Chapter 15

DECONTAMINATION

CHARLES G. HURST, M.D.*

Colonel, Medical Corps, U.S. Army; currently, Special Assistant for Medical Programs, Office of the Deputy Assistant Secretary of Defense, Counterproliferation and Chemical/Biological Matters, Room 3E808, 3050 Defense Pentagon, Washington, D.C. 20301-3050; formerly, Commander, U.S. Army Medical Research Institute of Chemical Defense, Aberdeen Proving Ground, Maryland 21010-5425

INTRODUCTION

Decontamination is defined as the reduction or removal of chemical (or biological) agents so they are no longer hazards. Agents may be removed by physical means or be neutralized chemically (detoxification). Decontamination of skin is the primary concern, but decontamination of eyes and wounds must also be done when necessary. Decontamination can be further defined:

- *personal* decontamination refers to decontamination of oneself,
- *casualty* decontamination refers to the decontamination of casualties, and
- *personnel* decontamination usually refers to decontamination of noncasualties.

The most important and most effective decontamination after any chemical or biological exposure is that decontamination done within the first minute or two after exposure. This is personal-decontamination. Early action by the soldier to decontaminate himself will make the difference between survival (or minimal injury) and death (or severe injury). Good training can save lives.

Decontamination of chemical casualties is an enormous task. The process requires dedication of both large numbers of personnel and large amounts of time. Even with appropriate planning and training, decontamination of casualties demands a significant contribution of resources. Liquids and solids are the only substances that can be effectively removed from the skin. It is generally not possible or necessary to decontaminate skin following vapor exposure. Removal from the atmosphere containing the vapor is all that is required.

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 will rapidly and completely remove or detoxify all known chemical and biological warfare agents. Furthermore, a suitable skin decontaminant must have certain properties that are not requirements for decontaminants for equipment.[1,2] Recognized desirable traits of a skin decontaminant are shown in Exhibit 15-1.

Decontamination issues have been explored since the beginning of modern chemical warfare. After years of research worldwide, simple principles that consistently produce good results are still recommended.

The first, which is without equal, is timely physical removal of the chemical agent. To remove the substance by the best means available is the primary objective. Chemical destruction (detoxification) of the offending agent is a desirable secondary objective. Physical removal is imperative because none of the chemical means of destroying these agents destroy them instantaneously. While decontamination preparations such as fresh hypochlorite (either sodium or calcium hypochlorite) react rapidly with some chemical agents (eg, the half-time for destruction of the nerve agent VX by hypochlorite at pH 10 is 1.5 min), the half-times of destruction of other agents, such as mustard, are much longer.[3] If a large amount of agent is present initially, a longer time is

EXHIBIT 15-1

DESIRABLE TRAITS OF A SKIN DECONTAMINANT

- Neutralizes all chemical and biological agents
- Is safe (nontoxic and noncorrosive)
- Is applied easily by hand
- Is readily available
- Acts rapidly
- Produces no toxic end products
- Is stable in long-term storage
- Is stable in the short term (after issue to unit/individual)
- Is affordable
- Does not enhance percutaneous agent absorption
- Is nonirritating
- Is hypoallergenic
- Is easily disposed of

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. COR Decontamination/Contamination Control Master Plan Users' Meeting. 11–13 September 1985. Unpublished.

needed to completely neutralize the agent to a harmless substance.

Decontamination studies have been conducted using common household products. The goal of these studies was identification of decontaminants for civilians as well as field expedients for the soldier. Timely use of water, soap and water, or flour followed by wet tissue wipes produced results equal, nearly equal, or in some instances better than those produced by the use of fuller's earth, Dutch Powder, and other compounds.[4] (Fuller's earth [diatomaceous earth] and Dutch Powder [Dutch variation of fuller's earth] are decontamination agents currently fielded by some European countries.) Because no topical decontaminant has ever shown efficacy with chemical agent that has penetrated into the skin, and because chemical agents may begin penetrating the skin before complete reactive decontamination (detoxification) takes place, early physical removal is most important.

Military personnel may be questioned for guidance by local civilian authorities or may deal with supply shortages in the field. Knowledge of the U.S. doctrinal decontaminating solutions may not suffice in these situations, and awareness of alternative methods of decontamination will prove very beneficial. What decontamination method is used is not as important as how and when it is used. Chemical agents should be removed as quickly and completely as possible by the best means available.

The M291 resin kit and 0.5% hypochlorite for chemical casualty decontamination are currently fielded by the U.S. military. The M291 kit is new, whereas hypochlorite solution has been around since World War I. The M291 kit is our best universal dry decontaminant for skin. Fresh 0.5% hypochlorite solution with an alkaline pH is our universal liquid decontaminating agent and is recommended for all biological agents.

The M291 resin kit is best for spot-decontamination of skin (Figure 15-1). The dry, black resin rapidly adsorbs the chemical agent, with carbonaceous material physically removing the agent from skin contact. Later, an ion-exchange resin neutralizes the offending agent by chemical detoxification. Since the M291 kit is small and dry and easily carried by the soldier, it is well suited for field use.[5,6] Early intervention with the use of this kit will reduce chemical injury and save life in most cases.

Decontamination of the casualty using an M291 kit does not obviate the need for decontamination at a field medical treatment facility (MTF).

Fig. 15-1. The six individual decontamination pads of the M291 kit are impregnated with the decontamination compound Ambergard XE-555 Resin, which is the black, free-flowing, resin-based powder. Each pad has a loop that fits over the hand. As the soldier holds the pad in one hand, he scrubs the pad over his 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. Photograph: Courtesy of Michael R. O'Hern, Sergeant First Class, US Army (Ret) and Larry L. Harris, Sergeant First Class, US Army (Ret).

Chemical agent transfer is a potential problem that can be resolved by a second, deliberate decontamination. This thorough decontamination at the MTF prevents spread of the agent to areas of the body previously uncontaminated, contamination of personnel assisting the patient, and contamination of the MTF itself.

Liquids are best for decontaminating large or irregular surface areas. Hypochlorite solutions are well suited for MTFs with adequate water supplies. For hypochlorite to be most effective, it has to be relatively fresh (made daily or more frequently, particularly in a warm environment where evaporation will occur) and have a concentration of 0.5% at an alkaline pH (pH 10–11). Hypochlorite solutions are for use on skin and soft-tissue wounds only. Hypochlorite should *not* be used in abdominal wounds, in open chest wounds, on nervous tissue, or in the eye. Surgical irrigation solutions should be used in liberal amounts in the abdomen and chest. All such solutions should be removed by suction instead of sponging and wiping. Only copious amounts of water, normal saline, or eye solutions are recommended for the eye. Contaminated wounds are discussed later in this chapter.

METHODS OF DECONTAMINATION

Three basic methods of decontamination are physical removal, chemical deactivation, and biological deactivation of the agent. Biological deactivation has not been developed to the point of being practical.

Physical Removal

Several types of physical and chemical methods are at least potentially suitable for decontaminating equipment and material. Flushing or flooding contaminated skin or material with water or aqueous solutions can remove or dilute significant amounts of chemical agent. Scraping with a wooden stick (ie, a tongue depressor or Popsicle stick) can remove bulk agent by physical means. A significant advantage of most physical methods is their nonspecificity. Since they work nearly equally well on chemical agents regardless of chemical structure, knowledge of the specific contaminating agent or agents is not required.

Flushing With Water or Aqueous Solutions

When animal skin contaminated with the nerve agent GB was flushed with water at 2 minutes (a method in which physical removal predominates over hydrolysis of the agent), 10.6 times more GB was required to produce the same mortality rate as when no decontamination occurred.[7] In another study, the use of water alone produced better results than high concentrations of hypochlorite (ie, 5% or greater, which is not recommended for skin).[8] Timely copious flushing with water physically removes the chemical agent and will produce good results.

Adsorbent Materials

Adsorption refers to the formation and maintenance of a condensed layer of a substance, such as a chemical agent, on the surface of a decontaminant, as illustrated by the adsorption of gases by charcoal particles and by the decontaminants described in this section. Some North Atlantic Treaty Organization (NATO) nations use adsorbent decontaminants in an attempt to reduce the quantity of chemical agent available for uptake through the skin. In emergency situations, dry powders such as soap or detergents, earth, and flour may be useful. Flour followed by wiping with wet tissue paper is reported[4] to be effective against the nerve agents soman (GD) and VX and against mustard.

M291 Resin

The current method of battlefield decontamination by the individual soldier involves the use of a carbonaceous adsorbent, a polystyrene polymeric, and ion-exchange resins (the M291 kit; see Figure 15-1). The resultant black powder is both reactive and adsorbent. The M291 kit has been extensively tested and has proven highly effective for skin decontamination.[5,6] It consists of a walletlike carrying pouch containing six individual decontamination packets. Each packet contains a nonwoven, fiberfill, laminated pad impregnated with the decontamination compounds. Each pad provides the individual with a single-step, nontoxic, nonirritating decontamination application, which can be used on the skin, including the face and around wounds. Instructions for use are marked on the case and packets.

Chemical Methods

Three types of chemical mechanisms have been used for decontamination: water/soap wash; oxidation; and acid/base hydrolysis.[9] Mustard (HD) and the persistent nerve agent VX contain sulfur molecules that are readily subject to oxidation reactions. VX and the other nerve agents (tabun [GA], sarin [GB], soman [GD], and GF) contain phosphorus groups that can be hydrolyzed. Therefore, most chemical decontaminants are designed to oxidize mustard and VX and to hydrolyze nerve agents (VX and the G series).[1]

Water and Water/Soap Wash

Both fresh water and sea water have the capacity to remove chemical agents not only through mechanical force but also via slow hydrolysis; however, the generally low solubility and slow rate of diffusion of chemical warfare agents in water significantly limit the agent hydrolysis rate.[10]

The predominant effect of water and water/soap solutions is the physical removal or dilution of agents; however, slow hydrolysis does occur, particularly with alkaline soaps. In the absence of hypochlorite solutions or other appropriate means of removing chemical agents, these methods are considered reasonable options.[4]

Oxidation

The most important category of chemical decontamination reactions is oxidative chlorination. This term covers the "active chlorine" chemicals like hypochlorite. 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.[11]

Both VX and HD contain sulfur atoms that are readily subject to oxidation. Current U.S. doctrine specifies the use of a 0.5% sodium or calcium hypochlorite solution for decontamination of skin and a 5% solution for equipment.

Hydrolysis

Chemical hydrolysis reactions are of two types: acid and 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.[11] Alkaline hydrolysis is initiated by the nucleophilic attack of the hydroxide ion on the phosphorus atoms 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 four for every 10°C rise in temperature. Several of the hydrolytic chemicals are effective in detoxifying chemical warfare agents; unfortunately, many of these (eg, sodium hydroxide) are unacceptably damaging to the skin. Alkaline pH hypochlorite hydrolyses VX and the G agents quite well.[3,12]

Certification of Decontamination

Regardless of the method used to decontaminate, certification of chemical decontamination is accomplished by any of the following: processing through the decontamination facility; M8 paper; M9 tape; M256A1 ticket; or by the CAM (chemical agent monitor). (See Chapter 16, Chemical Defense Equipment, for a discussion of this detection equipment.) If proper procedure is followed, the possibility of admitting a chemically contaminated casualty to a field MTF is extremely small. The probability of admitting a dangerously contaminated casualty is minuscule to nonexistent. Fear is the worst enemy, not the contaminated soldier.

WOUND DECONTAMINATION

All casualties entering a medical unit after experiencing a chemical attack are to be considered contaminated unless there is certification of noncontamination. The initial management of a casualty contaminated by chemical agents will require removal of mission-oriented protective posture (MOPP) gear and decontamination with 0.5% hypochlorite before treatment within the field MTF.

Initial Decontamination

During initial decontamination in the decontamination areas, bandages are removed and the wounds are flushed; the bandages are replaced only if bleeding recurs. Tourniquets are replaced with clean tourniquets and the sites of the original tourniquets decontaminated. Splints are thoroughly decontaminated, but removed only by a physician. The new dressings are removed in the operating room and submerged in 5% hypochlorite or placed in a plastic bag and sealed.

General Considerations

Of the chemical agents discussed, only two types, the vesicants and the nerve agents, might present a hazard from wound contamination. Cyanide is quite volatile, so it is extremely unlikely that liquid cyanide will remain in a wound. A very large amount of liquid cyanide is required to produce vapor sufficient to cause effect.

Mustard converts to a cyclic compound within minutes of absorption into a biological milieu, and the cyclic compound reacts rapidly (ie, within minutes) with blood and tissue components.[13] These reactions will take place with the components of the wound—the 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 much like an intramuscular absorption of the agent).

Although nerve agents cause their toxic effects by their very rapid attachment to the enzyme acetylcholinesterase, they also quickly react with other enzymes and tissue components. As they do with mustard, the blood and necrotic tissue of the wound will "buffer" the nerve agents. Nerve agent that reaches viable tissue will be rapidly absorbed, and since the toxicity of the nerve agents is quite high (a lethal amount is a small fraction of a drop), it is unlikely that casualties whose wounds are contaminated with much liquid nerve agent will survive to reach medical care.[14]

Potential risk to the surgeon from contaminated wounds arises from chemical agent on foreign bodies in the wound and from thickened agents.[15] Medical personnel treating biological casualties have only a minimal risk from secondary aerosolization of biological agents.

Thickened Agents

Thickened agents are chemical agents that have been mixed with another substance (commonly an acrylate) to increase their persistency. They are not dissolved 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 than other nerve agents and may persist in a wound longer than other nerve agents.

Thickened agents in wounds require more precautions. Casualties with thickened nerve agents in wounds (eg, from pieces of a contaminated battledress uniform or protective garment being carried into the wound tract) 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 extremely low, contact hazard from thickened agents does remain and should always be assumed.[14]

No country is currently known to stockpile thickened agents. In a chemical attack, the intelligence and chemical staffs should be able to identify thickened agents and to alert the medical personnel of their use.

Off-Gassing

The risk from vapor off-gassing from chemically contaminated fragments and cloth in wounds is very low and not significant. Further, there is no vapor release from contaminated wounds without foreign bodies. Off-gassing from a wound during surgical exploration will be negligible or zero. No eye injury will result from off-gassing from any of the chemical agents. A chemical-protective mask is not required for surgical personnel.[14]

Biological agents can only be transmitted to medical personnel from secondary aerosolization from dry agents. Decontamination with 0.5% hypochlorite solution or flooding with water or saline will make this risk negligible. No protective equipment is necessary for surgical personnel other than standard barrier protections, unless the patient is infected with the plague bacillus, smallpox, or a hemorrhagic fever virus, or if procedures likely to generate bloody aerosols are employed. In such cases, wearing of a filtered respirator is recommended.

Foreign Material

The contamination of wounds with mustard or nerve agents is basically confined to the pieces of contaminated fabric in the wound tract. The removal of this cloth from the wound effectively eliminates the hazard. There is little chemical risk associated with individual fibers left in the wound. No further decontamination of the wound for unthickened chemical agent is necessary.[14]

Wound Contamination Assessment

The CAM can be used to assist in locating contaminated objects within a wound; however, 30 seconds are required to achieve a bar reading. The CAM detects vapor but may not detect liquid (a thickened agent or liquid on a foreign body) deep within a wound. A single-bar reading on CAM with the inlet held a few millimeters from the wound surface indicates that a vapor hazard does not exist.[14]

Dilute Hypochlorite Solution

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.

Dilute hypochlorite solution is contraindicated for the eye; it may cause corneal injuries. This substance is also not recommended for brain and spinal cord injuries. Irrigation of the abdomen with hypochlorite solution may lead to adhesions and is therefore also contraindicated. The use of hypochlorite in the thoracic cavity may be less of a problem, but the hazard is still unknown.

Wound Exploration and Debridement

Surgeons and assistants are advised to wear a pair of well-fitting (thin) butyl rubber gloves or double latex surgical gloves and to change them often until they are certain there are no foreign bodies or thickened agents in the wound. Thin butyl rubber gloves will have no breakthrough for 60 or more minutes in an aqueous base. Double latex surgical gloves will have no breakthrough for 29 minutes in an aqueous medium; they should be changed every 20 minutes.[16] This is especially important where puncture is likely because of the presence of bone spicules or metal fragments.[14]

The wound should be explored 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. The wound can then be checked with the CAM, which may direct the surgeon to further retained material. It takes about 30 seconds to get a stable reading from the CAM. A rapid pass over the wound will not detect remaining contamination.

The wound should be debrided and excised as usual, maintaining a no-touch technique. Removed fragments of tissue should be dropped into a container of 5% to 10% hypochlorite. Bulky tissue such as an amputated limb should be placed in a plastic or rubber bag (chemical proof), which is then sealed.[14]

Dilute hypochlorite solution (0.5%) may be instilled into deep, noncavity wounds following the removal of contaminated cloth. This solution should be removed by suction to a disposal container. Within a short time (ie, 5 min), this contaminated solution will be neutralized and rendered nonhazardous. Subsequent irrigation with saline or other surgical solutions should be performed.

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. When possible, the CAM may be used to assist.

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. Although the risk to patients and medical attendants is minuscule, 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 0.5% hypochlorite and subsequent irrigation with normal saline or sterile water.

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

BIOLOGICAL AGENT DECONTAMINATION

Decontamination of personnel and equipment after a biological warfare attack is a lesser concern than after a chemical warfare attack because most biological warfare agents are not dermally active (the trichothecene mycotoxins are an exception). Still, decontamination remains an effective way to decrease the spread of infection from potential secondary aerosolization.

For biological agents, *contamination* is defined as the introduction of microorganisms into tissues or sterile materials, whereas *decontamination* is defined as disinfection or sterilization of infected articles to make them suitable for use (the reduction of microorganisms to an acceptable level). *Disinfection* is defined as the selective elimination of certain undesirable microorganisms to prevent their transmission (the reduction of the number of infectious organisms below the level necessary to cause infection), and *sterilization* is defined as the complete killing of all organisms. Biological warfare agents can be decontaminated by chemical and physical methods.

Chemical Method

Chemical decontamination renders biological warfare agents harmless by the use of disinfectants. Dermal exposure to a suspected biological warfare agent should be immediately treated by soap and water decontamination. Careful washing with soap and water removes a very large amount of the agent population from the surface. It is important to use a brush to ensure mechanical loosening from the skin surface structures, and then to rinse with copious amounts of water. This method is often sufficient to avert contact infection. The contaminated areas should then be washed with a 0.5% hypochlorite solution, if available, with a contact time of 10 to 15 minutes. The solution should be applied with a cloth or swab or can be sprayed on. As with hypochlorite in chemical decontamination, this solution should not be used in the eyes, abdominal cavity, or on nerve tissue. It will neutralize and render nonhazardous any biological agent within approximately 5 minutes.

For decontamination of fabric clothing or equipment, a 5% hypochlorite solution should be used. For decontamination of equipment, a contact time of 30 minutes prior to normal cleaning is required. Use of hypochlorite solution in this way is corrosive to most metals and injurious to most fabrics, so they should be rinsed thoroughly and metal surfaces should be oiled after completion.

An important point to remember is that soap and water washing followed by hypochlorite washing to decontaminate for biological agents should be prompt but should follow any needed use of decontaminants for chemical agents. Ampules of calcium hypochlorite granules are currently fielded in the chemical agent decontamination kit for mixing hypochlorite solutions. The 0.5% solution can be made adding one 6-ounce container of calcium hypochlorite granules to 5 gallons of water. The 5% solution can be made by adding eight 6-ounce containers of calcium hypochlorite granules to 5 gallons of water. These solutions evaporate quickly at high temperatures, so if they are made in advance, they should be stored in closed containers. The hypochlorite solutions should be placed in distinctly marked containers because it is very difficult to distinguish visually a 0.5% solution from a 5% solution.

Physical Method

Physical methods are concerned with rendering biological warfare agents harmless through such physical means as heat and radiation. To render agents completely harmless, dry heat requires 2 hours of treatment at 160°C. If steam is used at 121°C and 1 atm of overpressure (15 psi), the time may be reduced to 20 minutes, depending on volume. This last method is also known as autoclaving. The part of solar ultraviolet radiation that reaches the Earth's surface has a certain disinfectant effect, often in combination with drying. Ultraviolet radiation is effective but hard to standardize into practical usage for disinfection or decontamination purposes.

SUMMARY

Decontamination at the MTF is directed toward (1) eliminating any chemical agent transferred to the patient during removal of protective clothing; (2) decontaminating or containing of contaminated clothing and personal equipment; and (3) maintaining an uncontaminated MTF.

Current doctrine specifies the use of 0.5% hypochlorite solution for chemical or biological skin contamination or the M291 kit for chemically contaminated skin. Fabric and other foreign bodies that have been introduced into a wound can sequester and slowly release chemical agent, presenting a liquid hazard to both the patient and medical personnel. Dry biological agent could be a hazard through secondary aerosolization. Adequate liquid decontamination will mitigate this hazard. There is no vapor hazard, and protective masks are not necessary for surgical personnel.

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