	−56 °C	−39 °C (calculated)	8-12 °C (H) 14 °C (HD)	1 °C
Color	Clear to straw to amber	Clear to straw	Amber to dark brown	Amber to dark brown
Mode of action	Nervous system poison	Nervous system poison	Blistering of exposed tissue	Blistering of exposed tissue

[a] See Refs. [1,2,6].

[b] Chemical Abstracts Service Number.

[c] Varies with sample purity.

[d] Agent T is bis[2(2-chloroethylthio)ethyl]ester; CAS No. 63918-89-8.

pieced suits, hoods, booties, gloves, and expedient protective clothing (rain gear, etc.) are also considered. In addition, this information provided the basis for the selection of materials recently tested in a concurrent permeation study that included novel detection techniques (Pal et al., submitted [9]).

The findings presented in the current assessment are designed to provide an overview of available information, but do not represent an encyclopedic survey. This information is not intended as an endorsement of any commercial products listed.

Standards and regulations for the use of protective clothing

Basic to the discussion of commercially available chemical protective clothing (CPC) are the definitions and criteria of various federal agencies that have established performance requirements or recommendations to implement consumer selection of garment material and design. The following sources of standards and guidance will most likely have the greatest impact on future manufacturing trends in the commercial protective clothing market.

U.S. Environmental Protection Agency (EPA)

A collaborative report between the the U.S. Environmental Protection Agency (EPA), the National Institute for Occupational Safety and Health (NIOSH), the Occupational Safety and Health Administration (OSHA), and the U.S. Coast Guard (CG) describes a classification guide for protective clothing [10]. The Guide defines four categories of personnel protection that are identified as the "EPA Levels of Protection." These categories are summarized as follows [10,11]:

Level A —Provides the highest level of respiratory, skin, and eye protection. This level incorporates a fully encapsulating suit to prevent skin contact of any kind and a self-contained breathing apparatus (SCBA) inside. The recommended breathing apparatus consists of either a pressure-demand, full-facepiece SCBA or a pressure-demand supplied-air respirator with escape SCBA.

Level B—Provides the same level of respiratory protection as Level A, but less skin protection. The garment covers most of the body, but is not considered gas or vapor tight; thus, the chemical could make contact with the skin. The recommended breathing apparatus consists of either a pressure-demand, full-facepiece SCBA or a pressure-demand supplied-air respirator with escape SCBA.

Level C—Provides the same level of skin protection as Level B, but a lower level of respiratory protection; an air-purifying respirator (a filter-type "gas-mask") replaces the SCBA. The garments for Levels B and C do not protect against vapors, but only against liquids that may splash on the individual. Levels B and C clothing are generally referred to as "splash suits."

Level D—Consists of a pair of coveralls with boots and gloves. Level D protection is used in the limited number of cases when there is no indication of hazardous conditions and the work function precludes contact with hazardous substances.

The classifications "A1" and "B1", proposed for this report, designate clothing certified under the recent National Fire Protection Association (NFPA) standards: NFPA-1991, *Standard on Vapor-Protective Suits for Hazardous Chemical Emergencies* ("A1"), and NFPA-1992, *Standard on Liquid Splash Protective Suits for Hazardous Chemical Emergencies* ("B1") [12,13]. These publications are discussed in more detail in the NFPA text to follow.

Level A1—Protective clothing analogous to Level A garments, but certified to meet requirements under NFPA-1991.

Level B1—Protective clothing analogous to Level B and Level C (splash suit) garments, but certified to meet requirements under NFPA-1992.

The EPA, the U.S. Department of Agriculture, and NIOSH [14–17] have provided guidance for the use of protective clothing by pesticide handlers, but these recommendations are inadequate for protection against chemical agents and are not considered further here.

Occupational Safety and Health Administration (OSHA)

OSHA's Hazardous Waste Operations and Emergency Response Standard, Final Rule 29 CFR 1910.120 regulates the protection of an estimated two million workers at hazardous waste cleanup sites and treatment, storage and disposal facilities, as well as emergency response teams [18]. OSHA states that personal protective equipment (PPE) selection shall be based on an evaluation of the performance characteristics of the PPE relative to the requirements and limitations of the site, the task-specific conditions and duration, and the hazards and potential hazards identified at the site. OSHA refers to the EPA Levels of Protection [10] for guidance in the selection of protective ensembles.

American Society for Testing and Materials (ASTM)

Committee F23 of the ASTM was organized in 1977 to address the need for protective clothing standards for workers exposed to industrial chemical formulations [19]. This committee has subsequently become the international focus of these activities. The committee's responsibilities are to develop standard test methods as well as standard terminology, classifications, and performance specifications for occupational protective clothing. The Society originated ASTM F 1001, the *Standard Guide for Chemicals to Evaluate Protective Clothing Material* (Table 2) [20,21] and ASTM F 739, a *Test Method for Resistance of Protective Clothing Materials to Permeation by Liquids and Gases* [22], both of which have been widely adopted by the protective clothing industry for evaluating barrier properties of their products. A third test, ASTM F 903, *Test Method for Resistance of Protective Clothing Materials to Penetra-*

TABLE 2

ASTM F 1001 chemical test battery[a,b]

ASTM F 1001 liquids	ASTM F 1001 gases
Acetone	Ammonia
Acetonitrile	1,3-Butadiene
Carbon disulfide	Chlorine
Dichloromethane	Ethylene oxide
Diethylamine	Hydrogen chloride
Dimethylformamide	Methyl chloride
Ethyl acetate	
n-Hexane	
Methanol	
Nitrobenzene	
Sodium hydroxide	
Sulfuric acid	
Tetrachloroethylene	
Tetrahydrofuran	
Toluene	

[a] See Refs. [20,21].

[b] None of the chemicals in the battery would qualify as simulants for chemical warfare agents.

tion by Liquids, is used to evaluate the liquid barrier effectiveness of materials and integrity of protective clothing components (e.g. seams, closures) [12]. Note that none of the ASTM F 1001 chemicals listed in Table 2 would qualify as simulants for chemical agents.

National Fire Protection Association (NFPA)

On February 5, 1990, NFPA *Standard on Vapor-Protective Suits for Hazardous Chemical Emergencies* (NFPA-1991) [12], and NFPA *Standard on Liquid Splash Protective Suits for Hazardous Chemical Emergencies* (NFPA-1992) [13], went into effect. To meet the 1990 certification requirements, each primary suit component of the vapor-protective suit (garment, visor, gloves, and boots) is to be tested by the manufacturer for permeation resistance to each chemical of the NFPA liquid test battery (those specified in ASTM F 1001 (Table 2) plus anhydrous ammonia gas and chlorine gas). Splash-suit materials are to be tested for penetration resistance to chemicals selected from the ASTM F 1001 test battery. To assure that adequate protection will be afforded in the environment in which they will be used, both suit types must resist chemical intrusion for 1 hour and must also pass specific tests for burst strength, tear strength, abrasion resistance, flammability resistance, cold temperature performance, and flexural fatigue. These performance requirements were developed by the NFPA to simulate use conditions; test procedures are outlined in NFPA-1991. Totally encapsulating hazardous materials (HAZMAT) suits are not intended for use as primary garments during fire-fighting but must resist ignition when impinged by flame [12,18].

Identification and characterization of protective clothing available to civilian emergency response personnel

The primary source for identifying commercially available protective clothing is a well-known decision aid for users and buyers of protective clothing, *Guidelines for the Selection of Chemical Protective Clothing*, published by the American Conference of Governmental Industrial Hygienists (ACGIH) [23]. The *Guidelines* lists the primary materials used by domestic manufacturers of fully encapsulating suits (EPA level A, or in some cases level B), along with the distributors or manufacturers of the suits or suit materials. Because the 1987 issue of the *Guidelines* does not reflect recent advances in materials fabrication, updated information was solicited by the authors of the current document from the distributors and manufacturers of all EPA level A clothing identified in the ACGIH [23] publication. Informal interviews and literature searches provided additional information regarding the types of protective clothing actually used by community emergency responders, industries, and hazardous materials contractors.

Table 3 lists the commercially available chemical-protective suits identified by these sources, along with the "EPA Levels of Protection" afforded. Seven products are designated "level A1" indicating that they have met the testing requirements of the NFPA Standard 1991. First Team®[3], Responder®, Interceptor™ 1991, Forcefield™ and Chemrel Max® meet the criteria for NFPA 1991 if used in combination with flash oversuits, whereas Challenge® 6000 and Trellchem® HPS qualify as single layer material, chemical protective suits. Table 3 also lists the primary suit material and manufacturer. Results of the interviews and literature searches are briefly summarized in the following sections.

Communities

Firemen are usually the first to respond to a civilian emergency involving hazardous materials [24–29]. HAZMAT teams, whose response capabilities appear to range widely, may arrive with, or slightly later than, firemen [29].

Turn-out gear for fire protection is usually constructed of the commercial materials, Nomex® aramid fiber, PBI®, or a combination of PBI and Kevlar® aramid fiber [26,28–31]. Polybenzimidazole (PBI) is a high-performance fiber that can be blended with other high-performance fibers for enhanced thermal and flame resistance, durability, and/or chemical resistance [32]. PBI is

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[3] Products identified with registered (®) or unregistered (™) trademarks and the companies that own the trademarks are listed in Table A-1 of the Appendix.

TABLE 3

Commercially available totally encapsulating suits (TES) identified from the *ACGIH Guidelines for the Selection of Chemical Protective Clothing*, manufacturers' literature, and interviews with users of CPC

Ensemble (EPA Rating)	Primary material	Manufacturer
Acid King® Suit (47836P) (A)	Polyvinyl chloride/nylon/polyvinyl chloride	Wheeler Protective Apparel, Inc.
Acid King Suit (47876P)[a] (A)	Butyl/nylon	Wheeler Protective Apparel, Inc.
Acid King Suit (47967P)[a] (A)	Teflon®/Nomex®	Wheeler Protective Apparel, Inc.
Butyl TES[a] (A)	Butyl	Life-Guard
Challenge® 5000[a] (B1)	Teflon/Nomex/Teflon	Chemical Fabrics Corporation
Challenge 5100 (A)	Teflon/Nomex/Teflon	Chemical Fabrics Corporation
Challenge 5200 (A)	Teflon/fiberglass/Teflon	Chemical Fabrics Corporation
Challenge 6000[a] (A1)	Not available	Chemical Fabrics Corporation
Chempruf II™ Suit, Betex[a] (A)	Butyl/polyester/neoprene	Mine Safety Appliances
Chempruf II Suit, Vautex[a] (A)	Viton®/nylon/neoprene	Mine Safety Appliances
Chemrel Max GT™[a] (A1)	Not available	Chemron, Inc.
Chemturion™, Model 12 (No rating)	Chlorinated polyethylene	ILC Dover, Inc.
Chemturion, Model 13 (A)	Chlorinated polyethylene	ILC Dover, Inc.
Chemturion, Model 51 (A)	Chlorinated polyethylene	ILC Dover, Inc.
First Team™ HazMat Suit (Blue Max™)[a] (A)	"Synthetic non-woven substrate composite laminated on both sides with inert thermoplastic films"	Mine Safety Appliances
First Team™ II HazMat Suit (Blue Max™)[a] (A1)	"Synthetic non-woven substrate composite laminated on both sides with inert thermoplastic films"	Mine Safety Appliances
Forcefield™[a] (A1)	Teflon/Kevlar®/Teflon	Lakeland Fyrepel
FrontLine™[a] (B)	Composite film material (Barricade®)	Kappler, Inc.
Interceptor™[a] (A)	Laminate (no other information available)	Lakeland Fyrepel
Interceptor 1991[a] (A1)	Laminate (no other information available)	Lakeland Fyrepel
LL-100-Toxicological Butyl (A^{EU})[b]	Butyl/nylon/butyl	Andover Industries[c]
LL-100-Polyvinyl Chloride (A^{EU})[b]	Polyvinyl chloride/nylon	Andover Industries[c]
Metro SS (A)	Teflon/Nomex/chlorobutyl	Andover Industries[c]
Pacesetter™[a] (B1)	Nomex poplin/Gore-Tex® film/Nomex jersey	Lion Apparel, Inc.
PBI® Saratoga[a] (No rating)	PBI-Nomex (plain woven)/sorptive layer (Bluecher beads)/PBI-Nomex (jersey knit)	Hoechst® Celanese Corp.
PVC TES[a] (A)	Polyvinyl chloride	Life-Guard

Responder™[a] (A1)	"Multiple polymers"	Life-Guard
SCAPE RFHCO[d] (No rating)	Chlorobutyl/Nomex/chlorobutyl	Arrowhead Products
StaSafe Acidmaster (A)	Polyvinyl chloride/polyester	Standard Safety Equipment
TefGuard™-TES[a] (A,B)	"Teflon based"	Life-Guard
Trellchem® Butyl Extra (A)	Butyl/nylon/butyl	Trelleborg AB
Trellchem Butyl (B)	Butyl/nylon/butyl	Trelleborg AB
Trellchem Light Extra (A)	Polyvinyl chloride/nylon/polyvinyl chloride	Trelleborg AB
Trellchem Light (B)	Polyvinyl chloride/nylon/polyvinyl chloride	Trelleborg AB
Trellchem Super Extra (A)	Viton/butyl/nylon/butyl	Trelleborg AB
Trellchem Super (B)	Viton/butyl/nylon/butyl	Trelleborg AB
Trellchem HPS[a] (A1)	Viton/butyl/nylon polyamide/butyl/Trellchem super polymer barrier layer	Trelleborg AB
Viton®/Nomex®/Chlorobutyl TES[a] (A)	Viton/Nomex/chlorobutyl	Life-Guard
305 PVC/BA (A)	Polyvinyl chloride/nylon/polyvinyl chloride	Lakeland Fyrepel
306 PVC/BA (A)	Polyvinyl chloride/nylon/polyvinyl chloride	Lakeland Fyrepel
305 B/BA (A)	Butyl/nylon/butyl	Lakeland Fyrepel
305 V/BA (A)	Viton/polyester/Viton	Lakeland Fyrepel
306 B/BA (A)	Butyl/nylon/butyl	Lakeland Fyrepel
306 V/BA (A)	Viton/polyester/Viton	Lakeland Fyrepel
600 CK (No EPA rating)	Chloroprene/nylon	National Draeger, Inc.
500 CK (B)	Chloroprene/nylon	National Draeger, Inc.
700 PF (A)	Viton/nylon/chloroprene	National Draeger, Inc.
500 PF (B)	Viton/nylon/chloroprene	National Draeger, Inc.
700 PVC (A)	Polyvinyl chloride/nylon/polyvinyl chloride	National Draeger, Inc.
600 PVC (No EPA rating)	Polyvinyl chloride/nylon/polyvinyl chloride	National Draeger, Inc.
500 PVC (B)	Polyvinyl chloride/nylon/polyvinyl chloride	National Draeger, Inc.
720 PF[a,e]	Viton/butyl/chloroprene/ polyamide	National Draeger, Inc.
721 PF[a,e]	Viton/butyl/chloroprene/ polyamide	National Draeger, Inc.

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[a] Identified in current search.

[b] When used with "emergency egress unit".

[c] Product information from this company could not be verified.

[d] This material is highly specialized for use by rocket fuel handlers and would not normally be available in civilian communities.

[e] No EPA rating, appears to be level A from description in manufacturer's literature.

used in the manufacture of PBI Saratoga, a textile that, according to Alexandroff [33], demonstrated resistance to chemical agent permeation when challenged with vapors of HD and GD in tests conducted by the U.S. Air Force. It is the Saratoga, not the PBI, that confers chemical protection; therefore, PBI turnout gear, which does not contain Saratoga, would not be expected to provide any significant chemical protection. The suits used by community HAZMAT teams are generally fully encapsulating (although overalls are sometimes used); may be reusable, disposable or have limited reuse; and are sometimes used in conjunction with flash oversuits. Specialized HAZMAT teams might use suits made of butyl rubber, Viton®/butyl rubber, ChemFab®, Challenge® 5100 or 5200, Tyvek® spun-bonded olefin, and/or Saranex®-coated Tyvek.

Butyl rubber offers excellent protection from hazardous chemicals, but is costly, difficult to decontaminate, and difficult to repair and test [34]. Butyl rubber is considered to be the "old stand-by" of CPC and is still used either alone or bonded with other CPC materials such as Viton fluoroelastomer (fluorocarbon rubber [35]) in the manufacture of fully encapsulating level A suits (see Table 3). Butyl rubber boots and gloves are components of the U.S. Army Level A and Level B clothing designed for use on the chemical battlefield [36]. Note that the definitions for these levels do not correspond to EPA levels of protection. The U.S. Army's Level A ensemble for protection against nerve agents consists of a M9A1 mask worn with impermeable butyl rubber coveralls, whereas the Level B ensemble consists of a M9A1, M40, or M17 series mask worn with an impermeable butyl rubber apron [36]. Both levels require butyl rubber hoods, boots, and gloves with surgical gloves worn underneath. For protection against vesicants, both levels of protection require permeable impregnated clothing to be worn under the Level A or Level B ensemble.

The ChemFab Challenge is a reusable, fully encapsulating, level A suit made of either Teflon®/Nomex/Teflon (5100 model) or Teflon/fiberglass/Teflon (5200 model) [23]. These materials show good resistance to permeation of the ASTM 1001 test battery (Table 2) [37].

Tyvek, a spunbonded olefin, is particularly effective against particulates, but Du Pont cautions that suits made of Tyvek cannot be used for liquid chemicals or gases [38]. Tyvek products are disposable. Saranex is a laminate of low-density polyethylene copolymer containing layers of Saran film. The vinyl acetate/polyethylene layer can be bonded to Tyvek [39]. Saranex-laminated Tyvek, a much more effective barrier material than Tyvek alone, demonstrated breakthrough times of several hours for inorganic acids, bases, and polar organics; but breakthrough times were only a few minutes for the nonpolar organic solvents that were tested [34]. The effectiveness of the laminate when challenged by warfare agents is not known, but limited data show that the breakthrough time of GB is >360 minutes against Saranex 15, and >1320 minutes against Saranex 20 (liquid challenge/vapor penetration) [40]. However, suits made of the laminate are not intended for use in situations requiring gas-tight suits [38].

Industry/contractors

HAZMAT teams for private industries and commercial HAZMAT contractors specializing in hazardous waste cleanup are expected to respond to emergencies involving a variety of chemical hazards and are usually equipped with all levels of CPC. This practice allows selection of the most appropriate ensemble for individual circumstances [41–44]. Selections are based on such sources as manufacturers' recommendations, the *Guidelines for the Selection of Chemical Protective Clothing* [23], *Chemical Protective Clothing Performance Index Book* [45], and commercially available computerized databases, such as GlovES+ [45]. Among the garments stocked by the industrial and commercial HAZMAT groups contacted for this evaluation are:

(1) disposable suits made of Tyvek and Saranex-coated Tyvek;
(2) the totally encapsulating, limited use, level B suit, Frontline™ (manufactured with Barricade® chemical barrier fabric, a multilayered film bonded to a nonwoven polypropylene substrate); and
(3) totally encapsulating, level A suits, Responder (limited use, multiple polymers), TefGuard® (reusable, Teflon-based material), and ChemFab Challenge [20,41,43,44,46].

Permeation rate/breakthrough time data for commercial materials

To characterize barrier properties of the materials identified, permeation and breakthrough time data from challenge tests with commercially available protective clothing materials vs. chemical agents and/or their simulants were solicited from manufacturers, federal regulatory agencies and various commands of the Department of the Army and Air Force. Searches of the open literature were also conducted.

Concepts basic to evaluating the protective properties of clothing have been summarized by Stull [11], Jamke [47], and ASTM [22]. A chemical can affect a suit material and/or gain access into a suit or other forms of clothing via three principal processes:

(1) Degradation. The loss of one or more physical properties caused by surface contact with the chemical. Material weight change and elongation are common measures of degradation. Usually, degradation can be detected visually or by using appropriate measuring instruments.
(2) Penetration. The flow of a liquid or gaseous chemical on a non-molecular level through closures, seams, imperfections, etc. The process of laminating composite materials and coating fabrics can create imperfections due to improper curing or uneven application of polymer film. Pinholes can facilitate penetration.

TABLE 4

Permeation rate, penetration rate, and breakthrough time data for chemical warfare agents/simulants tested against protective clothing materials

Material	Agent (A)/Simulant (S)	Breakthrough time (min)	Permeation rate	Material thickness (mm)	Reference
Suit materials					
Chemrel™	Malathion, 10% (S)[a]	>360[b]	N.a.[c]	N.a.	[52]
Chemrel	Malathion, 60% (S)[a]	>240[b]	N.a.	N.a.	[53]
Chemrel	Methyl parathion, 10% (S)[a]	>360[b]	N.a.	N.a.	[53]
Chemrel	Methyl parathion, 57% (S)[a]	>120[b]	N.a.	N.a.	[53]
Chlorinated polyethylene (PE)	GB (A)	>300[d]	N.a.	0.51[e]	[53]
Chlorinated PE	GB (A)	>1440[f]	N.a.	0.51[e]	[52]
Chlorinated PE	HD (A)	>120<240[d]	N.a.	0.51[e]	[52]
Chlorinated PE	HD (A)	>1440[f]	N.a.	0.51[e]	[52]
Chlorinated PE	VX (A)	>240[d]	N.a.	0.51[e]	[52]
Chlorinated PE	GB (A)	>300[d]	N.a.	0.30[e]	[52]
Chlorinated PE	HD (A)	<60[d]	N.a.	0.30[e]	[52]
Chlorinated PE	VX (A)	>240[d]	N.a.	0.30[e]	[52]
Chlorinated PE (ILC Dover)	Dibutyl sulfide (S)[g]	N.a.	0.0041 μg/cm^2 (6 h)[h]	0.51[e]	[40]
Chlorinated PE (ILC Dover)	Dibutyl sulfide (S)[g]	N.a.	0.0026 μg/cm^2 (6 h)[h]	0.51[e]	[40]
Chlorinated PE (ILC Dover)	Dibutyl sulfide (S)[g]	N.a.	0.0038 μg/cm^2 (6 h)[h]	0.76[e]	[40]
Chlorinated PE/Saran (Dow Chemical)	Dibutyl sulfide (S)[g]	N.a.	0.0043 μg/cm^2 (6 h)[h] <0.0025 μg/cm^2 (6 h)[h]	0.30[e]	[40]
FEP 100 (Du Pont through ILC Dover)	Dibutyl sulfide (S)[g]	N.a.	N.d. (6 h)	N.a.	[40]
Gore A (Gore and Associates)	Dibutyl sulfide (S)[g]	N.a.	37.0 μg/cm^2 (6 h)	N.a.	[40]
Gore B (Gore and Associates)	Dibutyl sulfide (S)[g]	N.a.	28.5 μg/cm^2 (6 h)	N.a.	[40]
Gore C (Gore and Associates)	Dibutyl sulfide (S)[g]	N.a.	25.0 μg/cm^2 (6 h)	N.a.	[40]
Herculite 80J221	GB (A)	>240[d]	N.a.	N.a.	[40]
Herculite 80J221	HD (A)	>60<120[d]	N.a.	N.a.	[52]
Herculite L13-11	GB (A)	<300[d]	N.a.	N.a.	[40]
Herculite L13-11	GB (A)	>1440[f]	N.a.	N.a.	[52]
Herculite L13-11	HD (A)	>1440[d]	N.a.	N.a.	[52]
Herculite L13-11	HD (A)	>1560[f]	N.a.	N.a.	[52]
Herculite L13-11	VX (A)	>240[d]	N.a.	N.a.	[52]

Herculite L13-11	VX (A)	>240[f]	N.a.	N.a.	[40]
HiTuff MP1880	GB (A)	<60[d]	N.a.	N.a.	[40]
HiTuff MP1880	HD (A)	>60<120[d]	N.a.	N.a.	[52]
Interceptor™	GB (A)	>6186	N.a.	16	[54]
Interceptor	HD (A)	>4425	N.a.	16	[54]
Kapton (polyamide) (Du Pont)	Dibutyl sulfide (S)[g]	N.a.	0.0003 $\mu g/cm^2$ (6 h)	N.a.	[40]
Low density chlorinated PE/nylon coextrusion	Dibutyl sulfide (S)[g]	N.a.	<0.00025 $\mu g/cm^2$ (6 h)	N.a.	[40]
Nylon 6	GB (A)	>300[d]	N.a.	0.30[e]	[40]
Nylon 6	HD (A)	>240[d]	N.a.	0.30[e]	[40]
Polyamide	GB (A)	>360[d]	N.a.	N.a.	[52]
PE	GB (A)	<60[d]	N.a.	N.a.	[52]
PE	HD (A)	>60<120[d]	N.a.	N.a.	[52]
PE	VX (A)	>240[d]	N.a.	N.a.	[52]
PE (Du Pont Tyvek®)	Methyl parathion, 30–70% (S)[a]	15	1 $mg/m^2 \cdot min$	0.15	[45]
PE (Du Pont Tyvek)	Methyl parathion, <30% (S)[a]	30	2 $mg/m^2 \cdot min$	0.15	[45]
Polypropylene	GB (A)	>300[d]	N.a.	N.a.	[52]
Polypropylene	HD (A)	>1440; >360[d]	N.a.	N.a.	[52]
Polyimide	GB (A)	>360	N.a.	N.a.	[52]
Polyurethane (PU)	GB (A)	>240[d]	N.a.	N.a.	[52]
PU	HD (A)	>60<120[d]	N.a.	N.a.	[40]
PU	VX (A)	>240[d]	N.a.	N.a.	[40]
PU/Saran/nylon/PU (ILC Dover)	Dibutyl sulfide (S)[g]	N.a.	0.0008 $\mu g/cm^2$	N.a.	[40]
Saranex® 15	GB (A)	>360[d]	N.a.	N.a.	[52]
Saranex 20	GB (A)	>1320[d]	N.a.	N.a.	[52]
Saranex/Tyvek	Dibutyl sulfide (S)[g]	N.a.	N.d.[i]	N.a.	[40]
Saranex-23 (Du Pont Tyvek)	Methyl parathion, 30–70% (S)[a]	120	1 $mg/m^2 \cdot min$	0.15	[45]
Saranex-23 (Du Pont Tyvek)	Methyl parathion, <30% (S)[a]	>240	<1 $mg/m^2 \cdot min$	N.a.	[45]
Teflon® (ChemFab® Challenge® 5100)	Ethion (S)[a]	>288	0	N.a.	[40]
Teflon (ChemFab Challenge 5100)	Malathion, 50% (S)[a]	>186	1 $mg/m^2 \cdot min$	N.a.	[40]
Teflon (ChemFab Challenge 5100)	Naled (S)[a]	>204	0	N.a.	[40]
Teflon (ChemFab Challenge 5100)	Parathion (S)[a]	>180	N.a.	0.25[j]	[40]
Tuftane 310	GB (A)	>240[d]	N.a.	N.a.	[52]
Tuftane 310	GB (A)	>300<1320[f]	N.a.	N.a.	[52]
Tuftane 310	HD (A)	>60<120[d]	N.a.	N.a.	[52]

TABLE 4 (continued)

Material	Agent (A)/Simulant (S)	Breakthrough time (min)	Permeation rate	Material thickness	Reference
Tuftane 310	HD (A)	>300<1380[f]	N.a.	N.a.	[52]
Tuftane 310	VX (A)	>240[d]	N.a.	N.a.	[52]
Tuftane 410	GB (A)	<60[d]	N.a.	N.a.	[52]
Tuftane 410	HD (A)	<60[d]	N.a.	N.a.	[52]
Tuftane (2×7, 0.003 laminate)	GB (A)	>240<360[d]	N.a.	N.a.	[52]
Tuftane (2×7, 0.003 laminate)	HD (A)	>60<120[d]	N.a.	N.a.	[52]
Tuftane (2×7, 0.003 laminate)	VX (A)	>240[d]	N.a.	N.a.	[52]
Tyvek type 1422A, uncoated	Methyl parathion, 10% (S)[a]	<5	"High"	N.a.	[38]
Tyvek QC, coated with 1.25 mil PE	Methyl parathion, 57% (S)[a]	15[k]	0.015 $mg/m^2 \cdot s$[k]	N.a.	[38]
Tyvek QC, coated with 1.25 mil PE	Methyl parathion, 10% (S)[a]	>30[k]	0.033 $mg/m^2 \cdot s$[k]	N.a.	[38]
Tyvek Sanarex-23P (single ply)	Methyl parathion, 57% (S)[a]	>120[k]	0.0017 $mg/m^2 \cdot s$[k]	N.a.	[38]
Tyvek Saranex-23P (single ply)	Methyl parathion, 10% (S)[a]	>240[k]	<0.0003 $mg/m^2 \cdot s$[k]	N.a.	[38]
Uranex	GB (A)	>240[d]	N.a.	N.a.	[40]
Uranex	GB (A)	>1440[e]	N.a.	N.a.	[52]
Uranex	HD (A)	>240[d]	N.a.	N.a.	[52]
Uranex	HD (A)	>1380[e]	N.a.	N.a.	[52]
Uranex	VX (A)	>240[d]	N.a.	N.a.	[52]
Urethane-coated nylon	GB (A)	<60[d]	N.a.	N.a.	[52]
Vinyl	GB (A)	<240[d]	N.a.	N.a.	[52]
Viton® /chlorobutyl (ILC Dover)	Dibutyl sulfide (S)[g]	N.a.	<0.00025 $\mu g/cm^2$ (6 h)	0.30[e]	[40]
Glove materials					
Natural rubber (Edmont 36-124)	Guthion® (S)[a]	190	5	0.51	[45]
Neoprene (Edmont 29-865)	Guthion (S)[a]	>510	0	0.51	[45]
Nitrile (Edmont 37-175)	Guthion (S)[a]	>510	0	0.46	[45]
PVC (Edmont Canada 14112)	Guthion (S)[a]	250	12 $mg/m^2 \cdot min$	N.a.	[45]
Expedient materials					
Cotton	Methyl parathion, 0.12% (S)[a]	N.a.	0.0011 $\mu g/cm^2$[l]	0.30[e]	[49]
Cotton/polyester	Methyl parathion, 0.12% (S)[a]	N.a.	0.0015 $\mu g/cm^2$[l]	0.28[e]	[49]
Polyester	Methyl parathion, 0.12% (S)[a]	N.a.	0.0042 $\mu g/cm^2$[l]	0.25[e]	[49]

Waxed wrapping paper	VX (A)	240	N.a.	N.a.	[50]
Waxed wrapping paper (uncreased)	H (A)	12	N.a.	N.a.	[50]
Waxed wrapping paper (creased)	H (A)	1.8	N.a.	N.a.	[50]
Wrapping paper (grease resistant)	VX (A)	120	N.a.	N.a.	[50]
Wrapping paper (grease resistant, uncreased)	H (A)	6	N.a.	N.a.	[50]
Wrapping paper (grease resistant, creased)	H (A)	3	N.a.	N.a.	[50]
Cellulosic film (scrim reinforced)	VX (A)	2880	N.a.	N.a.	[50]
Cellulosic film (scrim reinforced, uncreased)	H (A)	1440	N.a.	N.a.	[50]
Cellulosic film (scrim reinforced, creased)	H (A)	1440	N.a.	N.a.	[50]
Polythene film	VX (A)	1800-2400	N.a.	0.25[j]	[50]
Polythene film (uncreased)	H (A)	120	N.a.	0.25[j]	[50]
Polythene film (creased)	H (A)	120	N.a.	0.25[j]	[50]
Polythene film	VX (A)	2880	N.a.	0.51[j]	[50]
Polythene film (uncreased)	H (A)	420	N.a.	0.51[j]	[50]
Polyvinyl chloride film	VX (A)	2880	N.a.	0.076[j]	[50]
Polyvinyl chloride film	H (A)	12	N.a.	0.076[j]	[50]

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[a] Simulant for VX and GB.

[b] Extrapolated from actual breakthrough data collected on similar chemical families tested in accordance with ASTM Standard F739-81 under laboratory conditions on the Chemrel fabric.

[c] N.a. = Not available.

[d] Liquid challenge/vapor penetration.

[e] Converted to mm from mil (authors' units) (mm = mil $\times 2.54 \times 10^{-2}$).

[f] Vapor challenge/vapor penetration.

[g] Simulant for mustard agent.

[h] Value questionable due to background interference.

[i] N.d. = Not detected.

[j] Converted to mm from inches (authors' units) (mm = inches $\times$ 25.4).

[k] Test conducted following ASTM F739 test method. Undiluted chemical, standard temperature and pressure.

[l] The materials were layered with a collector fabric and foil, the test layer was sprayed with pesticide, allowed to dry for 1 hour, followed by extraction of pesticide from each layer and analysis by gas chromatography.

(3) Permeation. The molecular process by which a liquid or gaseous chemical moves through a protective clothing material via sorption onto the surface of the material, diffusion of the sorbed molecules into the material, and desorption of the molecules from the inner surface of the material into the collecting medium. The time from initial adsorption of the chemical until it can be detected on the other side of the material is called "breakthrough time". Once breakthrough is achieved, permeation of the chemical may increase until it becomes constant with respect to time. This is the "steady state" permeation rate. Permeation may occur without degradation.

The proper selection of CPC requires strict attention to permeation rate, breakthrough time, penetration, degradation, garment design (zippers, seams, other closures, and visors), decontamination characteristics and physical strength (materials that rip, tear or puncture easily would not provide adequate protection, even though they may resist permeation [48]). However, the purpose of this document is to provide an overview of the available data pertinent to chemical warfare agent protection, not a selection guide for CPC. Thus, only permeation rate and breakthrough time are reported for chemical protective suit materials, and for glove and expedient materials challenged by chemical warfare agents or agent surrogates (Table 4). Table 4 also incorporates permeation/breakthrough time data for organophosphorus pesticides that are structurally similar to nerve agents and considered by some investigators to be nerve agent simulants. However, because of the significantly greater toxicity of nerve agents, the test results obtained with organophosphorus pesticides are not directly applicable to the issue of warfare agent protective clothing, and pesticide data are compiled in Table 4 solely for the sake of completeness.

Data characterizing permeation rate and breakthrough time result from complex processes that may be affected by variables in analytical procedures. Proper use of these data in the selection of protective clothing may require additional information. For example, details that are essential to the interpretation of breakthrough time data include physical state (gas, liquid phase) and concentration of challenge chemical, experimental details for test method, temperature at which the test was performed, minimum detectable level for the measurement system, and source of test data [47]. Schwope et al. [51] indicated that proper interpretation of breakthrough time values also requires knowledge of surface area and thickness of clothing material, as well as various analytical details.

Suit materials

The majority of data in Table 4 for the resistance of commercially available CPC to the agents GB, VX or sulfur mustard and their simulants are provided by only two military-sponsored reports [40,52], one guide for the selection for CPC [45], brochures from two manufacturers [38,53], and one personal communication [54]. Several suit materials exhibit good barrier properties to chemical agents or simulants. A comparison of Table 4 with Table 3, which lists 53 of the commercially available totally encapsulating suits identified for this evaluation, shows that ChemFab Challenge 5100 and Interceptor are the only products that appear in both tables. Some of the materials that have been tested against agents or simulants (Table 4) can be correlated, by inference, with suits listed in Table 3, but these data are extremely limited. For example, the chlorinated polyethylene listed in Table 4 is more than likely the same material as that used by ILC Dover in the manufacture of the Chemturion® protective suit listed in Table 3.

Although most manufacturers of CPC listed in Table 3 provide permeation data for their products, the challenge chemicals are often limited to the ASTM F1001 standard test battery, or consist of more extensive lists of commercial industrial chemicals. Manufacturers' literature provided no data for chemical agents and infrequent data for the simulants. Several manufacturers' representatives did indicate that their products had been tested for resistance to chemical agents by the military, but, for legal or proprietary reasons, could not provide that information.

Gloves and boots

Emergency planners recommend that gloves intended for wear with fully encapsulating suits be manufactured from the same material as the suit so that the barrier properties of the entire ensemble are identical; however, gloves of other materials are often used [41]. Chemical protective glove materials in common use include butyl rubber, chloroprene–natural rubber latex, chloroprene latex, chloroprene rubber, chloroprene rubber latex, fluorinated ethylene propylene (FEP), fluoroelastomer (FPM), natural rubber, natural rubber–chloroprene–nitrile, natural rubber latex, nitrile–PVC, nitrile rubber, nitrile rubber latex, polyethylene, polyurethane, polyvinyl alcohol, and polyvinyl chloride [23,45].

Interpretation of the results of permeability tests on gloves requires knowledge of the manufacturer's process and the thickness of the glove material. Neoprene or nitrile gloves from different manufacturers exhibited statistically significant differences in breakthrough times when challenged by ethanol, n-butyl acetate, n-hexane (neoprene); and *p*-xylene, and perchloroethylene, and n-butyl acetate (nitrile) [55]. In one case, a ten-fold difference was observed in the mean breakthrough time of two generically equal products (the Ansell 632 and the Pioneer A-15 nitrile gloves; mean thicknesses, 0.36 and 0.33 mm, respectively) against perchloroethylene. The Pioneer A-15, the thinner glove, was the most resistant to challenge. The Ansell 632 was subsequently discontinued and replaced with a new product [55].

Permeation testing carried out at the Edmont Division of Becton, Dickinson and Co., demonstrated that, for glove films of the same line, glove material thickness is an important factor in determining breakthrough time (but not necessarily permeation rate) [56]. These findings are supported by the results reported by Jencen and Hardy [57], who demonstrated that greater glove material thickness results in longer breakthrough time. The investigators observed that the square root of the breakthrough time is related linearly to thickness. The most dramatic results were observed with neoprene gloves tested with 1,1,1-trichloroethylene (TCE). For gloves ~6 mil[4] thick, the square root of the breakthrough time was ~2 minutes (breakthrough time of 4 minutes), while for gloves 20 mil thick, the square root of the breakthrough time was 5.5 min (breakthrough time of 30.25 min). In addition, the investigators observed an inverse linear relationship between the glove material thickness and steady-state permeation rate and concluded that greater glove thickness not only increases breakthrough time, but also reduces the degree of exposure [57].

The chemical resistance data for glove materials tested against chemical agent or simulant are limited, considering the number of glove types that are available. The glove materials nitrile, polyvinyl chloride, and Viton were tested for resistance to permeation by the simulant, trimethyl phosphate, which degraded glove materials too severely for any permeation measurement [45].

Common boot materials include butyl, natural rubber, chloroprene rubber, nitrile rubber, polyurethane rubber or polyvinyl chloride [23]. Test data for the resistance of boot-specific materials to chemical agents or simulants were not found. Fully encapsulating suits usually have built-in booties that can be covered with more functional boots [41]. The manufacturers of fully encapsulating ensembles usually make recommendations for boots and gloves to be used with their clothing.

Expedient materials

Expedient protective clothing is regular clothing that is donned to protect the wearer from agent skin deposition [5]. For example, rain gear, or layers of heavy (winter) clothing could provide short-term protection for the head, upper body, arms, legs, feet and hands. While expedient clothing can provide limited protection against skin exposures, it does not protect individuals from inhalation or ingestion exposure.

Plastic packaging materials, available in most households, could be used not only to protect food and inanimate objects from exposure to chemical agents, but could also serve as glove substitutes. A study sponsored by NATO tested the barrier properties of commercially available packaging papers and films against several chemical agents, including VX and H [50]. The agents were applied in 1.0 milligram drops to waxed wrapping paper, grease-resistant waxed paper, cellulosic film, polythene film I (0.01, 0.02, and 0.003 in. thick), and polythene film II (0.005, 0.01, 0.0025, and 0.004 in. thick). Penetration time,

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[4] 1 mil $= 2.54 \times 10^{-5}$ m.

penetration rate and ease of decontamination were determined at 20°C. No other experimental details were available. The resulting data [50] (Table 4) indicates that the thickest (0.02 in.) polythene (or polyethylene) film I provided the highest level of protection. The 0.02 in. sample resisted penetration by VX for up to 48 hours and by H agents for up to 7 hours, while the 0.0025-inch thick sample (polythene film II) resisted penetration by VX for only 3 hours and mustard for only 18 minutes. The wrapping papers demonstrated the least resistance to penetration. Polyvinyl chloride, a material commonly used for rainwear, resisted penetration by VX for 48 hours, but was permeable to mustard within 12 minutes [50].

Conclusions

The potential for an unplanned release of chemical warfare agents during the impending destruction of the lethal unitary chemical warfare agent stockpile prompted this evaluation of chemical protective clothing (CPC) available to civilian first responders. The objective was to determine, to the extent possible, the degree of clothing protection afforded against the chemical agents GB, VX, sulfur mustard, and their simulants. The conclusions resulting from this evaluation are as follows:

(1) First response to hazardous chemical emergencies is often provided by the fire department, either with or without a specialized HAZMAT team. However, this may not necessarily apply to CSEPP communities. Firefighters' turn-out gear is not specifically designed for chemical protection, whereas civilian HAZMAT teams are equipped with varying degrees of CPC.

The list of commercially available EPA level A and B totally encapsulating suits in Table 3 demonstrates the wide variety of products available to the public that would be accessible to civilian first responders in the event of a chemical warfare agent release accompanied by off-post contamination. The fully encapsulating EPA level A suits provide the highest level of protection to chemical hazards; they must be carefully selected to match the suit material to the hazard. The chemicals commonly tested for EPA levels A and B protection represent a broad range of liquid and gaseous chemical classes and properties [21], but do not include chemical warfare agents or their simulants.

(2) There is a paucity of data with which to evaluate the effectiveness of commercially available CPC challenged with the chemical warfare agents GB, VX, and H or their simulants. This is illustrated by the fact that only two suits (the ChemFab Challenge and Interceptor) of the 53 CP suits listed in Table 3 (commercially available materials used in the manufacture of totally encapsulating suits) could be definitely identified in Table 4 (agent/simulant permeation/breakthrough time data available for this evalua-

tion). However, some cautious inferences can be made. For example, it appears that chlorinated polyethylene, listed in Table 4 and demonstrating good resistance to almost all of the agents of interest (breakthrough times > 4 h), may be the same material as that used by ILC Dover in the manufacture of the Chemturion suit listed in Table 3.

(3) In the absence of any other alternative, expedient materials such as everyday clothes and food wrapping materials could be minimally effective against chemical agents and may provide some degree of protection to a person seeking shelter or in the process of evacuation. Polythene food wrap was highly resistant to the permeation of VX (breakthrough time, 1800–2400 min), while cellulosic film was resistant to both VX and H (breakthrough times, 2880 and 1440 min, respectively) [50].

(4) Guidance is provided to the protective clothing user by the EPA, OSHA, NIOSH, and manufacturers and distributors of CPC; however, there are no federal standards or regulations mandating the selection of CPC. Standards for the testing of clothing and clothing materials have been developed by the ASTM and the NFPA. Two new certification standards NFPA-1991, *Standard on Vapor-Protective Suits for Hazardous Chemical Emergencies*, and NFPA-1992, *Standard on Liquid Splash Protective Suits for Hazardous Chemical Emergencies*, have been developed to include requirements for limited flame resistance for chemical protective suit materials. These standards could influence the future designs of CPC, but do not contain guidance specific to chemical warfare agent exposure protection.

(5) In the absence of more comprehensive permeation and breakthrough time data for protective clothing exposed to the chemical agents, GB, VX, and sulfur mustard, there is a need to perform additional investigations to facilitate selection of efficient protective materials.

In summary, the civilian user of CPC has an array of garments at his disposal. However, available experimental data for the resistance of clothing materials to VX, GB, and sulfur mustard or their simulants are limited and marginally useful for the selection of CPC to protect against chemical agent challenge. Several of the clothing materials evaluated have undergone military testing with chemical warfare agents, but those data were not made available by their authors for use in this evaluation. Civilian access to these data could facilitate the selection of the most appropriate protective clothing, or provide information regarding the effectiveness of ensembles already "in-house".

The FEMA, OSHA, NIOSH, Mine Safety and Health Administration (MSHA), and the Department of the Army are currently developing recommendations for chemical protective clothing to be used by civilian first responders. Draft documents indicate that the likely recommendation will be a butyl rubber ensemble with duct tape at seams and closures, plus respiratory protection. At this writing a joint-agency policy statement has not been formalized and further details are not available.

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Appendix

TABLE A-1

Products with registered and unregistered trademarks, and the companies that own the trademarks

Product	Company
Acid King®	Wheeler Protective Apparel, Inc.
Barricade® chemical barrier fabric	E.I. Du Pont de Nemours and Co.
Blue Max™	Mine Safety Appliances Co.
Challenge®	Chemical Fabrics Corporation
ChemFab®	Chemical Fabrics Corporation
Chempruf II™	Mine Safety Appliances Co.
Chemrel™	Chemron, Inc.
Chemrel Max™ GT	Chemron, Inc.
Chemturion™	ILC Dover, Inc.
First Team™	Mine Safety Appliances Co.
Forcefield™	Fyrepel Products
Frontline™	Kappler, Inc.
Gore-Tex®	W.L. Gore Associates, Inc.
Guthion®	Bayer AG
Interceptor™	Lakeland Fyrepel
Kevlar® aramid fiber	E.I. Du Pont de Nemours and Co.
Nomex® aramid fiber	E.I. Du Pont de Nemours and Co.
Pacesetter™	Lion Apparel, Inc.
PBI®	Celanese Corporation
Responder™	Life-Guard, Inc.

TABLE A-1 (continued)

Product	Company
Saranex®	Dow Chemical Co.
TefGuard™ teflon-based material	Life-Guard
Teflon®	E.I. Du Pont de Nemours and Co.
Trellchem®	Trelleborg AB
Tyvek® spun-bonded olefin	E.I. Du Pont de Nemours and Co.
Viton® fluoroelastomer	E.I. Du Pont de Nemours and Co.