

Chapter 16

DECONTAMINATION OF CHEMICAL CASUALTIES

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INTRODUCTION

Decontamination is the process of removing or neutralizing hazardous substances from people, equipment, structures, and the environment.^{1,2} This chapter focuses on the safe decontamination of medical casualties exposed to chemical agents; however, the patient decontamination process discussed here also is appropriate for those exposed to biological and radiological hazards (although procedures, operator protective ensemble, and detectors may vary slightly).

Decontamination performed within the first few minutes after exposure is the most effective for protecting the patient, although later skin decontamination, which can benefit the patient by reducing the agent dose, should not be ignored. Early skin decontamination can often mean the difference between patient survival (or minimal injury) and death (or severe injury). Patient decontamination serves two primary purposes: (1) protecting the casualty by removing harmful agents from the skin, thus reducing the dose and severity of the agent's hazardous effects, and (2)

protecting emergency responders, transport personnel, medical personnel, and other patients from secondary exposure. Cross contamination from dry or liquid agent on the patient's clothing or skin can sicken others or make equipment temporarily unusable. Cloth fibers can hold agent liquid and vapors. The off-gassing of liquid contaminants, or vapor trapped in clothing and hair, can cause those who work near the casualty to become symptomatic if they are not wearing respiratory protection. Often removing clothing and brushing the hair greatly reduces the level of contaminant carried on the patient; in some instances, these actions are the only necessary decontamination.

Contaminated persons who present for decontamination may additionally have conventional wounds, psychological stress reactions, physiological reactions to heat or cold, or any combination of these. Persons wearing individual protective ensemble (IPE) are particularly prone to heat injuries caused by extended time in this gear.

MILITARY AND CIVILIAN DECONTAMINATION PROCEDURES

The decontamination of chemical casualties is a challenging task that may require large numbers of personnel, water and equipment resources, and time. Casualty decontamination takes place at all levels of patient care, from the exposure site to the door of the medical treatment facility (MTF). In the military, there are three levels of patient decontamination (these same processes may differ in the civilian sector)³:

1. *Immediate decontamination* is conducted by the individual exposed to the agent, or another individual (a buddy), who comes to assist the victim, as soon as possible after exposure. Ideally it is performed within minutes after exposure. The individual decontaminates exposed skin and garments using a military decontamination kit. If a kit is not available, any material, dry or wet, that can be applied or used to physically remove agent from the skin is beneficial. This process is very effective in reducing the hazard posed by agent on the skin, particularly if IPE is already being worn.
2. *Patient operational decontamination* is carried out by members of the individual's unit to prepare the individual for transport. At this level the casualty is kept in IPE, from which any large concentration of agent is removed. The casualty is placed on a litter covered

with plastic and loaded into a transport vehicle dedicated to evacuating contaminated patients. Evacuation vehicles are kept well ventilated, and crew members wear protective ensemble. Operational decontamination helps to reduce the level of contamination on the patient, thereby reducing the level of cross contamination to the transport vehicle. This level of decontamination allows for large numbers of contaminated casualties to be quickly evacuated to patient decontamination facilities that are prepared to handle them.

3. *Patient thorough decontamination* is performed outside the MTF that receives the contaminated patients. At the decontamination station the patients' clothing is removed and their skin and hair are thoroughly decontaminated. It is critical that patients are prevented from entering a medical facility until patient thorough decontamination has been conducted.

In civilian industry, workers are usually trained in self-decontamination methods pertinent to the hazards for that setting. In a civilian or homeland defense scenario, however, immediate decontamination by the victims themselves may not be possible because they may not have access to decontaminants or know what to do. Immediate decontamination in a civilian

setting is often referred to as emergency decontamination, self decontamination, or buddy rescue. The first decontamination in the civilian setting may not occur until a fire department decontamination unit arrives. Patient operational decontamination might not readily apply in the civilian setting because private ambulance services may refuse to accept contaminated patients and civilian patients do not have IPE.

Individuals who escape the scene of the release before the arrival of the first responders may manage to access transportation while still in contaminated clothing. This was the case during the Tokyo subway sarin attack, in which many victims either walked or took taxis to hospitals.⁴ Otherwise, contaminated individuals must be moved to a decontamination station established by the fire department or set up at a hospital for patient thorough decontamination. De-

contamination stations near the incident site are often referred to as mass casualty decontamination stations or gross decontamination areas.^{2,5} Victims might also be moved to a water source, such as a hose or shower, for buddy decontamination. Because fleeing casualties might bypass decontamination, or responding fire departments may fail to perform adequate decontamination, it is important that every hospital has the capability of establishing its own patient thorough decontamination area outside its entrance.

Since the events of September 11, 2001, military and civilian agencies have sought to improve their patient decontamination capabilities.⁶ Industry has responded with a wide array of decontamination equipment and materials for simplifying this process. Civilian and military sectors are now much better prepared for the challenges of patient decontamination.

ACTION OF CHEMICAL AGENTS ON THE SKIN

Crone described the function of the skin as a barrier and the possible effect of chemical agents on tissues.^{7,8}

The skin consists of a number of layers of living cells of varied function bounded on the outside by a thin layer of dead cells, the stratum corneum. This layer is the main diffusion barrier to the entry of foreign substances. The blood supply to the skin does not reach directly to the epidermis. Therefore, a liquid contacting the skin surface first has to penetrate the stratum corneum, and then diffuse through the largely aqueous medium of the cell layers to the nearest blood capillaries, from whence it is carried round the body. There is opportunity for a chemical to be bound to the outer skin layers, so that further delay and storage can occur.⁷

Chemicals that act directly on the skin, such as sulfur mustard, need little penetration for their effects to begin; they act directly on the integrity of the skin cells. This same process occurs with other highly reactive chemicals such as acids and alkalis. More systemically acting chemicals, such as nerve agents, may need to cross the skin barrier before they can affect body systems. Generalizations about the permeability of skin are often inadequate.⁸ The skin is not a simple system, and its permeability depends on many factors including temperature and the skin's thickness, integrity, and hydration.

The stratum corneum retains moisture and provides a barrier to outside hazards. This barrier is very effective against water-soluble chemicals. However, it is more permeable to fat-soluble (lipophilic) chemicals because of the layers of lipids in the epidermis that underlie and surround the keratinized dead skin

cells making up the stratum corneum.⁸ When tracing agent progress from the surface of the skin to the bloodstream, three skin "compartments" must be considered: (1) the outer application layer, where the agent lies on the skin; (2) the boundary layer, where the agent is moving through the skin; and (3) the area where a dermal reservoir of agent that has diffused into the lipid area of the stratum corneum may form.⁹ Rapid decontamination seeks to prevent large doses of agent from penetrating to the lipid area of the stratum corneum and subsequently into the circulation. Later decontamination seeks to remove any agent that remains on the surface of the skin.

A liquid chemical warfare agent (CWA) is often thought to be accessible on the surface of the skin for up to 3 minutes, taking approximately 30 minutes for the agent to cross the skin barrier and enter the capillaries. Some of the hazardous agent is likely to be temporarily sequestered in the skin during this transit. According to Buckley et al,¹⁰ inappropriate skin treatments could theoretically aid in the dermal transit of agent, and the resulting store of hazardous agent could potentially make the situation worse for the victim.¹⁰

Most CWAs (particularly VX and mustard) are moderately fat-soluble, enabling them to be absorbed through the stratum corneum over time. Lipid-soluble chemical agents move quickly through the lipids surrounding the cells in the stratum corneum and then more slowly into the hydrophilic (water-soluble) bloodstream.

Contact time, concentration, solubility, temperature, hydration state, and physical condition of the skin are all factors that affect the absorption of agent through the skin's epithelial layer. Vascularity of tissue plays an

important part in the rate at which agents access the bloodstream and act systemically on the body. Studies by Lundy et al¹¹ administering VX dermally to juvenile male Yorkshire-Landrace cross pigs and earlier experiments on dermal VX exposure on human subjects by Sim¹² showed that skin that was highly vascularized

led to more rapid systemic agent effects as indicated by reduced levels of acetylcholinesterase. Sim's study also noted that VX spread thinly over areas of the skin had much less of an effect on acetylcholinesterase, a reduced systemic effect, than the agent concentrated in one area, which increased the penetration rate (see Exhibit 16-1).

BARRIER SKIN CREAMS

History

Improving the skin as a barrier to chemical agents has been a concern since at least World War I, when sulfur mustard (HD) was first used in warfare. Ap-

plying a topical protectant to vulnerable skin surfaces before entry into a chemical combat arena was proposed as a protective measure against percutaneous CWA toxicity soon after Germany used HD at Ypres, Belgium, in 1917.¹³ The US Army began examining various soaps and ointments for protective capabilities in the summer of that year. Although several simple formulations were found to be effective in reducing "skin redness" produced by agents such as hydrogen sulfide, no product was available before the end of the war.¹³ Research continued but did not produce a fielded product before World War II began. During World War II, a concentrated effort to develop ointments for protection against HD took place at the Chemical Warfare Service, Edgewood Arsenal, Maryland. The Army produced the M-5 protective ointment, which was manufactured in 1943 and 1944. However, because of limited effectiveness, odor, and other cosmetic characteristics, the M-5 ointment was no longer issued to soldiers by the mid 1950s.¹⁴

EXHIBIT 16-1

VX STUDIES

Lundy et al¹ conducted a study in which 31 Yorkshire-Landrace cross pigs were exposed to pure liquid VX, and VX in isopropyl alcohol. Both of these exposures were at the calculated median lethal dose. In some animals the nerve agent was placed on the ventral surface of the ear (thin tissue with generous blood flow), and on others the agent was placed on the belly just above the naval (thicker tissue with a less pervasive blood flow). Liquid agent absorption was measured by blood cholinesterase inhibition. Those swine with VX applied to the ear showed more than 90% cholinesterase inhibition within 45 minutes, resulting in apnea (within 2 hours) requiring ventilatory assistance thereafter and death within 45 minutes after ventilatory support was initiated. Those animals with belly VX exposure showed only 75% cholinesterase inhibition within the 6-hour timeframe of the experiment, but developed the same progression of symptoms requiring ventilatory support. In neither case were the animals provided with antidotes within the time period that would have slowed or ameliorated the effects. This study demonstrates, in part, that death from liquid VX can be delayed by up to several hours depending on a variety of factors, one being the specific body area exposed. Earlier human studies by Sim² also show the variable and delayed effects of exposure to liquid VX.

Data sources: (1) Lundy PM, Hamilton MG, Hill I, Conley J, Sawyer TW, Caneva DC. Clinical aspects of percutaneous poisoning by the chemical warfare agent VX: effects of application site and decontamination. *Mil Med.* 2004;169:856-862. (2) Sim VM. *VX Percutaneous Studies in Man*. Aberdeen Proving Ground, Md: US Army Chemical Research and Development Laboratories; 1960. Technical Report 301.

Skin Exposure Reduction Paste Against Chemical Warfare Agents

Between 1950 and the early 1980s, research focus shifted to medical countermeasures rather than protective creams. Then, a limited research effort at the successor to the Chemical Warfare Service, the US Army Medical Research Institute of Chemical Defense (USAMRICD), produced two non-active barrier skin cream formulations based on a blend of perfluorinated polymers. The two formulations were transferred to advanced development in October 1990.¹⁵ The best formulation was selected and progressed through development as an investigational new drug filed with the US Food and Drug Administration in 1994 and approval of a new drug application in 2000. This new product was called skin exposure reduction paste against chemical warfare agents (SERPACWA). SERPACWA consisted of fine particles of polytetrafluoroethylene solid (Teflon; DuPont, Wilmington, Del) dispersed in a fluorinated polyether oil. The excellent barrier properties of this polymer blend were related to the low solubility of most materials in it. Only highly fluorinated solvents like Freon (DuPont, Wilmington,

Del) were observed to show appreciable solubility. SERPACWA is now a standard issue item to US forces facing a threat of CWA use.

Function

SERPACWA is an antipenetrant barrier cream for use by service members to protect against the toxic effects of CWAs (eg, blister [vesicant] and nerve agents) and percutaneously active biological agents. When used in conjunction with IPE, or mission-oriented protective posture (MOPP) gear, SERPACWA will prevent or significantly reduce the toxicity following percutaneous exposure to such agents. It is used as an adjunct to IPE, not as a substitute. The effective barrier of SERPACWA also has been found to protect against poison ivy and poison oak.

Effectiveness

SERPACWA was developed to extend the protection afforded by the current protective garments and allows a longer window for decontamination. It provides for excellent protection against liquid challenges of GD (soman), VX, and HD, but its protection against HD and GD vapor is less than optimal. It does not neutralize CWAs into less toxic products.

Application

SERPACWA is used at the direction of the commander. Each service member is issued six packets of SERPACWA, sufficient material for six applications or for 2 days of use. Its effectiveness depends on the thickness and integrity of the layer applied and the length of time between application and agent exposure (wear time). The cream should be applied first to skin areas adjacent to IPE closures (such as at the neck, wrists, and lower legs around the top of the boots). If the situation permits, SERPACWA should also be applied to the armpits, groin area, creases and crack of the buttocks, and around the waist. It is not applied to open wounds. It should never be applied to the entire body, because its occlusiveness can interfere with the ability to dissipate heat. Under normal conditions, SERPACWA is effective when spread over the skin as a thin layer (0.1 mm thick, or 0.01 mL/cm²). One packet of SERPACWA contains 1.35 fluid ounces (about 2.7 weight ounces or 84 g) for one application. This amount of SERPACWA is sufficient to cover the indicated skin areas with a smooth coating that has a barely visible cream color and is slightly detectable by touch.

SERPACWA is not water soluble, so it cannot be washed off by water or removed by sweat without

brushing and scrubbing, but it may physically wear off with time. Abrasion of SERPACWA by clothing or other contacts, such as sand or dirt, will reduce the wear time. SERPACWA must be reapplied if the coating becomes embedded with particulate matter (dirt or sand), if the sites are decontaminated, or after 8 hours on the skin. Normally, SERPACWA is effective for 4 hours in preventing CWAs from contacting and penetrating the skin. Insect repellents such as DEET (N,N-diethyl-meta-toluamide) decrease its effectiveness. If DEET is wiped off before application using a dry towel, gauze, or piece of cloth, SERPACWA can still provide significant protection.

Effects on Decontamination

The use of SERPACWA makes decontamination easier in areas protected by the barrier. It is easier to physically remove CWA from a SERPACWA layer than from the skin. Service members should still perform skin decontamination immediately after chemical contamination, because SERPACWA's effectiveness decreases with time. SERPACWA can be removed by brushing and scrubbing the skin areas with soap and water. SERPACWA has no vapors, so it does not register a false alarm with automatic vapor detectors such as the improved chemical agent monitor (ICAM), nor does it register with systems that detect chemical liquid such as M8 paper. M8 paper, however, detects agent on the surface of the SERPACWA layer (however, it has been noted that if moist SERPACWA paste coats the surface of M8 paper, it can prevent CWA from contacting the paper).

Active Barrier Creams

In 1994, to overcome the limitations of SERPACWA, USAMRICD began development of an improved substance that would act as both a protective barrier and an active destructive matrix to detoxify CWAs. The types of molecules that could potentially neutralize or detoxify CWAs have been known for a long time. These compounds fall into three general classes: oxidizers, reducers, and nucleophiles. The USAMRICD researchers were required to find a final formulation that does not irritate the skin, however, which eliminated many of the most reactive species. The aprotic nonpolar environment of SERPACWA provides a unique but challenging medium for active moieties to neutralize CWA. Reaction mechanisms that do not involve charged transition states are favored in this medium. The improved SERPACWA containing a reactive matrix became known as active topical skin protectant (aTSP). Four criteria were established for aTSP: (1) the

protectant must neutralize CWAs including HD, GD, and VX; (2) the barrier properties of SERPACWA must be maintained or increased; (3) protection against HD and GD vapor must be increased; and (4) the cosmetic characteristics (eg, odor, texture) of SERPACWA must be maintained.¹⁶ Additionally, aTSP could not degrade a soldier's performance.

Using the two components of SERPACWA, perfluorinated polyether oil and polytetrafluoroethylene solid, as a base cream, USAMRICD scientists evaluated over 150 different active components. Classes of compounds tested included organic polymers, enzymes, hybrid organic-inorganic materials, polyoxometalates, inorganic composites, inorganic

oxides, metal alloys, and small organic molecules. These compounds were incorporated into the base cream to produce over 500 candidate formulations (see Table 16-1).¹⁷

Two candidate formulations were selected for transition to advanced development. The lead aTSP formulation, a mixture of organic polymers, surfactants, and the base cream of perfluorinated-polyether oil and polytetrafluoroethylene solid, was ready for advanced development in 2004. Although it is not currently funded for further research, this new product is expected to dramatically improve protection from CWAs when it is fielded, and it may reduce the need for a full protective ensemble.

METHODS OF DECONTAMINATION

The first and most effective method of decontamination is timely physical removal of the chemical agent. To remove the substance by the best means available is the primary objective of effective decontamination. Chemical destruction (detoxification) of the offending

agent is a desirable secondary objective (but is not always possible). Physical removal is imperative because none of the chemical means of destroying these agents work instantaneously.

The US military has actively explored personnel and

TABLE 16-1

PATENTS COVERING WORK ON ACTIVE TOPICAL SKIN PROTECTANT AT THE US ARMY MEDICAL RESEARCH INSTITUTE OF CHEMICAL DEFENSE

Name	Authors	US Patent No.	Date
Active Topical Skin Protectants Containing OPAA Enzymes and CLECs	Braue EH Jr et al (Hobson, Govardhan, and Khalaf)	6,410,603	6/25/2002
Active Topical Skin Protectants Containing S-330	Braue EH Jr et al (Mershon, Braue CR, and Way)	6,472,438	10/29/2002
Active Topical Skin Protectants Using Polyoxometalates	Braue EH Jr et al (Hobson, White, and Bley)	6,420,434	7/16/2002
Active Topical Skin Protectants Using Polyoxometalates and/or Coinage Metal Complexes	Braue EH Jr et al (Hobson, Hill, Boring, and Rhule)	6,414,039	7/2/2002
Active Topical Skin Protectants	Braue EH Jr, Hobson ST, Lehnert EK	6,472,437	10/27/2002
Active Topical Skin Protectants Using Polymer Coated Metal Alloys	Hobson ST, Braue EH. Jr, Back D	6,437,005	8/20/2002
Active Topical Skin Protectants Using Reactive Nanoparticles	Hobson ST et al (Braue, Lehnert, Klabunde, Koper, and Decker)	6,403,653	6/11/2002
Active Topical Skin Protectants Using Organic Inorganic Polysilsesquioxane Materials	Hobson ST, Braue EH Jr, Shea K	6,417,236	7/9/2002
Active Topical Skin Protectants Using Combinations of Reactive Nanoparticles and Polyoxometalates or Metal Salts	Hobson ST et al (Braue, Lehnert, Klabunde, Decker, Hill, Rhule, Boring, and Koper)	6,410,603	6/25/2002
Polyoxometalate Materials, Metal-Containing Materials, and Methods of Use Thereof	Hill CL et al (Xu, Rhule, Boring, Hobson, and Braue)	6,723,349	4/20/2004



Fig. 16-1. (a) Treatment barracks for gas cases. Evacuation Hospital #2 [ca World War I]. (b) Mobile degassing unit #1. Tours, France. November 21, 1918.

Photographs: Courtesy of the National Museum of Health & Medicine, Armed Forces Institute of Pathology (a: Reeve 1179; b: Reeve 12196).

patient decontamination methods since World War I, the beginning of modern chemical warfare (Figure 16-1). Many substances have been evaluated for their usefulness in skin decontamination. The most common problems with potential decontaminants are irritation of the skin, toxicity, ineffectiveness, or high cost. An ideal decontaminant would rapidly and completely remove or detoxify all known chemical (as well as biological and radiological) warfare agents from both skin and equipment (Exhibit 16-2). Decontaminants used for equipment have often been considered for human skin but are found unsuitable because they cause chemical burns.¹⁸

Recent research has explored the use of water, soap and water, polyethylene glycol and polyvinylpyrrolidone¹⁹; polyethylene glycol (PEG 300, PEG 400) and glycerol or industrial methylated spirit mixtures²⁰; hydrogen peroxide foam mixtures (Sandia foam, Modec Decon Formula)²¹; immobilized enzymes (Gordon sponge)²²⁻²⁵; cyclodextrines²⁶; ozones (L-Gel)²⁷; organophosphorus acid anhydrolases²⁸; phosphotriesterases²⁹; chloroperoxidases³⁰; a mixture of bovine hemoglobin, gelatin, and poi³¹; blends of catitonic and anionic tensides³²; hydroperoxides and hydroperoxycarbonate anions, dichloroisocyanurate, and oxidants such as sodium hypochlorite and calcium hypochlorite³³; polyglycol and corn oil³⁴; and technology such as the use of atmospheric pressure plasma jets³⁵ and postexposure cooling.³⁶

Currently recommended decontamination materials for US service members that are safe for human skin include soap and water (hydrolysis is probably the most

economical choice if water is readily available in ample quantities); dry decontaminants (eg, fuller's earth, M291 skin decontamination kit [SDK]); packaged liquid decontaminants (eg, the Canadian-manufactured Reactive Skin Decontamination Lotion [RSDL; E-Z-EM Canada Inc, Anjou, Quebec, Canada]); and chemical decontaminants that create an oxidative reaction with the agent (eg, dilute 0.5% hypochlorite solution [dilute bleach]). Table 16-2 gives the suggested applications for the various decontamination materials.

HD and the persistent nerve agent VX contain sulfur atoms that are readily subject to oxidation and/or dehydrochlorination reactions. VX and the other nerve agents (GD, GA [tabun], GB [sarin], and GF [cyclosarin]) contain phosphorus groups that undergo alkaline hydrolysis. HD can also be neutralized by hydrolysis or other nucleophilic substitution, but the rate is generally slow. Therefore, most chemical decontaminants are designed to neutralize CWAs by either oxidative chlorination or hydrolysis.¹

Soap and Water: Hydrolysis

Many classes of CWA, including HD, V agents, and G agents, can be detoxified by reaction with nucleophiles (water is the nucleophile). Chemical hydrolysis reactions are either acid or alkaline. Acid hydrolysis is of negligible importance for agent decontamination because the hydrolysis rate of most chemical agents is slow, and adequate acid catalysis is rarely observed.⁸ Alkaline hydrolysis is initiated by the nucleophilic attack of the hydroxide ion on the phosphorus atoms

EXHIBIT 16-2

DESIRABLE TRAITS OF A SKIN DECONTAMINANT

- Effective against chemical, biological, radiological, and nuclear agents, toxic industrial material, toxic industrial chemicals, and new threat agents.
- Neutralizes all chemical and biological agents.
- Safe (nontoxic and noncorrosive) for skin, eyes, and wounds.
- Removes agent from below the skin surface.
- Applied easily by hand.
- Readily available.
- Acts rapidly over a wide temperature range.
- Produces no toxic end products.
- Stable in long-term storage.
- Stable in the short term (after issue to unit / individual).
- Affordable.
- Does not enhance percutaneous agent absorption.
- Nonirritating.
- Hypoallergenic.
- Disposed of easily.

Data sources: (1) Chang M. *A Survey and Evaluation of Chemical Warfare Agent Contaminants and Decontamination*. Dugway Proving Ground, Utah: Defense Technical Information Center; 1984. AD-202525. (2) Baker JA. Paper presented at: COR Decontamination/Contamination Control Master Plan Users' Meeting; 11–13 September 1985. (3) Joint Requirements Office for Chemical, Biological, Radiological and Nuclear Defense. *Joint Service Personnel / Skin Decontamination System (JSPDS)*. Washington, DC: Joint Requirements Office, 2004.

found in VX and the G agents. The hydrolysis rate is dependent on the chemical structure and reaction conditions such as pH, temperature, the kind of solvent used, and the presence of catalytic reagents. The rate increases sharply at pH values higher than 8, and increases by a factor of 4 for every 10°C rise in temperature.³⁷ Many nucleophilic agents are effective in detoxifying chemical warfare agents; unfortunately, many of these (eg, sodium hydroxide) are unacceptably damaging to the skin. Alkaline pH hypochlorite hydrolyzes VX and the G agents quite well.^{1,38,39}

The rate of detoxification of HD in water, however, is slow and depends more on the limited solubility of HD in water (approximately 0.8 g/L at room temperature) than on the reaction rate of hydrolysis (half-life

at 20°C is 14.7 min). HD is highly soluble in oils and fats.⁴⁰ The hydrolysis rate is not affected by pH and decreases with increasing salt concentration in aqueous solutions (seawater and saline intravenous bag). Using stronger nucleophiles such as sulfides and amines does not increase the reaction rate, because the rate-determining step is the initial formation of the cyclic ethylene sulfonium ion, which forms directly from the HD molecule. Thus, while nucleophilic detoxification of HD is possible, oxidative chlorination is much more effective, although still slow.⁸

Liquids are best for decontaminating large or irregular surface areas. Soapy water solutions are well suited for MTFs with adequate water supplies. Soap and water are low-cost materials that remove agents by hydrolysis and by simply washing them away if used in copious amounts. These solutions do not kill biological agents or neutralize radiological or chemical agents; therefore, water run-off must be collected. Liquid soap acts as a surfactant. The surfactant molecule reduces the water surface tension, making it "wetter" so that it spreads out. Also, one end of the surfactant molecule is soluble in oily substances, and the other end is soluble in water.^{41,42} This enables water to better loosen and suspend agent particles in the water so they can be washed away. Fat-based soaps and emulsifiers/surfactants (eg, Dawn dishwashing liquid [Procter & Gamble, Cincinnati, Ohio],⁴³ baby shampoo, castile liquid soap, or soft soap) are much more effective than detergents that dry the skin (the latter should not be used).⁴⁴ Soap and water is best used during patient thorough decontamination, but also can be used for immediate and operational patient decontamination if available and practical. Copious amounts of soap and water should not be used on the joint service lightweight integrated suit technology or similar MOPP garments, because dampening the fabric reduces its protective abilities.

Dry Decontaminants

Any material that can absorb a liquid and then be brushed or scraped off without abrading the skin can be used as an effective skin or equipment decontaminant to remove liquid agents. Clean sand, baking powder, fuller's earth, diatomaceous earth, and baby wipes (dry or wet) can be applied to the agent, allowed to absorb it, and then carefully wiped away. Initially, large quantities of thickened liquid agent can be removed from clothing and skin by scraping it off with an uncontaminated stick or similar device.

Van Hooidek⁴⁵ conducted animal studies to determine the effectiveness of common household compounds for decontamination of liquid agents on

TABLE 16-2
APPROPRIATE USES FOR MILITARY DECONTAMINANTS

Decontaminant	Types of Patient Decontamination Station (PDS)	When and Where Used
M291 Skin Decontamination Kit	All types of PDS with limited water or freezing temperature conditions	For dry decontamination of liquid chemical agents only; very useful if water is not available or ambient temperature is freezing; used on skin and equipment
M295 Decontamination Kit	All types of PDS with limited water or freezing temperature conditions	For the dry decontamination of liquid chemical agents only, used on equipment
Soap and water	Used at all PDSs; the primary decontaminant used at PDSs with plumbed tentage and on water vessels. It is very cost effective.	Used for <ul style="list-style-type: none"> • skin (copious amounts) • equipment (copious amounts) • washing down decontamination team's TAP aprons and rinsing their gloves after washing with 5% bleach • best for washing away radiological, biological, and most chemical agents, but does not neutralize or kill them
0.5% hypochlorite (bleach) solution	PDSs with minimal equipment.	Used on skin, also can be used to wipe down TAP aprons.
5% hypochlorite (bleach) solution	PDSs with minimal equipment: to wash patient mask hood; decontamination team member gloves. All PDSs: to soak cutting tools (chemical and biological agents only; for radiation use soap and water).	Used only on equipment, NOT skin. Not used with radiological agents. Used for chemical and biological agents to <ul style="list-style-type: none"> • wipe down rubber mask hoods • wash gloves of patients and decontamination team members (then rinse with fresh water) • fill pail for cutting tools • wash decontaminated litters (then rinse with fresh water) • wipe down equipment (30 min contact time, then rinse)
Locally available absorbent material: <ul style="list-style-type: none"> • clean sand • baking powder • fuller's earth • baby wipes • flour • bread • other dry, non-toxic, absorbent items 	Any PDS	Used for the dry decontamination of liquid chemical agents only on skin and equipment; used if water and M291 or M295 are not available or ambient temperature is freezing.
Reactive skin decontamination lotion (RSDL)	Any PDS	Expected to replace or supplement the M291 kit. Used on skin and equipment for all types of agents. It wipes away contaminants and oximes and neutralizes some chemical agents and biological toxins.

PDS: patient decontamination station
TAP: toxicological agent protective

the skin. They found that wiping the skin with a dry absorbent object (such as paper, aseptic gauze, toilet paper, or a towel) or covering the liquid with absorbent powders, such as flour, talcum powder, diatomaceous earth, fuller's earth, or Dutch powder (the Dutch variation of fuller's earth), and then wiping the residue off with wet tissue paper were reasonably effective for removing both nerve agent and mustards. Either procedure had to be performed within 4 minutes, before the agent permeated the epidermis, to be maximally effective. The study also found that washing with small amounts of water or soap and water was effective for removing nerve agents, but not effective for mustard agents.⁴⁵ Fuller's earth and Dutch powder are decontamination agents currently fielded by some European countries to absorb liquid agents.¹

Developed to absorb and slowly neutralize liquid chemical agent, the M291 SDK (Figure 16-2) was first issued to US forces in 1989 and is the current method of battlefield decontamination used by individual service members. The M291 kit was extensively tested in a rabbit model and proved effective for immediate decontamination of skin.^{46,47} Recent studies in the clipped-haired guinea pig model, however, demon-



Fig. 16-2. The six individual decontamination pads of the M291 kit are impregnated with the decontamination compound Ambergard XE-555 resin (Rohm and Haas Co, Philadelphia, Penn), a black, free-flowing, resin-based powder. Each pad has a loop that fits over the hand. Holding the pad in one hand, the user scrubs the pad over contaminated skin. The chemicals are rapidly transferred into and trapped in the interior of the resin particles. The presence of acidic and basic groups in the resin promotes the destruction of trapped chemical agents by acid and base hydrolysis. Because the resin is black, the area that has been decontaminated is easy to see.

strated that the M291 SDK is only marginally effective against GD, GF, VX, and VR.⁴⁸

The M291 SDK consists of a wallet-like carrying pouch containing six individual decontamination packets. Each packet contains a nonwoven, fiberfill, laminated pad impregnated with the decontamination compounds: a carbonaceous adsorbent, a polystyrene polymeric, and ion-exchange resins. The resultant black powder is both reactive and adsorbent. Each pad provides the individual with a single-step, nontoxic, nonirritating decontamination application, which can be used on intact skin, including the face and around wounds, but should not be used in wounds or on abraded skin.¹ Instructions for its use are marked on the case and packets. Small, dry, and easily carried, the M291 SDK is well suited for field use and is particularly useful in areas where water is scarce. It is not effective for removing dry chemical, biological, or radiological agents or for neutralizing them. Early intervention with the use of this kit will reduce liquid chemical agent injury and save lives in most cases.

Packaged Wet Decontaminants

In 2004 the joint services established an operational requirements document to procure an effective skin decontaminant, referred to as the joint service personnel decontamination system, that could be used effectively on the skin and eyes, around wounds, and on equipment against all CBRN agents as well as other toxic industrial materials.⁴⁹ In March 2007, RSDL was selected as the joint service personnel decontamination system and is scheduled to replace the M291 SDK.

RSDL is a bright yellow viscous liquid dispensed on a sponge that washes away chemical agent contamination (Figure 16-3). The lotion is a solution of potassium 2,3-butanedione monoximate and free oxime in a mixture of water and polyethyleneglycol monoethylether.^{11,50} RSDL can be used to decontaminate intact skin around wounds, but it is not approved for the decontamination of wounds or eyes. Testing at USAMRICD demonstrated that RSDL is superior to the M291 SDK, 0.5% hypochlorite solution, and 1% soapy water against a broad spectrum of chemical agents.⁴⁸ It was even effective against a 5-median-lethal-dose challenge of VX when applied up to 25 minutes after exposure.⁵¹ In addition to VX, RSDL neutralizes the effects of G agents, HD, and T-2 mitoxin.⁵² After breaking down the chemical agent or toxin, it becomes a nontoxic liquid that can be washed from the skin with water.⁵³ RSDL is approved by the Food and Drug Administration as a medical device.⁵⁴



Fig. 16-3. (a) Reactive Skin Decontamination Lotion (E-Z-EM Canada Inc, Anjou, Quebec, Canada) packets and (b) blue training packets.

Photographs: Courtesy Lt Col Charles Boardman, US Air Force, US Army Medical Research Institute of Chemical Defense.

The manufacturer (E-Z-EM Inc, Lake Success, NY) also produces a training stimulant (Figure 16-3[b]) without oxime, packaged in a blue pouch, that allows for realistic training and the incorporation of human decontamination into civil defense scenarios.

Chemical Decontaminants: Oxidation

Electrophilic reactions are the oxidative processes associated with CWA detoxification. The most important category of chemical decontamination reactions is oxidative chlorination. This term covers active chlorine chemicals (such as hypochlorite), which under the proper conditions generate the positively charged chloride ion, a very reactive electrophile. The pH of a solution is important in determining the amount of active chlorine concentration; an alkaline solution is advantageous. Hypochlorite solutions act universally against the organophosphorus and mustard agents.^{1,8}

Both VX and HD contain sulfur atoms that are readily subject to oxidation. Current US doctrine specifies

the use of 0.5% sodium or calcium hypochlorite solution for decontamination of skin and a 5% solution for equipment.¹ Decontamination preparations such as fresh hypochlorite solution (either sodium or calcium hypochlorite) react rapidly with some chemical agents (eg, the half-time for destruction of VX by hypochlorite at pH 10 is 1.5 min), but the half-times of destruction of other agents such as mustard are much longer. If a large amount of agent is initially present, more time is needed to completely neutralize the agent.

Dilute hypochlorite (0.5%) is an effective skin decontaminant for patient use. The solution should be made fresh daily with a pH in the alkaline range (pH 10–11). Plastic bottles containing 6 ounces of calcium hypochlorite crystals are currently fielded for this purpose.¹ Dilute hypochlorite solution is contraindicated for the eye; it may cause corneal injuries. It also is not recommended for brain and spinal cord injuries. Irrigation of the abdomen with hypochlorite solution, which can cause adhesions, is also contraindicated. The use of hypochlorite in the thoracic cavity may be less of a problem, but the hazard remains unknown.¹

WOUND DECONTAMINATION

All casualties entering a medical unit after experiencing a chemical attack must be considered contaminated unless they have been certified as non-contaminated. The initial management of a casualty contaminated by chemical agents requires removal of IPE and decontamination before treatment within the field MTF.

Initial Wound Decontamination

During thorough patient decontamination at a patient decontamination station, all bandages suspected of contamination are removed and the wounds are flushed with isotonic saline solution or water. Bandages are replaced only if bleeding begins after decontamination. Tourniquets suspected of being contaminated are replaced with clean tourniquets, and the sites of the original tourniquets decontaminated. Both bandage replacement and tourniquet replacement are performed by medical personnel. Splints are thoroughly decontaminated but removed only by a physician or under physician supervision. Once the patient has been thoroughly decontaminated and enters the medical facility, the new dressings are removed and submerged in 5% hypochlorite or sealed in a plastic bag.⁵⁵

General Considerations

Three classes of chemical agent (vesicants, nerve agents, and cyanide) might present a hazard from wound contamination. Hydrogen cyanide is a blue-white liquid with a boiling point of 26°C (79°F). It can be absorbed slowly through unbroken skin but much more rapidly through an open wound. Cyanide may be delivered as pure hydrogen cyanide (liquid or gas depending on temperature), pure solid salt (sodium cyanide), or an aqueous solution of the metal salt. Cyanide is very toxic but less so than vesicants and nerve agents, and therefore less of a concern in open wounds.

Mustard converts to a reactive cyclic intermediate compound within a few minutes of absorption into a biological milieu, and the cyclic intermediate reacts rapidly (within a few minutes) with blood and tissue components.¹³ In a wound, the compound reacts with blood, the necrotic tissue, and the remaining viable tissue. If the amount of bleeding and tissue damage is small, mustard will rapidly enter the surrounding viable tissue, where it will quickly biotransform and attach to tissue components, and its biological behavior will be similar to an intramuscular absorption of the agent.

Although nerve agents cause their toxic effects by very rapid attachment to the enzyme acetylcholinesterase, they also quickly react with other enzymes and tissue components. As with mustard, the blood and necrotic tissue of the wound "buffers" the nerve agents. Nerve agent that reaches viable tissue will be rapidly absorbed, and because of the high toxicity of nerve agents (a small fraction of a drop is lethal), casualties with wounds contaminated by liquid nerve agent are unlikely to reach medical care alive.⁵⁶ The potential risk from contaminated wounds arises from chemical agent on foreign bodies in the wound and from thickened agents.⁵⁷

Thickened Agents

Thickened agents are chemical agents mixed with another substance (commonly an acrylate) to increase their persistency. They do not dissolve as quickly in biological fluids, nor are they absorbed by tissue as rapidly as other agents. (VX, although not a thickened agent, is absorbed less quickly and may persist in a wound longer than other nerve agents.) Thickened agents are not known to be stockpiled by any country. In a chemical attack, the intelligence and chemical staff should be able to identify thickened agents and alert medical personnel of their use.

Casualties with thickened agents in wounds (eg, from pieces of a contaminated battle-dress uniform or protective garment being carried into the wound tract) require more precautions and are unlikely to survive to reach surgery. Thickened mustard has delayed systemic toxicity and can persist in wounds even when large fragments of cloth have been removed. Although the vapor hazard to surgical personnel is low, contact hazard from thickened agents remains and should always be assumed.⁵⁶

Foreign Material and Off-Gassing

The contamination of wounds with mustard, nerve agents, or cyanide is mostly confined to the pieces of contaminated fabric in the wound tract. The removal of this cloth from the wound effectively eliminates the hazard. Little chemical risk is associated with individual fibers left in the wound. No further decontamination of the wound for un-thickened chemical agent is necessary.⁵⁶ Cooper et al⁵⁶ reported that the risk from vapor off-gassing of chemically contaminated fragments and cloth in wounds is low or nonexistent, and that off-gassing from a wound during surgical exploration is negligible. Eye injury is not expected

from off-gassing from any of the chemical agents, and chemical-protective masks are not required for surgical personnel. However, recent studies⁵⁸ indicate that swine exposed to 400 μ L of neat HD continue to off-gas up to 48 hours postexposure.

Wound Exploration and Debridement

No single glove material protects against every substance. Butyl rubber gloves generally provide better protection against chemical warfare agents and most toxic industrial chemicals (but not all) than nitrile gloves, which are generally better than latex surgical gloves. Surgeons and assistants are advised to wear two pairs of gloves⁴⁴: a nitrile (latex if nitrile is not available) inner pair covered by a butyl rubber outer pair. Thicker gloves provide better protection but less dexterity. Latex and nitrile gloves are generally 4 to 5 mils thick (1 mil = 1/1,000 of an inch). The recommended butyl rubber glove is 14 mils thick; if greater dexterity is needed a 7-mil butyl glove may be worn. A study at the US Army Soldier and Biological Chemical Command⁵⁹ showed breakthrough times for HD and GB depended on glove material and thickness. N-Dex (Best Manufacturing, Menlo, Ga) nitrile gloves (4 mil) had a breakthrough time of 53 minutes for HD and 51 minutes for GB. North (North Safety Products, Cranston, RI) butyl gloves (30 mil) had a breakthrough time of over 1,440 minutes for both HD and GB. The safety standard operating procedure at USAMRICD⁶⁰ for working with neat agents requires a maximum wear time of 74 minutes for HD and 360 minutes for G agents and VX when wearing 7-mil butyl rubber gloves over 4-mil N-Dex nitrile gloves. Wearing this glove combination is recommended until users ascertain that no foreign bodies or thickened agents are in the wound. Double latex surgical gloves have no breakthrough for 29 minutes in an aqueous medium; they should be changed every 20 minutes⁶¹ (changing gloves is especially important when bone spicules or metal fragments can cause punctures).⁵⁶

The wound should be debrided and excised as usual, maintaining a no-touch technique (explore the wound with surgical instruments rather than with the fingers). Pieces of cloth and associated debris must not be examined closely but quickly disposed of in a container of 5% hypochlorite. Recent studies at USAMRICD by Graham⁵⁸ demonstrated significant off-gassing during laser

debridement of HD-exposed skin in swine. Removed fragments of tissue should be dropped into a container of 5% to 10% hypochlorite. Bulky tissue such as an amputated limb should be sealed in a chemical-proof plastic or rubber bag.⁵⁶ Penetrating abdominal wounds caused by large fragments or containing large pieces of chemically contaminated cloth will be uncommon. Surgical practices should be effective in the majority of wounds for identifying and removing the focus of remaining agent within the peritoneum.

Cooper et al⁵⁶ suggest checking a wound with an ICAM, which may direct the surgeon to further retained material. However, this process is slow (a stable reading takes about 30 seconds; a rapid pass over the wound will not detect remaining contamination) and is not effective unless vapors are emanating from wound debris. A single bar reading on an ICAM with the inlet held a few millimeters from the wound surface indicates that a vapor hazard does not exist; more than one bar is needed to indicate a vapor has been detected.⁵⁶

Dilute hypochlorite solution (0.5%) should not be used to flush wounds. Isotonic saline or water may be instilled into deep, noncavity wounds following the removal of contaminated cloth. Subsequent irrigation with saline or other surgical solutions should be performed.¹ Saline, hydrogen peroxide, or other irrigating solutions do not necessarily decontaminate agents but may dislodge material for recovery by aspiration with a large-bore suction tip. The irrigation solution should not be swabbed out manually with surgical sponges; rather, it should be removed by suction to a disposal container and handled like other agent-contaminated waste within a short time (5 min). Although the risk to patients and medical attendants is low, safe practice suggests that any irrigation solution should be considered potentially contaminated. Following aspiration by suction, the suction apparatus and the solution should be decontaminated in a solution of 5% hypochlorite. Superficial wounds should be subjected to thorough wiping with normal saline or sterile water.¹

Instruments that have come into contact with possible contamination should be placed in 5% hypochlorite for 10 minutes before normal cleansing and sterilization. Reusable linen should be checked with the ICAM, M8 paper, or M9 tape for contamination. If found to be contaminated, the linen should be soaked in a 5% to 10% hypochlorite solution or discarded.¹

PATIENT THOROUGH DECONTAMINATION

Need

The focus of patient decontamination is identical

throughout the services and in the civilian sector: it is the removal of hazardous substances from the contaminated individual to protect that person and sub-

sequently reduce the incidence of cross contamination to others. Early removal of the hazardous substance is key to significantly reducing the dose of agent an individual is exposed to. When early removal (within the first 15 minutes—ideally within the first 2 minutes) is not possible, later removal can reduce the effects from a chemical agent but to a lesser degree. Removal at any time reduces the threat that others may be cross-contaminated. Patient thorough decontamination, performed before allowing a contaminated patient inside the confines of a hospital, provides two benefits. First, it can potentially reduce the dose the patient receives, and, second, it protects hospital staff from exposure to the hazardous agent and its vapors.

In the United States, healthcare workers are the 11th most common group injured in hazardous materials incidents, but injury to emergency department workers is even more infrequent, only 0.2% of some 2,562 events from 1995 to 2001 documented in the Agency for Toxic Substances and Disease Registry Hazardous Substance Emergency Events Surveillance System.⁴⁴ In these instances, the injured workers were not wearing respiratory protection and suffered eye and respiratory tract irritation.⁶²

Several studies and reports illustrate the need for the thorough decontamination of patients before hospital admission. Okumura et al⁶³ published a survey of the staff of Saint Luke's International Hospital in Tokyo. This facility was closest to the Tokyo subway sarin release and received 640 patients, the largest number of victims from the event. The study indicated that 110 staff members, 23% of the 472 medical personnel in the hospital at the time, reported acute poisoning symptoms including headache, blurred vision, dyspnea, nausea, and dizziness. None of the staff at this facility wore respiratory protection, and none of the patients were decontaminated in any way. Particularly affected were staff working in the hospital temporary triage area, which was located in the poorly ventilated hospital chapel, and those in the intensive care unit.⁶³

Nozaki et al⁶⁴ conducted a retrospective study of care providers at another facility, the University Hospital of Metropolitan Japan, who also attended to subway victims. Of the 15 physicians who worked in the emergency room, none wore any protective equipment; 13 became aware of symptoms of exposure while resuscitating two of the casualties. Eleven of these doctors complained of dim vision lasting several days, and eight showed significant miosis (pupils < 2 mm). Eight had rhinorrhea (runny nose), four had dyspnea (shortness of breath or tightness of the chest), and two had a cough. Six of the symptomatic care providers were given atropine sulfate, and one, who had more predominant dim vision than the others, was also

given pralidoxime methiodide. Subsequent removal of the patients' contaminated clothing and ventilation of the emergency room helped reduce exposure.⁶⁴ Table 16-3 summarizes the signs and symptoms displayed by medical personnel at St Luke's and University hospitals.

Similarly, reports by Foroutan⁶⁵ indicate that unprotected medical staff caring for contaminated Iranian victims of an Iraqi poison chemical gas bombardment also became ill. In one instance, a doctor and a nurse providing patient resuscitation in a busy treatment area became dizzy, were short of breath, and had severe headaches and cough. Within 5 minutes the remainder of the medical staff in the emergency room developed the same symptoms, could no longer stand up, and had to sit on the floor. The staff was evacuated to another hospital and the emergency room closed and ventilated for 3 hours. In this case both cyanide antidotes and later atropine were administered, which reduced the providers' symptoms.⁶⁵

Another documented relevant example took place in 2001 in the emergency room of a hospital in an agricultural area of Great Britain. Pesticides are among the top choices for those committing suicide and homicide, particularly in agricultural regions of the world.⁶⁶ A man who attempted suicide by ingesting an organophosphate pesticide was brought into the emergency room, where he vomited, causing a chemical spill. The incident caused 25 hospital workers to seek medical attention, and 10 complained of symptoms indicative of toxic exposure.⁶⁷ These events illustrate the importance of thorough decontamination for contaminated patients, prompt clean-up of pesticide-tainted vomit, and adequate protection, particularly respiratory protection, for hospital workers when vapor hazard from contamination exists.

Personnel

Patient thorough decontamination operations are personnel intensive. Typically from 7 to 20 personnel are needed to staff decontamination teams, not including medical treatment personnel. In the military, with the exception of the US Air Force and some ship-based units that deploy trained patient decontamination teams composed of medical personnel, the military patient decontamination process is carried out by nonmedical augmentees supervised by trained medical personnel.³ In the civilian sector gross decontamination is often performed by fire departments or hazardous materials (HAZMAT) teams, and thorough decontamination at medical facilities is carried out by hospital personnel assigned to perform the job as an additional duty.^{2,68}

TABLE 16-3

SIGNNS AND SYMPTOMS REPORTED BY TOKYO HOSPITAL WORKERS TREATING VICTIMS OF SARIN SUBWAY ATTACKS*

Symptom	Number/percentage of the 15 physicians who treated patients at UH		Number/percentage of 472 care providers reporting symptoms at SLI	
Dim vision	11	73%	66	14%
Rhinorrhea	8	53%	No information	
Dyspnea (chest tightness)	4	27%	25	5.3%
Cough	2	13%	No information	
Headache	No information		52	11%
Throat pain	No information		39	8.3%
Nausea	No information		14	3.0%
Dizziness	No information		12	2.5%
Nose pain	No information		6	1.9%

*Data reflect reported survey of self-reported symptomatology of physicians at the University Hospital of Metropolitan Japan emergency department and all hospital workers at Saint Luke's International Hospital exposed to sarin vapors from victims of the Tokyo subway attack.

SLI: Saint Luke's International Hospital

UH: University Hospital

Data sources: (1) Nozaki H, Hori S, Shinozawa Y, et al. Secondary exposure of medical staff to sarin vapor in the emergency room. *Intensive Care Med.* 1995;21:1032-1035. (2) Okumura T, Suzuki K, Fukuda A, et al. The Tokyo subway sarin attack: disaster management, Part 1: community emergency response. *Acad Emerg Med.* 1998;5:613-617. (3) Okumura T, Suzuki K, Fukuda A, et al. The Tokyo subway sarin attack: disaster management, Part 2: Hospital response. *Acad Emerg Med.* 1998;5:618-624.

Close medical monitoring and treatment of casualties before, during, and after thorough decontamination must be an integral part of all patient decontamination operations. Medical conditions can change as individuals undergo the stressful process of decontamination. If the exposure is to a liquid agent, it may take time for the agent to transit the skin layers. A patient exposed to a liquid chemical agent may appear stable or well during decontamination but can become worse during or after the decontamination process.

Decontamination Operator Protection

Heat and musculoskeletal injury are primary concerns for decontamination team members. Individuals must perform heavy work (patient treatment, triage, and litter movement) while wearing IPE. Working in a hot environment lowers individual mental alertness and physical performance. Increased body temperature and physical discomfort can cause workers to overlook safety procedures or divert their attention from hazardous tasks. These critical issues must be addressed before and throughout decontamination operations.

Musculoskeletal injury can occur from lifting

patients, carrying litters, or falling while wearing protective ensemble. Injury reduction strategies such as removing tripping hazards, policing the decontamination area for debris, working at a safe pace, rehearsing ergonomically correct patient lifts, enforcing frequent rest breaks, using special equipment to reduce lifting (such as wheeled litter carriers), and insuring adequate staffing are all useful strategies to prevent worker injury.

The chemical protective ensemble prevents an individual's sweat from readily making contact with the air, which inhibits heat transfer from the body, making it difficult for the body to cool itself, which can lead to heat injury. The National Institute for Occupational Safety and Health publication *Working in Hot Environments* describes a variety of heat conditions including heat stroke (the most life threatening), heat exhaustion, heat cramps, fainting, heat rash, and transient heat fatigue.⁶⁹ All decontamination personnel must be trained in preventative measures for these conditions, be able to identify their signs and symptoms, and know what to do when they occur. It typically takes humans 5 to 7 days to adjust to working in hot temperatures. Heat stress can be reduced by reducing prolonged exposure

to heat. Effective measures include enforcing work–rest cycles; providing shaded work and rest areas; reducing the amount of protective ensemble worn (eg, wearing level C during decontamination operations or only respiratory protection if the principal chemical hazard is vapor); and maintaining adequate supplies of potable water and encouraging its consumption by decontamination team members.

A safety officer must be appointed whose primary duty during decontamination operations is to monitor the health status of decontamination team members in IPE. This individual enforces safe patient lifting techniques, insures the decontamination area is free from debris that can cause a tripping hazard, manages team member work–rest cycles, stays abreast of temperature conditions, and insures that adequate fluids are available and used by decontamination team members.

Occupational Safety and Health Administration (OSHA) first receiver guidance suggests that medical monitoring of decontamination personnel should be conducted before protective ensemble is donned or soon after, during rest breaks in the warm area, and after decontamination operations. These measures are particularly important when temperatures in the work area exceed 70°F (21°C). Monitoring may not be practical on the battlefield or in the fast-paced mass casualty environment; however, it is a useful measure to prevent heat injury during training and should be

TABLE 16-4

AMERICAN HEART ASSOCIATION RECOMMENDED VALUES FOR SAFE CARDIOVASCULAR FUNCTION

Function	Value
Blood pressure (max)	140 bpm systolic / 100 bpm diastolic
Pulse rate (max)	100 bpm
Temperature	min: 98.0°F (36.6°C) max: 99.2°F (37.3°C) or +/- 0.6°F (1.08°C) from normal

bpm: beats per minute

integrated into exercises when feasible. The American Heart Association–recommended safe limits are noted in Table 16-4. Automated wrist cuffs are now available that make ongoing blood pressure monitoring of workers in IPE much easier. Readings taken through IPE, however, may not be accurate. Individuals with elevated readings who are not under work or anxiety duress should receive particular attention.⁴⁴

In the field, a more practical way to reduce both heat and musculoskeletal injury is to distribute the

EXHIBIT 16-3

OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION LEVELS OF PERSONAL PROTECTIVE EQUIPMENT

- Level A** Provides the greatest level of skin and respiratory protection. Level A consists of a totally encapsulating suit with gloves and boots attached. A self-contained breathing apparatus (SCBA) is worn inside the suit, or a supplied-air system (with escape SCBA) is used for respiratory protection.
- Level B** Used when the highest level of respiratory protection is necessary, but a lesser level of skin and eye protection is needed. This level consists of nonencapsulating, chemical-resistant suits, often called splash suits or rain suits. The SCBA or a supplied-air system is worn either inside or outside the suit, depending on the configuration.
- Level C** Worn when the concentration and type of airborne substance is known and the criteria for using air purifying respirators are met. The level C ensemble consists of a full facepiece, an air-purifying respirator, and a chemical agent-resistant suit. Military MOPP 4 is similar to level C. Level C is the preferred IPE for decontamination operators (first receivers).
- Level D** A work uniform affording minimal protection. The military battle dress uniform, Army combat uniform, or coveralls meet the requirements for level D protection.

IPE: individual protective ensemble

MOPP: mission-oriented protective posture

SCBA: self-contained breathing apparatus

Adapted from: US Departments of the Army, Marine Corps, Navy, and Air Force, and Marine Corps. *Multiservice Tactics and Procedures for Nuclear, Biological, and Chemical (NBC) Protection*. Washington, DC: DoD; 2003. FM 3-11.4, MCWP 3-37.2, NTTP 3-11.27, AFTTP (I) 3-2.46.

workload among team members. Failure to enforce appropriate work–rest cycles increases the risk of injury and ultimately depletes personnel pools on subsequent days. Work–rest cycles insure adequate hydration, give the body an opportunity to disperse ex-

cessive heat, and slow down the production of internal body heat created during physical work. Chapter 14, Field Management of Chemical Casualties, provides further discussion on work–rest cycles and a table for calculating them.

EQUIPMENT FOR PATIENT THOROUGH DECONTAMINATION

Individual Protective Equipment

All decontamination team members must wear IPE for their protection.^{3,44} OSHA and the Federal Chemical Stockpile Emergency Preparedness Program recommend OSHA level C as the most appropriate wear for first receivers, which include decontamination team members.^{44,70,71} In the military, MOPP level 4 is roughly equivalent to OSHA level C. OSHA levels A and B (Exhibit 16-3) are normally worn at an incident site (hot zone; Exhibit 16-4) when the contamination is unknown. This high level of protection, which creates an additional heat burden on the worker and restricts mobility, is not necessary for decontamination operations in the warm zone, where the chemical risk is greatly reduced. For more information on OSHA levels see Chapter 17, Chemical Defense Equipment.

Decontamination team members using dry decontaminants, water, soap and water, or other liquid decontaminants must wear IPE that allows for easy operator wipe down. The IPE must also prevent undergarments from being saturated with water if water is used during decontamination. Tornngren et al⁷² showed that aerosolized agent simulants and their vapors penetrate protective equipment that becomes saturated with water during patient decontamination

operations.⁷² In this study, the wet underwear of the decontamination operators became contaminated. Preventing this saturation is best accomplished by



Fig. 16-4. An example of a hooded, powered air pressure respirator with a Tyvek F [(DuPont, Wilmington, Del) overgarment. Note the filter power unit worn at the waist. Photograph by Peter Hurst, US Army Medical Research Institute for Chemical Defense.

EXHIBIT 16-4

ZONES OF CONTAMINATION

Hot zone: Area of agent release that is directly contaminated.

Warm zone (or decontamination zone): Area outside the hot zone where contamination consists only of that brought into the area by contaminated patients and workers from the hot zone.

Cold zone (postdecontamination zone): Area beyond the warm zone that is free of solid, liquid, and vapor contamination. Patients are decontaminated before entering this area.

wearing a butyl rubber toxicological agent protective apron over IPE or wearing IPE that is impermeable to water (eg, Tyvek F [DuPont, Wilmington, Del]). These impermeable garments, however, increase the heat load on the worker. Protective aprons serve several purposes: they allow team members to easily decontaminate themselves between patients, keep undergarments free from contaminated moisture, and allow workers the option to remove this layer and more easily cool themselves in a rest area.

Military decontamination team members may wear the standard military M40 series, MCU2P, or new joint service general-purpose mask (see Chapter 17, Chemical Defense Equipment, for more information). An alternative is to wear a powered-air purifying respirator, which has a blower motor that pulls air through filters and into the mask hood (Figure 16-4). The circulated air blown into the mask hood helps keep the wearer cool, eliminates the effort to inhale air through filters, and reduces carbon dioxide buildup in the mask during heavy work. Produced by several companies, these masks must be rated at a protective factor of 1,000, per OSHA first receiver guidance, and should be approved by the National Institute of Occupational Safety and Health.⁴⁴ OSHA also dictates that all individuals must be medically cleared to wear full-face protective masks and equipment.⁷³ A variety of voice amplifiers that fit to the mask, throat or voice-activated microphones that work with head-mounted radios, and other types of communications systems that improve communication with mask use are available on the market.

Transport Equipment

Only litters or backboards made of plastic material that can be readily and thoroughly decontaminated should be used to hold contaminated patients. Cloth litters will hold agent, cannot be decontaminated effectively, and rapidly deteriorate when decontaminated with bleach solution.

Detection Devices

Detectors and monitors can be used at the arrival point, to assess which patients require decontamination, or after the decontamination process, to check for thoroughness of decontamination. In some instances the thoroughness of the decontamination process may make detectors less necessary (for example, when plumbed tent systems are used and ample supplies of soapy water and rinse water are available). The use of detectors is dictated by unit operating plans and specific service concepts of operation and tactics, techniques, and procedures.

Currently fielded chemical warfare agent detection and monitoring equipment does not identify all possible CWAs or toxic industrial chemicals (see Chapter 17, Chemical Defense Equipment for more detail). Existing military chemical detectors that can be useful during patient decontamination operations include M8 chemical detector paper, M9 chemical detector paper, the ICAM, the M22 automatic chemical agent detector alarm, and the HAPSITE Smart Chemical Identification System (INFICON, East Syracuse, NY).⁵⁵

Decontamination Shelters

Decontamination equipment varies from the simple use of buckets and sponges, or the use of fire trucks to spray down victims, to the more complex deployment of pop-up shelters or patient decontamination systems built on existing medical facilities. The variety of decontamination equipment has dramatically expanded since the terrorist events of September 11, 2001. Most decontamination systems use soap and water as the primary decontaminant. Some examples are shown in Figures 16-5 through 16-7. Shelters differ in construction, method of erection, plumbing, and system for moving litters. All of these factors can impact on overall system weight, durability, ease of set-up and tear down, and shelter footprint.

Decontamination shelters are useful for a variety of reasons. They protect decontamination workers and patients from wind and poor weather conditions, as well as providing privacy for patients during the decontamination process. Shelters provide a framework to support built-in plumbing, which makes set-up and processing of patients faster and easier than using buckets and sponges. Some degree of water pressure is necessary to operate the systems. Each system requirement is different, but the ideal system incorporates a high volume of water at low pressure.² Air and water heaters should be added to improve patient comfort. Roller systems can be incorporated to more rapidly process litter patients while reducing the incidence of musculoskeletal injuries among decontamination workers. Roller systems also reduce the number of workers necessary to perform decontamination procedures. A crew of 12 is recommended by the Air Force for decontamination shelter operations, but the process can be performed with a staff (not including medical personnel) of four individuals for the litter line, one for the ambulatory line, and two for the clean (cold) side of the hot line (or liquid control line).^{74,75} More individuals, encompassing several shifts, are needed to insure adequate rest cycles to reduce injury to decontamination operators. A variety of roller systems that differ in weight, ease of portability, and ease of



Fig. 16-5. TVI (TVI Corporation Inc, Glenn Dale, Md) decontamination pop-up shelter consisting of a light-weight scissor frame tent, integrated plumbing, heater, water bladder, and quickly expandable light-weight roller system with back-board. It can easily be erected within a few minutes by two individuals. Shown is a small size tent. Can be configured for both ambulatory and litter patients.
Photograph: Courtesy TVI Corporation.



Fig. 16-6. A medium sized Reeves DRASH (deployable rapid assembly shelter). The scissors construction allows for tent expansion similar to the TVI tent but with the framework on the inside of the shelter. It also has integrated plumbing and a litter roller system. Can be configured for both ambulatory and litter patients.
Photograph: Courtesy of Lt Col Charles Boardman, US Air Force, US Army Medical Research Institute of Chemical Defense. Reproduced with permission from Reeves EMS LLC, Orangeburg, NY.

assembly are on the market.

OSHA's recommended best practice for fixed facilities such as hospitals is to build decontamination facilities outside the building or near the emergency entrance.⁴⁴ Fixed decontamination facilities allow for immediate decontamination of casualties because no

set-up time is required. A well trained crew can typically set up a pop-up decontamination shelter in 10 to 20 minutes, depending on the type of equipment used.⁷⁶ For units expected to assist in decontamina-



Fig. 16-7. The US Army's method of using litter stands, buckets, and sponges. This process requires more frequent lifting of patients and water buckets than shelters with roller systems. The advantage, on the battlefield, is that this decontamination equipment is easy to carry. Ample quantities of water are still needed unless dry decontamination is used. This method is currently preferred by Army field units that cannot carry large quantities of equipment.
Photographs: Courtesy of Lt Col Charles Boardman, US Air Force, US Army Medical Research Institute of Chemical Defense, and Peter Hurst, US Army Medical Research Institute of Chemical Defense.

tion operations near an incident site, pop-up shelters or covered configurations of fire trucks that allow for

privacy and some protection from the elements are preferred.

ESTABLISHING A PATIENT THOROUGH DECONTAMINATION AREA

Patient thorough decontamination areas are established in locations considered to be free from contamination. Once contaminated patients arrive, these areas become designated as warm areas because low levels of dry, liquid, and vapor contamination may be brought in on the clothing, equipment, hair, and skin of patients admitted to the area. The direct hazard to workers is much reduced compared to the hot zone, but decontamination team members must wear protective ensemble because vapors and particles, even in small amounts, pose a hazard to those working directly with the contaminated patients. For more information on zones of contamination and the relationship of the decontamination area to triage and treatment areas see Chapter 14, Field Management of Chemical Casualties.

Water Concerns

Decontamination operations may use dry decontaminants, such as the M291 kit or diatomaceous earth; prepackaged wet decontaminants such as RSDL; soap and water; or chemical decontaminants such as 0.5% hypochlorite solutions. Critical to operations using soap and water is the availability of an adequate supply of water and a way to collect waste water run-off. Water trucks or water buffalos are needed for locations where water is scarce and fire hydrants are not available. In an urban setting, such as the civil response to a homeland incident, ample water is usually available through access to fire hydrants. Water is typically, however, not easily available in a battlefield situation.

If casualties are wearing full MOPP ensemble, as in a battlefield environment, the need for a comprehensive washing of the whole body is reduced, because much of the body is protected by the IPE. Casualties without protective clothing will have greater dermal exposure, because liquid chemical agents penetrate regular clothing, and subsequently will usually require washing of the whole body.

The disposition of waste water is an issue both on the battlefield and during homeland operations. Failure to contain contaminated waste water will pollute an area and prevent its later use. Federal regulations that apply to homeland operations in emergency situations allow for water run-off, as long as the action is not performed intentionally as a way of ignoring waste disposal regulations. Environmental Protection

Agency regulation 550-F-00-009,⁷⁷ which addresses first responder liability to mass decontamination run-off, considers the release of chemical or biological warfare agents from a terrorist event to be the same as a HAZMAT event and therefore covered under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, section 107.⁷⁷ This act notes that under the good Samaritan provision, which would apply to emergency response HAZMAT operations, "No person shall be liable under this sub chapter for costs or damages as a result of actions taken or omitted in the course of rendering care, assistance, or advice in accordance with the National Contingency Plan or at the direction of an on-scene coordination with respect to an incident creating a danger to public health or welfare or the environment as a result of any release of a hazardous substance or the threat thereof."⁷⁷

The decontamination of patients with large amounts of water is expected to result in waste water run-off containing a minimal concentration of chemical agent.⁷⁸ Currently most response agencies have received funding to purchase adequate decontamination equipment, which would include the use of waste water containment systems. In the United States in particular, failure to use these systems could be seen as negligence, if a response agency washed contamination down a sewer as an alternative to avoiding the extra costly and sometimes problematic effort of appropriate waste water collection and disposal using containment berms and bladders. The provisions cited above do not protect an agency against failing to develop a plan for collection and disposal of contaminated water during an incident. Plans may be overcome by events, but if no plans exist, a unit could be liable for damages. Even when protected by the Comprehensive Environmental Response, Compensation, and Liability Act, agencies can still be sued by state agencies, private agencies, and private individuals or groups. Tort reform is different in each state, so it is important for response agencies to participate in their local area planning committee early to work out these issues in writing.⁷⁷ It is critical that military units responding to homeland events follow these guidelines.

Training exercises should be used to determine the number of waste water bladders needed for expected mass casualty decontamination operations. If bladders are filling during exercises, additional ones should

be purchased. Decontaminating one individual is estimated to take 10 gallons of water, so a 200-gallon water bladder will become full sometime during the decontamination of the 20th patient. Bladders in a variety of sizes are made by several manufacturers; some models are now available with handles that can be lifted onto a truck. Site plans should include the staging of additional bladders so that an empty bladder is always available when needed. Training water decontamination crews to turn off water sprayers when they are not needed will keep bladders from filling as quickly. Procedures for cleaning bladders and disposing of waste material should be practiced. Written contracts should be made with hazardous waste disposal agencies before an incident occurs.

Handling Patients

Writings by Foroutan⁶⁵ and others^{63,79} note the importance of triage and treatment to stabilize patients before they undergo more thorough decontamination. Medical facilities must also be prepared for walk-in contaminated casualties who have bypassed emergency response teams. These patient triage and treatment areas should be established at the front of patient thorough decontamination operations. Decontamination can take time, typically from 10 to 20 minutes for litter patients and at least 5 minutes for ambulatory patients. In mass casualty situations medical personnel will be needed to manage patients awaiting decontamination. Because patients can also become medically unstable during decontamination, medical personnel are also needed to follow patients through the decontamination line.

Whether shelters, fixed facilities, or buckets and sponges are used, the thorough decontamination process is similar: patient arrival, triage, medical stabilization, securing of personal effects, clothing removal, washing, checking for any remaining contamination (where dictated), crossing the hot line, drying and re-clothing or covering the patient, and finally disposition of the patient to the medical treatment area on the clean side of the hot line. See Chapter 14, *Field Management of Chemical Casualties*, for more information.

Removal of contaminated IPE from patients should be done by carefully cutting and rolling the ensemble away from the patient's underclothing and skin. This process helps to contain any agent on the garment and prevents cross contamination of the patient's undergarments and now unprotected skin. If the patient is not wearing protective clothing, the containment of contamination is not as critical, and the clothing should be cut off as quickly as possible. During a

suspected terrorist incident, clothing should be individually bagged and labeled for forensic investigation by law enforcement agencies.

Sharp, long-handled seat belt cutters (not listed in medical equipment sets) and bandage scissors are ideal for quickly cutting off clothing and IPE; however, they typically become dull after cutting three to five garments, so operators should have a dozen or more of each cutter available (placed in a bucket of 5% bleach). To reduce the possibility of cross contamination, the cutting tools should be dipped into the bleach or exchanged after every long cut.

Additionally, litters used on the warm side should not cross the hot line. Rather, the patient is transferred to a clean litter at the hot line, and the warm-side litter is cleaned and reused. This process further reduces any cross-contamination hazard. Medical information should be transferred from contaminated patient triage cards to clean ones as the patient is moved across the hot line. A variety of patient card systems are available. In the battlefield, the military currently uses the field medical card (DD Form 1380).

Night Operations

Night operations make patient triage, treatment, and decontamination more challenging. Floodlights are not appropriate in a battlefield situation where blackout conditions are imposed, but in a noncombat environment their use should be encouraged to enhance visibility. Also, fluorescent light sets are available for use inside decontamination shelters to improve visibility.

To reduce the incidence of accidents under light-restricted conditions, decontamination lanes should be set up during daylight hours, if possible. The lanes should be clearly marked with reflective tape or waist-high, hanging chemical lights that glow in the dark. Lanes must be kept free from debris and should be familiar to litter bearers. Effective traffic control and off-load procedures are critical at the arrival point to prevent vehicles from hitting patients or operators.

To help identify personnel, operators should have their names and job clearly marked on the front and back of their protective ensemble. If available, reflective vests are ideal and serve to both enhance visibility and identify personnel. Voice amplifiers or other communication devices fitted to protective masks will help communications. Adequate flashlights, with red lens filters, are essential for operators during tactical scenarios.

Night operations require careful planning and additional resources; even in optimal weather conditions such operations pose great challenges. To minimize

the challenges and risks associated with night operations, leaders should develop night plans to meet their organizational mission objective and train their

personnel accordingly. These plans should then be incorporated into the organization's tactical standing operating procedures.

DECONTAMINATION IN COLD WEATHER

Although cold temperatures can decrease the effectiveness of deploying some chemical agents, various chemical formulations have been developed for cold-weather use, such as Lewisite, which can remain a liquid at freezing temperatures. A more realistic threat today is the purposeful or accidental release of hazardous industrial chemicals during cold weather. Accidents of this type regularly occur in the United States through ground and rail transportation mishaps, such as the January 2005 train derailment in Graniteville, South Carolina, which released chlorine gas.⁸⁰ On a cold day, chemical agents can also be dispersed in warm areas such as buildings. In the event of a building evacuation, casualties might be required to report to an outside assembly area or decontamination station. Additionally, nighttime temperature drops and rainy conditions produce reduced temperature situations even in warm climates.

Cold Shock and Hypothermia

Cool temperatures greatly increase the risk of cold shock and hypothermia.⁸¹ Cold shock occurs when an individual is suddenly exposed to cold temperatures,

such as cold water in a decontamination shower.⁸² Cold shock can cause death by triggering peripheral vasoconstriction, a gasp reflex, hyperventilation, and rapid heart rate leading to heart failure.⁸³ Casualties who are medically compromised, elderly, or have heart disease are particularly at risk. Hypothermia, though less of a threat than cold shock, occurs when the body core temperature drops below its normal 98.6°F (37°C) range.⁸²

Giesbrecht, who studied hypothermia extensively, identified its symptoms and stages (Table 16-5).⁸³ Mild hypothermia begins when victims are no longer able to shiver and their motor responses begin to become impaired. A narrow window of only 7°C (13°F) below normal core body temperature exists before severe hypothermia can develop. A rapid drop in core body temperature will occur in patients who are already medically compromised (eg, have symptoms of chemical agent exposure or coexisting traumatic injuries). Trauma itself causes hypothermia.⁸⁴ Those with hypothermia who are already medically compromised are at much higher risk of death than those who are normothermic.^{85,86} The use of benzodiazepines (eg, diazepam), the anticonvulsant for exposure to nerve

TABLE 16-5
STAGES AND SYMPTOMS OF HYPOTHERMIA

Stage	Core Temp		Status	Symptoms
	°C	°F		
Normal	35.0–37.0	95.0–98.6	Muscle and mental control and responses to stimuli fully active.	Cold sensation; shivering.
Mild	32.0–35.0	89.6–95.0		Physical (fine and gross motor) and mental (simple and complex) impairment.
Moderate	28.0–32.0	82.4–89.6	Muscle and mental control and responses to stimuli reduced or cease to function.	At 86°F (30°C) shivering stops, loss of consciousness occurs.
Severe	< 28.0	< 82.4	Responses absent.	Rigidity; vital signs reduced or absent; risk of ventricular fibrillation/ cardiac arrest (especially with rough handling).
	< 25.0	< 77.0	Spontaneous ventricular fibrillation; cardiac arrest.	

Data sources: (1) Giesbrecht GG. Pre-hospital treatment of hypothermia. *Wilderness Environ Med.* 2001;12:24-31. (2) US Army Soldier and Biological Chemical Command. *Guidelines for Cold Weather Mass Decontamination During a Terrorist Chemical Agent Incident.* Revision 1. Aberdeen Proving Ground, Md: SBCCOM; 2003.

agents, can cause an acute and transient hypothermia.⁸⁷ Individuals in wet clothing, or those who are stationary, will lose body heat more rapidly. Heat is conducted out through cool, damp clothing,⁸⁸ and wind convection against wet skin also facilitates rapid body cooling and, in cooler temperatures, hypothermia.⁸⁹

Those who are not medically compromised can tolerate ambient temperatures down to 65°F (18.3°C) for several minutes. Colder ambient temperatures, however, are uncomfortable and may cause shivering. Shivering, although it heats the body and is a sign of healthy thermoregulation, is very uncomfortable and depletes a patient's available energy stores.

Protection for Decontamination Team Members

Cold climates reduce the risk of heat injury for decontamination team members, but heat injury can occur if individuals wear excessive thermal undergarments under their protective ensemble and fail to anticipate the heat their bodies generate once they begin working. Cold injuries also can result if personnel sweat heavily and then rest in the cold. Larimer⁹⁰ suggests wearing a complete uniform under protective overgarments in extremely cold climates to increase insulation. Thin long underwear made of polypropylene or other materials can wick sweat away from the body,⁹⁰ which is particularly helpful when temperatures fall below 30°F (−1°C). Keeping active warms the body, and layered clothing, although difficult to remove while in IPE, can be worn under a rubber protective apron. In cool conditions cotton or wool liners worn under rubber gloves help insulate workers' hands against the cold. Teams should train at various temperatures to gain a better understanding of the amount of layered underclothing appropriate for their work level, so that they do not become overheated while working.

A warming tent is important for decontamination staff to use when needed.⁸² If a heated warming tent is not available, blankets must be made available for staff in the rest area. Ideally, heated triage and treatment tents as well as heated decontamination shelters should be used in operations where cold temperatures are frequent. Available buildings can be used if the situation permits. Heated tents and buildings will reduce both staff and patient exposure to the cold. If contaminated clothing is not removed from patients before they are brought into heated areas, these areas must be well ventilated so hazardous chemical vapors do not build up inside the enclosed space. Ideally, patient clothing should be removed just inside or outside the entrance to these facilities. Shelter air heaters and water heaters are available from most pop-up tent manufacturers.

Other cold weather risks are dehydration and ice.

In a cold environment individuals may not feel as thirsty as they would in warm weather, fail to drink the necessary amount of water, and become dehydrated.⁹⁰ Rehydration is critical for decontamination team members, and warm liquids should always be available. At freezing temperatures slips and falls on ice can pose a real hazard to patients and decontamination team members, especially around decontamination shelters where soap and water are used. In freezing conditions rock salt or a similar deicing material should be applied to ice patches around shelters and along routes of travel.

Protection for Patients

The Department of the Army suggests four decontamination methods based on the ambient temperature (Table 16-6).⁸² The closer the ambient temperature is to freezing, the more patient operations are conducted inside a heated enclosure. Regardless of the ambient temperature, individuals who have been exposed to a known life-threatening level of chemical contamination should disrobe, undergo decontamination, and be sheltered as soon as possible. Water heaters and decontamination shelter air heaters make decontamination operations in cold temperatures possible, although 6 to 20 minutes are needed to set up this equipment.

IPE worn by patients should not be removed until the patient appears medically stable enough to undergo decontamination. Asymptomatic patients may be left in IPE, still masked, and moved to a warm and well-ventilated holding area, or they may have IPE removed, be promptly decontaminated with warm water, and be moved directly to a warm holding area free of contamination. If clothing is removed, replacement clothing or blankets must be provided. If the patient may have been exposed to a liquid agent, clothing can be removed and areas not covered by clothing can be decontaminated. Thicker, layered winter clothing worn during exposure provides more protection against chemical agents than thin summer clothing, and thicker clothing should provide adequate protection against dry particles. Once clothing removal begins, decontamination should be accomplished as quickly as possible so that the patient can be covered again with a blanket and moved to a warm area.

If temperatures are near freezing, a dry decontaminant such as sand, paper towels, an M291 or M295 kit, or other absorbent material should be used for immediate decontamination before the patient is moved into a warm tent or room for clothing removal. Heavily contaminated outer protective clothing should be removed in a ventilated area immediately outside or near the entrance to the heated room. Ample sup-

TABLE 16-6
DECONTAMINATION METHODS BASED ON AMBIENT TEMPERATURE

Temperature	Method*	Warm Side Triage and Treatment	Clothes Removed	Location/Technique	After decontamination, patient moved to...
65°F (18°C) and above	1	Outside	Outside	Decontaminate outside	Outside clean side triage area OR Heated clean side triage area*
64°F to 36°F (17°F to 2°C)	2	Outside	Inside	Heated decontamination enclosure	Heated clean side triage area
35°F (1.6°C) and below	3	Inside	Inside	Dry decontamination such as flour, sand, paper towel; M291 or M295 kit for immediate decontamination	Transport to indoor heated decontamination area, preferably in a building

*Grey areas indicate activities performed inside a heated enclosure.

Adapted from: US Army Soldier and Biological Chemical Command. *Guidelines for Cold Weather Mass Decontamination During a Terrorist Chemical Agent Incident*. Revision 1. Aberdeen Proving Ground, Md: SBCCOM; 2003.

plies of blankets are critical during cold weather decontamination to cover patients as soon as they are decontaminated and while they are in assembly areas (this important detail is sometimes neglected in response operations).⁹¹

An air heater can keep the temperature comfortable for operators and patients. Air heaters should be placed at the clean side of the tent and blow toward the showering and disrobing area; this will move the air away from clean areas and also encourage patients to move toward the heat.⁹¹ A local gym or indoor swimming pool near the site of the incident can serve as a warmed treatment and decontamination area,⁸² but clean-up operations in commandeered buildings may be difficult.

If decontamination operations are typically conducted in ambient temperatures below 65°F (18°C), a decontamination system that heats the water is essential. Water may have to be heated to 100°F (38°C) or

greater so that it is comfortably warm, but not hot, by the time it reaches the patient.⁹² Heaters are also needed for water and waste water bladders in below freezing temperatures. Water transport lines should be covered and insulated to prevent freezing and rupture.⁹³ Power generators should remain on or be kept warm so that they do not freeze. Once operations have ceased, all pumps, lines, water heaters, and tent plumbing must be thoroughly drained before they freeze and rupture. These items should then be moved to a warm area to prevent freezing.

Additionally, chemical vapor detectors such as the automatic chemical agent detector alarm and ICAMs do not work effectively in the cold because agents give off few vapors in low temperatures. Also, battery life is significantly reduced, especially at temperatures below freezing. Chemical vapor detectors can be placed in warm shelters or tents to measure any vapors in these areas.⁹⁰

SPECIAL POPULATIONS

In the past, military decontamination doctrine has not addressed the medical management and decontamination of special populations such as infants, children, the disabled, or elderly. Recent operations in southwest Asia, relief efforts throughout the world, and the military's involvement with homeland defense have made it imperative that military decontamination teams are familiar with managing these special populations.

Pediatric Patients

Children and infants will inevitably be among those exposed to chemical agents during an industrial accident or purposeful attack, and they are at greater risk of injury for several reasons. Their small size and position close to the ground make them more susceptible to agent clouds that hang low to the ground, a classic characteristic of most chemical agents. Their respira-

tory rate is faster than adults (increased minute ventilation), so they will inhale a greater quantity of toxins.⁹⁴ Children have a reduced fluid reserve, so diarrhea and vomiting can rapidly lead to shock.⁹⁵ They will also absorb a greater dose of agent than adults because of their thinner skin, reduced weight, and larger body surface area related to volume of agent.⁹⁴

Children have limited vocabulary and may be nonverbal or crying, which makes assessing their needs difficult and complicates the decontamination process.⁹⁵ Young children will also be anxious about the unfamiliar and inhuman appearance of decontamination operators dressed in IPE. An additional challenge is identifying children; a patient numbering system incorporating photographic identification in combination with an identification bracelet that is difficult to remove is ideal.

If possible, parents and children should be decontaminated as a family so parents can assist in the process, although staff will need to direct them. If children are unaccompanied, provisions must be made for appropriate custodial care through the decontamination line and for several hours thereafter, and operators need to wash younger children who cannot bathe independently. Ideally, these operators should have some training and be comfortable working with children.

Soap and water is the safest decontaminant for children. Chemical decontaminants may cause skin breakdown.^{94,95} Wet agents with components that can transit the skin, such as RSDL, should be used with caution with this population until their safety is proven, and any use should be followed by a soap and water wash. Children have greater difficulty maintaining body temperature, so warm showers, ample towel supplies, and other means to warm them before and after decontamination are critical.

Other Special Populations

Individuals with physical or mental disabilities may require escorts during decontamination. If these

patients can walk independently, they should be processed through the ambulatory decontamination line. Ideally, relatives or acquaintances among fellow ambulatory patients can help individuals with special needs wash themselves; otherwise decontamination operators or other staff members must guide these patients. Hands-on assistance will probably be required for those with limited comprehension or movement limitations that impede their ability to shower independently.

Patients in wheelchairs, using walkers, or with limited mobility are more safely processed through the decontamination line as litter patients because floor grates, slippery floors, and water collection berms can pose hazards or barriers. Individuals with limited vision will need to be escorted through the decontamination line. Plastic chairs, which can be readily decontaminated, can be placed in disrobing, showering, and redressing areas as room allows to help those with limited mobility undress themselves. They should be washed off between patients. Canes, crutches, and other assistive devices should be thoroughly washed with soap and water, dried, and returned to the patients or caregivers after the decontamination process is complete. Eyeglasses can be worn during decontamination but must be thoroughly washed.

Wheelchairs must be decontaminated with special attention paid to cracks, crevices, movable joints, and water-resistant cushions. Contaminated cushions and other items that absorb water should be discarded. If a wheelchair cannot be decontaminated at the same time as its owner, it should be labeled for later decontamination and returned.

Communication challenges may occur with those who are deaf, blind, or nonverbal; additional staff will be required to assist these individuals through the decontamination line. Professionals with occupational therapy, physical therapy, mental health, or nursing backgrounds are ideal as members of decontamination teams to assist those with special needs. They should be trained, qualified to wear IPE, and integrated into decontamination operations.

SUMMARY

Decontamination is a process in which hazardous materials are removed from an individual, used in some form since World War I. Chemical liquids, dry powders, and vapors pose a significant risk to contaminated patients and individuals they come in contact with. Early removal prevents or reduces a patient's injury from a chemical agent. Later removal also protects the patient, but its primary purpose is to reduce any contamination in an MTF and reduce

injury to medical staff.

Current doctrine specifies the use of soap and water, the M291 kit, or 0.5% hypochlorite solution to decontaminate skin. RSDL was recently selected to replace the M291 kit. Fabric and other foreign bodies that have entered a wound can present a hazard to both the patient and medical personnel. These objects should be irrigated with fresh water or saline solution and removed carefully using a no-touch technique.

A variety of decontamination shelters have recently been developed to protect patients and workers from the weather, provide privacy, and provide a framework for plumbing. Most shelters use soap and water as the decontaminant. Various patient litter roller systems are available to reduce the risk of musculoskeletal injury for workers and speed the decontamination process. All decontamination operations, whether using buckets and sponges or plumbed shower systems, follow the same sequence of steps: patient arrival,

triage, patient stabilization, securing of personal effects, clothing removal, washing, checking for any remaining contamination (where dictated), crossing the hot line, drying and reclothing or covering the patient, and finally disposition of the patient to the medical treatment area on the clean side of the hot line. Both military and civilian decontamination processes will benefit from additional streamlining and, as the military plays a greater role in homeland defense, increased integration.

REFERENCES

1. Hurst CG. Decontamination. In: Sidell FR, Takafuji ET, Franz DR, eds. *Medical Aspects of Chemical and Biological Warfare*. In: Zajtchuk R, Bellamy RF, eds. *Textbook of Military Medicine*. Washington, DC: Department of the Army, Office of The Surgeon General, Borden Institute; 1997: Chap 15.
2. US Department of Health and Human Services, Technical Support Working Group. *Best Practices and Guidelines for CBR Mass Personnel Decontamination*. 2nd ed. Washington, DC: DHHS; 2004.
3. US Departments of the Army, Marine Corps, Navy, and Air Force, and Marine Corps. *Multiservice Tactics, Techniques, and Procedures for Chemical, Biological, Radiological, and Nuclear Decontamination*. Washington, DC: DoD; 2006. FM 3-11.5, MCWP 3-37.3, NTTP 3-11.26, AFTTP (I) 3-2.60.
4. Okumura T, Suzuki K, Fukuda A, et al. The Tokyo subway sarin attack: disaster management, Part 1: community emergency response. *Acad Emerg Med*. 1998;5:613–617.
5. US Department of Health and Human Services, Agency for Toxic Substance and Disease Registry. *Emergency Medical Services, A Planning Guide for the Management of Contaminated Patients*. Vol 1. In: *Managing Hazardous Materials Incidents*. Atlanta, Ga: DHHS; 2001: Chap 9.
6. Vogt BM, Sorensen JH. *How Clean is Safe? Improving the Effectiveness of Decontamination of Structures and People Following Chemical and Biological Incidents*. Oak Ridge, Tenn: Oak Ridge National Laboratory; 2002. ORNL/TM-2002/178.
7. Crone HD. Simple methods for the removal of chemical agents from the skin. In: *Proceedings of the International Symposium on Protection Against Chemical Warfare Agents, 6-9 June 1983*. Stockholm, Sweden: National Defense Research Institute; 1983: 169–171.
8. Trapp R. *The Detoxification and Natural Degradation of Chemical Warfare Agents*. Stockholm, Sweden: Stockholm International Peace Research Institute; 1985: 44–75.
9. McHargue CA, Commander, MC, US Navy Reserve, Chemical/Biological Incident Response Force, email, February 24, 2004.
10. Buckley JT, Sapkota A, Cardello N, Dellarco MJ, Klinger TD, of Colormetric Laboratories Inc. A rational approach to skin decontamination. Unpublished document; 2004.
11. Lundy PM, Hamilton MG, Hill I, Conley J, Sawyer TW, Caneva DC. Clinical aspects of percutaneous poisoning by the chemical warfare agent VX: effects of application site and decontamination. *Mil Med*. 2004;169:856–862.
12. Sim VM. *VX Percutaneous Studies in Man*. Aberdeen Proving Ground, Md: US Army Chemical Research and Development Laboratories; 1960. Technical Report 301.
13. Papirmeister B, Feister A, Robinson S, Ford R. *Medical Defense Against Mustard Gas: Toxic Mechanisms and Pharmacological Implications*. Boca Raton, Fla: CRC Press; 1991: 2–3.
14. Romano JR, US Army Medical Research Institute of Chemical Defense, Aberdeen Proving Ground, MD, personal communication, 2001.

15. McCreery MJ. Topical Skin Protectant. US patent 5,607,979. March 4, 1997.
16. Braue EH. Development of a reactive topical skin protectant. *J Appl Toxicol.* 1999;19(suppl 1):47–53.
17. Hobson ST, Lehnert EK, Braue EH Jr. The US Army reactive topical skin protectant (rTSP): challenges and successes. *MRS Symp Ser CC: Hybrid Org Inorg Mater* [serial online]. 2000;628:CC10.8.1-CC10.8.8.
18. Chang M. *A Survey and Evaluation of Chemical Warfare Agent Contaminants and Decontamination.* Dugway Proving Ground, Utah: Defense Technical Information Center; 1984. AD-202525.
19. Monteiro-Riviere NA, Inman AO, Jackson H, Dunn B, Dimond S. Efficacy of topical phenol decontamination strategies on severity of acute phenol chemical burns and dermal absorption: in vitro and in vivo studies. *Toxicol Ind Health.* 2001;17:95–104.
20. Brown VK, Box VL, Simpson BJ. Decontamination procedures for skin exposed to phenolic substances. *Arch Environ Health.* 1975;30:1–6.
21. *Formulations for the Decontamination and Mitigation of CB Warfare Agents, Toxic Hazardous Materials, Viruses, Bacteria and Bacterial Spores.* Denver, Colo: Modec Inc, 2001. Technical Report MOD2001-1008-M. Available at: http://www.deconsolutions.com/pdf_files/TECHNICAL%20REPORT%20MOD2001-1008-M. Accessed December 20, 2007.
22. Gordon RK, Feaster SR, Russell AJ, et al. Organophosphate skin decontamination using immobilized enzymes. *Chem Biol Interact.* 1999;119–120:463–470.
23. Gordon RK et al. Preparation of enzymatically active sponges or foams for detoxification of hazardous compounds. US patent 6,642,037. November 4, 2003.
24. Gordon RK et al. Detoxification with sponges or foams containing plurality of enzymes and encapsulated indicator. US patent 6,541,230. April 1, 2003.
25. Gordon RK et al. Immobilized enzymes biosensors for chemical toxins. US patent 6,406,876. June 18, 2002.
26. Cabal J, Kuca K, Sevelova-Bartosova L, Dohnal V. Cyclodextrines as functional agents for decontamination of the skin contaminated by nerve agents. *Acta Medica (Hradec Kralove).* 2004;47:115–118.
27. Raber E, McGuire R. Oxidative decontamination of chemical and biological warfare agents using L-Gel. *J Hazard Mater.* 2002; 93:339–352.
28. Cheng TC, DeFrank JJ, Rastogi VK. Alteromonas prolidase for organophosphorus G-agent decontamination. *Chem Biol Interact.* 1999;119–120:455–462.
29. Ghanem E, Raushel FM. Detoxification of organophosphate nerve agents by bacterial phosphotriesterase. *Toxicol Appl Pharmacol.* 2005;207(2 Suppl):459–470.
30. Amitai G, Adani R, Hershkovitz M, Bel P, Rabinovitz I, Meshulam H. Degradation of VX and sulfur mustard by enzymatic haloperoxidation. *J Appl Toxicol.* 2003;23:225–233.
31. Cerny LC, Cerny ER. The effect of biological media on the hydrolysis of mustard simulants. *Biomed Sci Instrum.* 1997;33:535–540.
32. Cabal J, Kassa J, Severa J. A comparison of the decontamination efficacy of foam-making blends based on cationic and nonionic tensides against organophosphorus compounds determined in vitro and in vivo. *Hum Exp Toxicol.* 2003;22:507–514.
33. Fitch JP, Raber, E, Imbro DR. Technology challenges in responding to biological or chemical attacks in the civilian sector. *Science.* 2003;302:1350–1354.

34. Wester RC, Xialing H, Landry TD, Maibach HI. In vivo evaluation of MDI skin decontamination procedures. Paper presented at: Polyurethane Expo Sponsored by the International Isocyanate Institute, September 1998; Des Plaines, Ill.
35. Neutralizing chemical and biological warfare agents—a new approach. *Environmental Health*. 1999;62(1):52.
36. Sawyer TW, Nelson P, Hill I, et al. Therapeutic effects of cooling swine skin exposed to sulfur mustard. *Mil Med*. 2002;167:939–943.
37. Chang AMH, Ciegler A. Chemical warfare: part 1—chemical decontamination. *Nucl Bio Chem Defense Technol Int*. 1985;1:59–65.
38. Yurow HW. *Decontamination Methods for HD, GB, and VX: A Literature Survey*. Aberdeen Proving Ground, Md: Army Armament Research and Development Command, Chemical Systems Laboratory; 1981. AD-B057349L.
39. Block F, Davis GT. *Survey of Decontamination Methods Related to Field Decontamination of Vehicles and Material*. Dugway Proving Ground, Utah: Defense Technical Information Center; 1978: 59–60. AD-B031659.
40. US Departments of the Army, Marine Corps, Navy, and Air Force, and Marine Corps. *Potential Military Chemical / Biological Agents and Compounds*. Fort Monroe, Va: US Army Training and Doctrine Command; 2005. FM 3-11.9, MCRP 3-37.1B, NTRP 3-11.32, AFTTP (I) 3-2.55.
41. Swanson MB, Davis GA, Perhac DG. *Environmentally Preferable Cleaners: All Purpose Cleaners, Glass Cleaners, and Dish-washing Liquids*. Knoxville, Tenn: Center for Clean Products and Clean Technologies, University of Tennessee; 1995.
42. Hunt B. Surfactants. Available at: <http://www.spraytec.com/articles/octnov97/surfactants.asp>. Accessed June 20, 2006.
43. Bryndza HE, Foster JP, McCartney JH, Lundberg B, Lober JC. Surfactant efficacy in removal of petrochemicals from feathers. Available at: http://www.ibrrc.org/pdfs/ibrrc_policy.pdf. Accessed June 18, 2006.
44. Occupational Safety and Health Administration. *The OSHA Best Practices for Hospital-Based First Receivers of Victims from Mass Casualty Incidents Involving the Release of Hazardous Substances*. Washington, DC: OSHA; 2005.
45. Van Hooidonk C. CW agents and the skin: penetration and decontamination. In: *Proceedings of the International Symposium on Protection Against Chemical Warfare Agents, 6–9 June 1983*. Stockholm, Sweden: National Defense Research Institute; 1983.
46. Hobson D, Blank J, Menton R. *Comparison of Effectiveness of 30 Experimental Decontamination Systems and Evaluation of the Effect of Three Pretreatment Materials Against Percutaneous Application of Soman, Thickened Soman, VX, and Sulfur Mustard in the Rabbit*. Edgewood Area, Aberdeen Proving Ground, Md: US Army Medical Research Institute of Chemical Defense; 1985. MREF Task 85-12: Final Report.
47. Hobson D, Blank J, Menton R. *Testing of Candidate CSM Decontamination Systems*. Edgewood Area, Aberdeen Proving Ground, Md: US Army Medical Research Institute of Chemical Defense; 1986. MREF Task 86-25: Final Report.
48. Braue E. Unpublished test results at the US Army Medical Research Institute of Chemical Defense, Edgewood, Md. 2006.
49. Joint Requirements Office for Chemical, Biological, Radiological and Nuclear Defense. *Joint Service Personnel/Skin Decontamination System (JSPDS)*. Washington, DC: Joint Requirements Office, 2004. Operational Requirements Document.
50. Bide RW, Burczyk AF, Risk DJ. *Comparison of Skin Decontaminants for HD: Canadian Reactive Skin Decontamination Lotion, Canadian Decontaminating Mitt and US Skin Decontaminant Kit*. Medicine Hat, Alberta, Canada: Defence Research Establishment; nd.

51. Hanssen KA, Doxzon BF, Lumpkin HL, Clarkson E, Braue EH Jr. Evaluation of decontamination systems challenged with nerve agents. In: *Proceedings of the 25th Army Science Conference, 27–30 November 2006* [CD-ROM]. Arlington, Va: Assistant Secretary of the Army (Acquisition, Logistics and Technology); 2006. Paper KP-16.
52. FDA clears skin lotion for military to protect against chemical burns [press release]. Washington, DC: US Food and Drug Administration; March 28, 2003.
53. Sweeney R, Director, Government Contracting, O'Dell Engineering Ltd. Personal e-mail communication with Boardman CH, 2004.
54. Letter from the Food and Drug Administration to the US Army authorizing the marketing of RSDL in the United States, March 25, 2003, archived at Joint Program Executive Office for Chemical and Biological Defense, Falls Church, Va.
55. US Departments of the Army, Marine Corps, Navy, and Air Force. *Health Service Support in a Nuclear, Biological, and Chemical Environment*. Draft. Washington, DC: DoD; 2004. FM 4-02.7, MCRP 4-11.1F, NTTP 4-02.7, AFTTP (I) 3-2.47.
56. Cooper GJ, Ryan JM, Galbraith KA. The surgical management in war of penetrating wounds contaminated with chemical warfare agents. *J R Army Med Corps*. 1994;140:113–118.
57. Hobson D, Snider T. *Evaluation of the Effects of Hypochlorite Solutions in the Decontamination of Wounds Exposed to Either the Organophosphate Chemical Surety Material VX or the Vesicant Chemical Surety Material HD*. Columbus, Ohio: Battelle Memorial Institute; 1992. Task 89-04.
58. Graham JS, Research Biologist, US Army Medical Research Institute of Chemical Defense, Aberdeen Proving Ground, Md. Unpublished research.
59. Lindsay RS. *Swatch Test Results of Phase 2 Commercial Chemical Protective Gloves to Challenge by Chemical Warfare Agents: Executive Summary*. Aberdeen Proving Ground, Md: Defense Technical Information Center; 2001. AD-A440407. Available at: <http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA440407&Location=U2&doc=GefTRDoc.pdf>. Accessed December 20, 2007.
60. US Army Medical Research Institute of Chemical Defense. *General Provisions for Neat Research Chemical Agent (NRCA)*. Aberdeen Proving Ground, Md: USAMRICD; 2006. SOP No. 96-124-RS-02.
61. Smith W, PhD. US Army Medical Research Institute of Chemical Defense, Aberdeen Proving Ground, Md. Personal communication with Charles Hurst, 1996.
62. Horton DK, Berkowitz Z, Kaye WE. Secondary contamination of ED personnel from hazardous materials events, 1995–2001. *Am J Emerg Med*. 2003;21:199–204.
63. Okumura T, Suzuki K, Fukuda A, et al. The Tokyo subway sarin attack: disaster management, Part 2: Hospital response. *Acad Emerg Med*. 1998;5:618–624.
64. Nozaki H, Hori S, Shinozawa Y, et al. Secondary exposure of medical staff to sarin vapor in the emergency room. *Intensive Care Med*. 1995;21:1032–1035.
65. Foroutan A. Medical notes on the chemical warfare: part IX. *Trans. Kowsar Med J*. Fall 1997;2(3).
66. World Health Organization. The impact of pesticides on health. Available at: http://www.who.int/mental_health/prevention/suicide/en/PesticidesHealth2.pdf. Accessed June 12, 2006.
67. Stacey R, Morfey D, Payne S. Secondary contamination in organophosphate poisoning: analysis of an incident. *Q J M*. 2004;97:75–80.
68. Cox R. Hazmat. *Emedicine* [serial online]. Available at: <http://www.emedicine.com/emerg/topic228.htm>. Accessed August 17, 2005.

69. National Institute for Occupational Safety and Health. *Working in Hot Environments*. Washington, DC: NIOSH; 1992. Available at: <http://www.cdc.gov/niosh/hotenvt.html>. Accessed June 12, 2006.
70. US Department of Health and Human Services, Centers for Disease Control and Prevention. CDC recommendations for civilian communities near chemical weapons depots: guidelines for medical preparedness. *Federal Register* 60, no. 123 (June 27, 1995): 3308.
71. Hick JL, Hanfling D, Burstein JL, Markham J, Macintyre AG, Barbera JA. Protective equipment for health care facility decontamination personnel: regulations, risks, and recommendations. *Ann Emerg Med*. 2003;42:370–380.
72. Torngren S, Persson SA, Ljungquist A, et al. Personal decontamination after exposure to simulated liquid phase contaminants: functional assessment of a new unit. *J Toxicol Clin Toxicol*. 1998;36:567–573.
73. 29 CFR, Part 1910.134. Available at: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=12716. Accessed June 14, 2006.
74. Bocek TJA, Reed T, Walker WW. *USAF Concept of Operations, In-Place Patient Decontamination Capability (IPPDC)*. Langley Air Force Base, Va: HQ Air Combat Command, SGPM; 2004.
75. Boardman CH. Notes from final demonstration of Contamination Avoidance at Seaports of Debarkation Advanced Concept Demonstration Exercise, 2005, and from observations at Field Management of Chemical and Biological Casualties Course, June 2006.
76. Boardman CH. Personal communication with vendors and personal experience during Field Management courses, 2006.
77. US Environmental Protection Agency. *First Responders' Environmental Liability Due to Mass Decontamination Runoff*. Washington, DC: EPA; 2000. 550-F-00-009.
78. National Association of Clean Water Agencies. *Planning for Decontamination Wastewater: A Guide for Utilities*. Washington, DC: NACWA; 2005.
79. Macintyre AG, Christopher GW, Eitzen E, et al. Weapons of mass destruction events with contaminated casualties: effective planning for health care facilities. *JAMA*. 2000;283:242–249.
80. US Department of Health and Human Services, Agency for Toxic Substances and Disease Registry. Train derailment and chemical release in Graniteville, South Carolina, January 2005. Available at: <http://www.atsdr.cdc.gov/HS/HSEES/sctrain.html>. Accessed June 6, 2006.
81. Hudson TL, Reilly K, Dulaigh J. Considerations for chemical decontamination shelters. *Disaster Manag Response*. 2003;1:110–113.
82. US Army Soldier and Biological Chemical Command. *Guidelines for Cold Weather Mass Decontamination During a Terrorist Chemical Agent Incident*. Revision 1. Aberdeen Proving Ground, Md: SBCCOM; 2003.
83. Giesbrecht GG. Pre-hospital treatment of hypothermia. *Wilderness Environ Med*. 2001;12:24–31.
84. Segers MJ, Diephuis JC, van Kesteren RG, van der Werken C. Hypothermia in trauma patients. *Unfallchirurg*. 1988;101:742–749.
85. Shafi S, Elliott AC, Gentilello L. Is hypothermia simply a marker of shock and injury severity or an independent risk factor for mortality in trauma patients? Analysis of a large national trauma registry. *J Trauma*. 2005; 59:1081–1085.
86. Wang HE, Calloway CW, Peitzman AB, Tisherman SA. Admission hypothermia and outcome after major trauma. *Crit Care Med*. 2005;33:1296–1301.
87. Echizenya M, Mishima K, Satoh K, et al. Enhanced heat loss and age-related hypersensitivity to diazepam. *J Clin Psychopharmacol*. 2004;24:639–646.

88. Rav-Acha M, Heled Y, Moran DS. Cold injuries among Israeli soldiers operating and training in a semiarid zone: a 10-year review. *Mil Med.* 2004;169:702–706.
89. Irwin BR. A case report of hypothermia in the wilderness. *Wilderness Environ Med.* 2002;13:125–128.
90. Larimer E. Extreme cold weather decontamination—the challenge—chemical warfare. *CML Army Chemical Review.* 2001;Aug. Available at: http://www.findarticles.com/p/articles/mi_m0IUN/is_2001_August/ai_79855465. Accessed September 26, 2007.
91. Bocek T. Representative for TVI Corporation and Reeves Corporation. Personal communication, 2006.
92. Boardman CH. Personal notes from Contamination at Seaports of Debarkation Advanced Concept Demonstration, 2005.
93. Fitzgerald DJ, Sztajnkrzyer MD, Crocco TJ. Chemical weapon functional exercise—Cincinnati: observations and lessons learned from a “typical medium-sized” city’s response to simulated terrorism utilizing Weapons of Mass destruction. *Public Health Rep.* 2003;118:205–214.
94. Rotenberg JS, Burklow TR, Selanikio JS. Weapons of mass destruction: the decontamination of children. *Pediatr Ann.* 2003;32:260–267.
95. Department of Health and Human Services, Agency for Healthcare Research and Quality. *The Decontamination of Children: Preparedness and Response for Hospital Emergency Departments* [DVD]. Rockville, Md: AHRQ; 2006.

