Personal Protective Equipment and Decontamination of Adults and Children

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KEYWORDS

• Decontamination • Personal protective equipment (PPE) • Levels A, B, C, D
• HAZMAT • Chemical contamination

KEY POINTS

- Accurate identification of the chemical substances involved is the most important information necessary for proper care of the hazardous materials (HAZMAT) incident, but is often not available initially.
- Proper decontamination prevents further chemical injury, protects health care workers and prevents secondary contamination of facilities and equipment.
- Many patients will not have been decontaminated at the scene; proper triage and security must be in place to prevent contamination. Many "worried well" present without significant exposures, but can overwhelm staffing.
- Decontamination by health care workers in Level C suits is sufficient protection. Decontamination areas are located outdoors ideally to prevent hospital air becoming contaminated.
- Proper advanced planning and practice are essential for efficient performance in an emergency. Knowledgeable hospital security and efficient triage can effectively control patient flow.

PERSONAL PROTECTIVE EQUIPMENT IN HAZARDOUS MATERIALS INCIDENTS

Biological, chemical, and radiologic materials that result in adverse effects to the health and safety of exposed individuals are termed hazardous materials (HAZMAT). These substances represent significant risks to health care workers when hospitals receive patients contaminated with these materials. Therefore, hospitals and their

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workforce must be prepared to use personal protective equipment (PPE) to protect themselves when these situations arise. Federal, state, and local regulations may specify types of PPE for specific job tasks when dealing with specific HAZMAT. There are 4 key issues which must be fully understood whenever PPE is required[1]:

1. The various types of PPE
2. The basics of a "hazard assessment"
3. How to select appropriate PPE; and
4. Training in the proper use of PPE.

It is only after these 4 key issues have been adequately addressed that a properly equipped and well-trained health care staff facility can provide a safe and effective response.

TYPES OF PERSONAL PROTECTIVE EQUIPMENT

PPE are articles worn or equipment used to protect the user from harmful contaminants released into the environment. In this article, this means the PPE used by hospital personnel when decontaminating and caring for patient(s) involved in a HAZMAT incident. The main function of PPE is to provide a barrier between the user and respiratory or skin exposure to the contaminant in the environment or on the skin/clothing of contaminated patients. PPE can be listed in the following categories:

1. Respiratory protection
2. Eye and face protection
3. Hand protection
4. Foot protection; and
5. Body protection.

A specific combination of PPE from each of these categories is normally needed to properly protect the wearer from each specific contaminant.

Respiratory Protection

Respiratory equipment prevents airborne contaminants from being inhaled, and some types can also protect the eyes and face. There are 2 primary types of respirators, air purifying and supplied air respirators. Air-purifying respirators (APRs) have filters, cartridges, or canisters that trap contaminants from the air. APRs are the most common protection method for particulates and vapors, and are used in environments where there is no chance of an oxygen-deficient state. Available filters should protect against, at a minimum, organic vapors and also contain a high-efficiency particulate air cartridge for particulates.[2] Supplied air respirators provide breathable air from a clean source such as an air tank or air compressor located outside the contaminated area, and are suitable for use in an oxygen-deficient environment. Respiratory protection must only be used in compliance with the applicable Occupational Safety and Health Administration (OSHA) regulations and National Institute for Occupational Safety and Health (NIOSH) publications.

The advantages and disadvantages of various styles of respirator face pieces are discussed in the OSHA best practices document.[3] Half-face pieces allow workers to wear any appropriate eyewear that does not interfere with the respirator seal, but they provide no eye protection themselves, and contaminated air can enter the mask if the seal is broken. Full face pieces provide eye protection and a tight-fitting face piece may be able to pull filtered air into the face piece if the battery fails on a powered APR (PAPR). Loose-fitting helmet/hood face pieces provide eye and head

protection, fit testing is not required, they can be worn by employees with facial hair, and they can wear their own glasses under the helmet/hood; the main disadvantage is when used with a PAPR, the hood will provide little or no protection if the battery fails. PAPRs have a motorized blower that delivers filtered air at a slight positive pressure into the face piece, reducing the chance of contaminated air reaching the user in the event of a leak.

Eye and Face Protection

OSHA requires that "eye and face protection must be provided whenever necessary to protect against chemical, environmental, radiological or mechanical irritants and hazards."[4] Liquid chemical contaminants may present hazards from splash, fumes, vapors, and mists. Solid chemical contaminants may involve airborne particles and dusts. Biological agents cause infections through eye contact. Eye protection typically takes the form of glasses, goggles, and face shields, or as part of full-face respirators.

Hand Protection

Gloves for hand protection are produced from a wide variety of both common and proprietary materials, including latex, nitrile, vinyl, polyurethane, butyl rubber, foils, and neoprene. Each material offers different ranges of protection, depending on the specific contaminant. Additionally, glove selection may need to be modified if there is a greater need for dexterity by the clinician. The appropriate type of glove necessary for each individual chemical can usually be found on the Material Safety Data Sheet/Safety Data Sheets when available. When dealing with unknown contaminants, standard latex or latex-free clinical examination gloves covered by nitrile or similar chemical-resistant gloves should be employed.

Foot Protection

Like gloves, chemical protective overboots and boots with steel toes are available in a variety of both common and proprietary materials, including vinyl, latex, polyvinyl chloride, polyurethane, and butyl rubber. Boots tend to have thicker side walls than gloves, and therefore are likely to provide more protection than gloves made of the same material.[3]

Body Protection

Protective clothing is available in a wide variety of styles and materials. Manufacturers produce a broad spectrum of protective fabrics that protect against a wide range of chemicals in liquid, solid, or vapor form. Protective clothing is typically illustrated as chemical protective suits but aprons, sleeves, and leggings are also available, which may represent a more appropriate selection in some instances. Chemical protective suits offer protection from radionuclides that are alpha and beta emitters, but do not offer protection from gamma or neutron radiation, and thus, it is important to assess radiation levels and determine staff exposure rates.[2]

HAZARD ASSESSMENT

OSHA published a handbook titled: *Best Practices for Hospital-Based First Receivers of Victims from Mass Casualty Incidents Involving the Release of Hazardous Substances*. This document "(1) provides information to assist hospitals in selecting personal protective equipment (PPE) based on current interpretations of OSHA standards, published literature, current hospital practices, stakeholder input, and the practical limitations of currently available respiratory protective devices and (2) consolidates OSHA standards and interpretations on training needs of first receivers."[3]

"First receivers" are defined as hospital employees who work at a site remote from the location where the hazardous substance release occurred. Therefore, their exposures are limited to the substances transported to the hospital on victims' skin, hair, clothing, or personal effects. Conditions necessary for hospitals to rely on the OSHA PPE recommendations include a thorough and complete hazard vulnerability analysis and emergency management plan (EMP), which have been conducted and developed with community input, and updated within the past year. Specifically, OSHA (2005) states: "By tailoring emergency plans to reflect the reasonably predictable "worst-case" scenario under which first receivers might work, the hospital can rely on these plans to guide decisions regarding personnel training and PPE.[1,3] The Joint Commission requires an all-hazard approach to allow organizations to be flexible enough to respond to emergencies of all types, whether natural or manmade (unintentional or intentional)."

HOW TO SELECT APPROPRIATE PERSONAL PROTECTIVE EQUIPMENT

OSHA guidelines typically rely on generalized statements, indicating PPE should be of safe design and construction, and selected to protect the employee from the hazards identified in the hazard assessment. Similarly, Material Safety Data Sheets and the new format Safety Data Sheets tend to recommend "appropriate protective equipment." More specific information can also be found in selection charts available from governmental and commercial agencies. Parker[5] states: "The most specific protective information and protective material compatibility information comes from the manufacturer." The author further notes that "the financial disincentive derived from legal liability from human injury and/or death drives these industries to thoroughly study their product and disseminate information to the public."

It is important to recognize the need to select the most appropriate and not necessarily the most protective PPE, because the use of PPE itself carries significant health risks for responders and greater levels of protection confer greater potential risk, including limited visibility, reduced dexterity, restricted movement, suit breach, hyperthermia owing to reduced heat dissipation, and dehydration.[6]

Respiratory protection should be selected first because it will be needed before and at greater distances than skin protection. Typically, supplied-air respirators are required for oxygen-deficient atmospheres, contaminants with inadequate warning properties, unidentified contaminants, and immediately dangerous to life and health environments. Immediately dangerous to life and health environments can only be identified when the contaminant is known and air monitoring has identified the concentration of the contaminant. These scenarios are present at a HAZMAT scene, and are not usually an issue in the hospital setting receiving contaminated patients.

Air-purifying respirators can only be used when the contaminant has adequate warning properties (eg, odor, taste, or irritation effects) that will alert the user if the respirator malfunctions. Additionally, they can only be used for certain ranges of air contaminant concentrations. OSHA has assigned a respirator protection factor to each type of respirator based on the overall effectiveness of the respirator. Respirator protection factors are used in conjunction with published or regulatory exposure limits to determine the upper concentration limit, and maximum use concentration for which the respirator is acceptable. Many hospitals have a strong interest in PAPRs with helmet/hoods because they require no fit testing, can be worn by employees with facial hair and eyeglasses, and are generally considered to be more comfortable than other air-purifying respirators.[3] However, they are also more costly to purchase than full-face masks.

Skin protection should be chosen after respiratory protection has been determined. Skin protection is intended to prevent direct contact with chemical liquids or vapors. Specific agents that might be problematic are the vesicants, such as sulfur mustard, and the persistent nerve agents, such as VX.[2] A variety of protective fabrics are available from manufacturers. OSHA provides a list of specific examples.[3]

A general description and discussion of the levels of protection and protective gear is provided in 29 CFR 1910.120 App B and is reproduced herein.[7]

Level A Protection

Level A provides the highest level of protection available, and protects the user from liquids, vapors and gases. Level A should be used when (1) the hazardous substance has been identified and requires the highest level of protection for skin, eyes, and the respiratory system based on either the measured (or potential for) high concentration of atmospheric vapors, gases, or particulates; or the site operations and work functions involve a high potential for splash, immersion, or exposure to unexpected vapors, gases, or particulates of materials that are harmful to skin or capable of being absorbed through the skin; (2) substances with a high degree of hazard to the skin are known or suspected to be present, and skin contact is possible; or (3) operations must be conducted in confined, poorly ventilated areas, and the absence of conditions requiring Level A have not yet been determined (**Fig. 1**).

Level A equipment (to be used as appropriate)

- Positive-pressure, full-face piece, self-contained breathing apparatus (SCBA), or positive-pressure supplied air respirator with escape SCBA, approved by NIOSH.
- Totally encapsulating chemical-protective suit.
- Gloves, outer, chemical resistant.
- Gloves, inner, chemical resistant.
- Boots, chemical resistant, steel toe and shank.
- Disposable protective suit, gloves, and boots (depending on suit construction), may be worn over totally encapsulating suit.[8]

Level B Protection

Level B protection provides adequate skin protection, but is not vapor impervious like Level A. Level B should be used when (1) the type and atmospheric concentration of substances have been identified and require a high level of respiratory protection, but less skin protection, (2) the atmosphere contains less than 19.5% oxygen, or (3) the presence of incompletely identified vapors or gases is indicated by a direct-reading organic vapor detection instrument, but vapors and gases are not suspected of containing high levels of chemicals harmful to skin or capable of being absorbed through the skin. (This involves atmospheres with immediately dangerous to life and health concentrations of specific substances that present severe inhalation hazards and that do not represent a severe skin hazard; or that do not meet the criteria for use of APRs.) SCBA present time restrictions on the use of a standard tank (~20–30 minutes of operational time) and the carrying weight of tanks make them impractical for most health care personnel.[2] This level of protection, like Level A, is generally used at a HAZMAT site, and not usually needed in health care facilities dealing with contaminated patients (**Fig. 2**).

Level B equipment (to be used as appropriate)

- Positive-pressure, full-face piece SCBA, or positive-pressure supplied air respirator with escape SCBA (NIOSH approved).

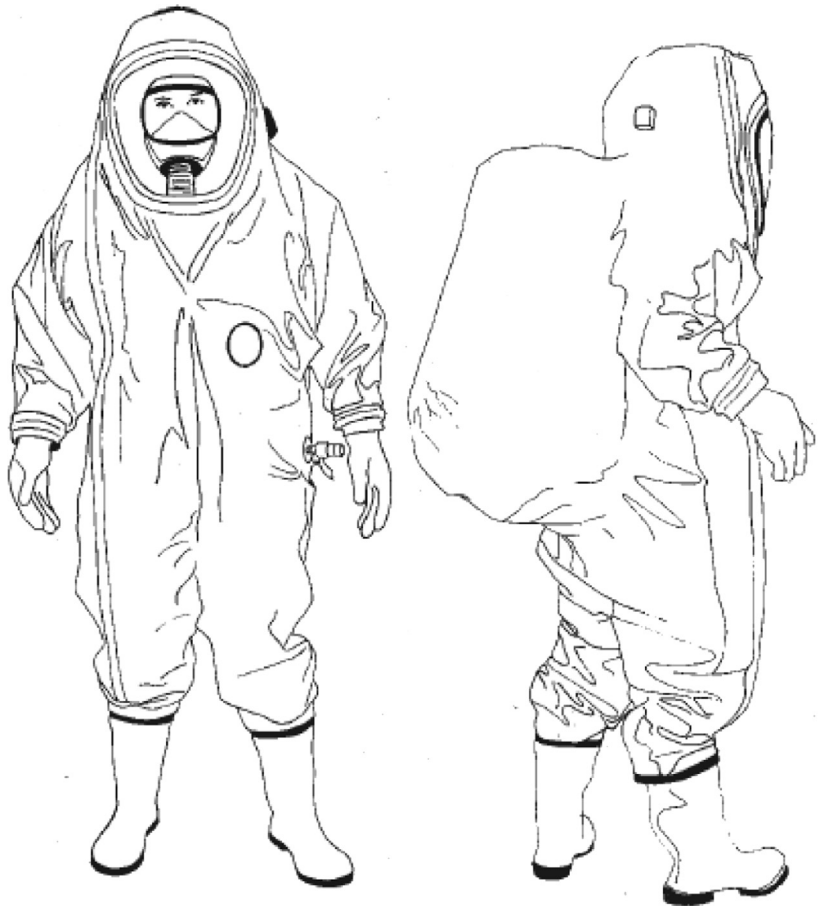

Fig. 1. Level A personal protective equipment. (*From* ATSDR. Managing Hazardous Material Incidents (MHMI). Volumes 1, 2, and 3. Agency for Toxic Substances and Disease Registry (ATSDR). Atlanta (GA): U.S. Department of Health and Human Services, Public Health Service; 2001. Available at: http://www.atsdr.cdc.gov/MHMI/index.asp. Accessed July 15, 2014).

- Hooded chemical-resistant clothing (1- or 2-piece chemical splash suit; disposable chemical-resistant overalls).
- Gloves, outer, chemical resistant.
- Gloves, inner, chemical resistant.
- Boots, outer, chemical-resistant steel toe and shank.
- Boot-covers, outer, chemical resistant (disposable).
- Face shield.[8]

Level C Protection

Level C is the most common type of PPE used in health care facilities when dealing with contaminated patients. Level C protection should be used when (1) the atmospheric contaminants, liquid splashes, or other direct contact will not adversely affect or be absorbed through any exposed skin, (2) the types of air contaminants have been identified, concentrations measured, and an APR is available that can remove the

Fig. 2. Level B personal protective equipment. (*From* ATSDR. Managing Hazardous Material Incidents (MHMI). Volumes 1, 2, and 3. Agency for Toxic Substances and Disease Registry (ATSDR). Atlanta (GA): U.S. Department of Health and Human Services, Public Health Service; 2001. Available at: http://www.atsdr.cdc.gov/MHMI/index.asp. Accessed July 15, 2014).

contaminants, and (3) all criteria for the use of APRs are met. Level C PPE has generally been agreed to be adequate for most hospital decontamination scenarios, unless specific releases require increased levels of protection.[2,9] Level C PPE is also the recommended PPE for first receivers in a radiation emergency from external or internal contamination in patients being treated; however, no PPE can protect against exposure from high-energy, highly penetrating forms of ionizing radiation (ie, gamma radiation) associated with most radiation emergencies, such as at a nuclear power plant or a radiation therapy source. Level D PPE can be used in postdecontamination areas or if the risk of external contamination is low as recommended by the hospital radiation safety officer (**Fig. 3**).[10]

Level C equipment (to be used as appropriate)

- Full-face or half mask, air-purifying respirators (NIOSH approved).
- Hooded chemical-resistant clothing (chemical splash suit; disposable chemical-resistant overalls).

Fig. 3. Level C personal protective equipment. (*From* ATSDR. Managing Hazardous Material Incidents (MHMI). Volumes 1, 2, and 3. Agency for Toxic Substances and Disease Registry (ATSDR). Atlanta (GA): U.S. Department of Health and Human Services, Public Health Service; 2001. Available at: http://www.atsdr.cdc.gov/MHMI/index.asp. Accessed July 15, 2014).

- Gloves, outer, chemical resistant.
- Gloves, inner, chemical resistant.
- Boots, outer, chemical-resistant steel toe and shank.
- Boot covers, outer, chemical resistant (disposable).
- Face shield.[8]

Level D Protection

Level D protection should be used when (1) the atmosphere contains no known hazard, and (2) work functions preclude splashes, immersion, or the potential for unexpected inhalation of or contact with hazardous levels of any chemicals (**Fig. 4**).

Level D equipment (to be used as appropriate)

- A work uniform affording minimal protection.
- Gloves.
- Boots/shoes, chemical-resistant steel toe and shank.
- Safety glasses or chemical splash goggles.
- Face shield.

Combinations of PPE other than those described for Levels A, B, C, and D may be more appropriate and may be used to provide the proper level of protection.

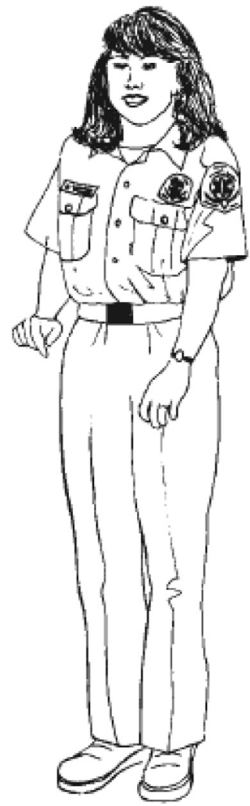

Fig. 4. Level D personal protective equipment. (*From* ATSDR. Managing Hazardous Material Incidents (MHMI). Volumes 1, 2, and 3. Agency for Toxic Substances and Disease Registry (ATSDR). Atlanta (GA): U.S. Department of Health and Human Services, Public Health Service; 2001. Available at: http://www.atsdr.cdc.gov/MHMI/index.asp. Accessed July 15, 2014).

Appropriate PPE for a decontamination team may be determined by consulting reference guidebooks, websites, database networks, telephone hotlines, or a regional Poison Control Center.[8] Appropriate dress for the decontamination team could include:

- A scrub suit
- Plastic shoe covers
- Disposable chemical protective clothing with built-in hood and booties, with hood taped at the neck
- Polyvinyl chloride gloves taped to sleeves
- Respiratory protection, as appropriate
- Multiple layers of surgical gloves, neoprene or disposable nitrile gloves, with the bottom layer taped; should be changed whenever torn; and
- Protective eyewear.[8]

OSHA defined the "Hospital Decontamination Zone" to include "any areas where the type and quantity of hazardous substance is unknown and where contaminated victims, contaminated equipment, or contaminated waste may be present." OSHA further identified 8 specific conditions necessary for hospitals to rely on the OSHA minimum PPE selections.[3]

1. Thorough and complete hazard vulnerability analysis and EMP, which consider community input, have been conducted/developed, and have been updated within the past year.
2. The EMP includes plans to assist the numbers of victims that the community anticipates might seek treatment at this hospital, keeping in mind that the vast majority of victims may self-refer to the nearest hospital.
3. Preparations specified in the EMP have been implemented (eg, employee training, equipment selection, maintenance, and a respiratory protection program).
4. The EMP includes methods for handling the numbers of ambulatory and nonambulatory victims anticipated by the community.
5. The hazardous substance was not released in close proximity to the hospital, and the elapsed time between the victims' exposure and victims' arrival at the hospital exceeds approximately 10 minutes, thereby permitting substantial levels of gases and vapors from volatile substances time to dissipate.
6. Victims' contaminated clothing and possessions are promptly removed and contained (eg, in an approved hazardous waste container that is isolated outdoors), and decontamination is initiated promptly upon arrival at the hospital. Hospital EMP includes shelter, tepid water, soap, privacy, and coverings to promote victim compliance with decontamination procedures.
7. EMP procedures are in place to ensure that contaminated medical waste and waste water do not become a secondary source of employee exposure.
8. The decontamination system and predecontamination victim waiting areas are designed and used in a manner that promotes constant fresh air circulation through the system to limit hazardous substance accumulation. Air exchange from a clean source has been considered in the design of fully enclosed systems (ie, through consultation with a professional engineer or certified industrial hygienist) and air is not recirculated.

The "hospital postdecontamination zone" is defined as an area considered uncontaminated and equipment and personnel are not expected to become contaminated in this area.[3] This zone requires seven conditions which hospital must be met to rely on the OSHA minimum PPE selections:

1. EMP is developed and followed in a way that minimizes the ED personnel's reasonably anticipated contact with contaminated victims (eg, with drills that test communication between the hospital and emergency responders at the incident site to reduce the likelihood of unanticipated victims).
2. Decontamination system (in the hospital decontamination zone) and hospital security can be activated promptly to minimize the chance that victims will enter the ED and contact unprotected staff before decontamination.
3. EMP procedures specify that unannounced victims (once identified as possibly contaminated) disrobe in the appropriate decontamination area (not the ED) and follow hospital decontamination procedures before admission (or readmission) to the ED.
4. Victims in this area were previously decontaminated by a shower with soap and water, including a minimum of 5 minutes under running water. Shower instructions are clearly presented and enforced. Shower facility encourages victim compliance (eg, shelter, tepid water, reasonable degree of privacy).
5. EMP procedures clearly specify actions ED clerks or staff will take if they suspect a patient is contaminated. For example, (1) do not physically contact the patient, (2) immediately notify supervisor and safety officer of possible hospital contamination, and (3) allow qualified personnel to isolate and decontaminate the victim.

6. The EMP requires that, if the ED becomes contaminated, that space is no longer eligible to be considered a hospital postdecontamination zone. Instead, it should be considered contaminated and all employees working in this area should use PPE as described for the hospital decontamination zone.

The US Department of Homeland Security and the US Department of Health and Human Services have posted a draft document regarding national planning guidelines for patient decontamination in a mass chemical exposure incident.[11] Readers are directed to this for further evidence-based analysis of best practices.

When used in conjunction with the *OSHA Best Practices for Hospital-based First Receivers of Victims from Mass Casualty Incidents Involving the Release of Hazardous Substances* the minimum PPE required for the hospital decontamination zone and hospital postdecontamination zone includes the following.

Hospital Decontamination Zone

- PAPR that provides a protection factor of 1000. The respirator must be NIOSH approved.
- Combination 99.97% high-efficiency particulate air/organic vapor/acid gas respirator cartridges (also NIOSH approved).
- Double layer protective gloves.
- Chemical-resistant suit.
- Head covering and eye/face protection (if not part of the respirator).
- Chemical-protective boots.
- Suit openings sealed with tape.

Hospital Postdecontamination Zone

- Normal work clothes and PPE, as necessary, for infection control purposes (eg, gloves, gown, and appropriate respirator).

TRAINING IN THE PROPER USE OF PERSONAL PROTECTIVE EQUIPMENT

Employees performing their duties while wearing PPE should receive training in its proper care and use, including hazards identification, orientation to the equipment, appropriate donning and doffing techniques, proper use, safety issues, and breakthrough times. Employees need to understand the situations in which their equipment can be safely used and those in which it cannot. Potential adverse health effects from the use of PPE include impaired vision, heat stress, dehydration, and impaired balance.[12] Responders in PPE can also be frightening to pediatric patients.[11] Regular drills and exercises "conducted to test emergency preparedness" are required by the Joint Commission that sets standards for accreditation under Emergency Management Standard EC 1.4 (Hick, 2003b).

DECONTAMINATION

Few things can be as anxiety provoking for ED personnel as being notified that a HAZMAT incident has occurred and patients with chemical, biological, or radiologic contamination will be arriving. This can be greatly diminished by educational and training programs concentrating on proper emergency response and frequent drills with mock patients to practice decontamination procedures and patient flow logistics. In this way, the required equipment will be familiar and accessible, and each ED employee will know their expected role in the incident response.

As in all medical conditions, history is the most important part; in the HAZMAT incident, the "history" is the information about the materials involved—the chemicals

involved, numbers and ages of exposed individuals, signs and symptoms being expressed by exposed individuals, and any associated injuries (ie, owing to fire or explosion). Many times, initial responders will know some specifics about the materials, and more information can be obtained from the regional Poison Control Center (PCC):1-800-222-1222. Other resources are listed in the article by Kirk and Iddins elsewhere in this issue.

Generally, plain tepid water is the best solution for decontamination; it is readily available, cheap, and effective.[13] If necessary for non–water-soluble chemicals, addition of mild liquid soap (ie, baby shampoo, body wash) and gentle scrubbing with a soft sponge or cloth can improve removal. However, older recommendations for addition of bleach to solutions because of their purported ability to neutralize nerve agents are no longer current owing to adverse effects that would occur before any neutralization owing to required contact time.[14] Rarely, reactive alkali metals (elemental sodium, elemental potassium) and other chemicals can react violently with water, indicating a need for alternative solutions in these cases. An US Food and Drug Administration–approved Reactive Skin Decontamination Lotion, used for both removal and neutralization of chemical warfare agents (vesicants and organophosphorus nerve agents), has been shown to be superior to water and other conventional solutions for decontamination of these agents.[15] This product is also available in soaked pads for the decontamination of a small area. Another commercially available solution, Diphoterine, has been shown to be efficacious as well, especially for chemical splashes to the eyes.[16,17] Finally, easyDECON spray foam has been used to decontaminate the US Senate of anthrax spores, and is approved for HAZMAT and military applications, but it is only for decontamination of equipment and rooms, and so on, and is not to be used on patients for personal decontamination.[18] Some of these commercial solutions, because of their ability to neutralize or bind a chemical as well as remove it, may be preferable to outdoor water showering in very cold weather areas.

Several strategies should be used to determine which patients need decontamination, and can help to rank the priority for decontamination in a mass casualty incident. Factors to consider include the presence of the expected signs and symptoms of exposure to the particular chemical involved (ie, the "toxidrome"; see the article by Tomassoni et al elsewhere in this issue), obvious visible contamination on the person or their clothing, and the victim's geographic proximity to the release or spill.

Experience from the Tokyo Subway sarin gas attack in 1995 showed that many more patients present to the ED on their own accord, rather than the numbers brought by EMS. EDs must be prepared for this by having a plan in place to avoid having contaminated patients present unannounced and enter the ED without proper decontamination, possibly leading to contamination of the entire ED, forcing evacuation and creating an inability to use the facilities for patient care. Security personnel should be trained to recognize this possibility, and a staging area outdoors should be set up to receive and decontaminate these patients. One option would be to have a local fire department or HAZMAT team not at the HAZMAT incident site respond to the ED and set up triage and decontamination stations outside the ED. These details need to be worked out in the planning drills and practice scenarios, as described.

DECONTAMINATION AREA PREPARATION

All patients received from the chemical HAZMAT incident should be considered contaminated until proven otherwise, and therefore need to be decontaminated before entry into the ED. If the logistics or the weather requires transfer of victims from the ED to an indoor decontamination area, proper protection and isolation

from the rest of the hospital must be ensured (such as plastic or paper taping of floors, covering/masking of handles, knobs, switches). The size of the decontamination area needed depends on the number of expected victims, and must be set up to accommodate that patient flow as well as the necessary ED staff and equipment. The preplanning stages and practice drills in advance of a true HAZMAT emergency will help to identify the logistics of what indoor area can serve this purpose, which must have a separate exhaust ventilation system that does not mix with the general hospital air handling system. For these reasons, outdoor areas such as ambulance entranceways to the ED are usually preferred sites for decontamination stations.[8]

EDs must also prepare for the many minimally exposed patients who arrive on their own and may not need full decontamination. An area for triage decisions regarding who needs to be decontaminated must therefore be available. Many of the "worried well" who present to EDs after HAZMAT incidents will have had exposure only to odors, gases, or vapors, and will not need decontamination.

Portable decontamination systems can be as simple as plastic garbage bags for sealing of contaminated clothing, handheld shower nozzles supplied by hoses, and showering patients who stand in portable plastic wading pools. These can be assembled and stored easily and cheaply in advance of an incident. Portable patient screens or similar visual barriers can be erected for privacy. More sophisticated, commercially available tents and decontamination systems are available.

CONTAMINATED PATIENT ENTRY

A properly trained and knowledgeable physician or nurse, wearing appropriate PPE, should perform triage upon arrival of ambulance patients to both assess patient condition as well as the degree of chemical or radiologic contamination and the need for decontamination. This initial evaluation involves removing clothing and jewelry and wiping or vacuuming away visible contamination.

Ideally, decontamination would be performed before patient transport from a HAZMAT site; however, the ability to decontaminate at the site might be limited, and all HAZMAT victims should be considered contaminated until proven otherwise (ie, only gas exposure has occurred or EMS confirms that the patient has been decontaminated). If a patient's clothing was not removed at the incident site, it should be removed before entry into the ED. This reduces further exposure to the patient and lessen the extent of contamination introduced into the ED. Contaminated clothing should be double bagged in plastic bags, sealed, and labeled. The decontamination team should bring the prepared stretcher to the ambulance, transfer the patient, and take him or her directly to the decontamination area along the predesignated route.[8]

Priority should be given to the fundamentals of emergency treatment: airway, breathing, and circulation (ABCs) simultaneous with contamination reduction by personnel in Level C PPE. Once life-threatening matters have been addressed, ED personnel can then direct their attention to thorough decontamination and thorough patient assessment. Appropriate PPE must be worn until it is deemed ED personnel are no longer at risk of secondary contamination.[8]

DECONTAMINATION PROCEDURES

Decontamination serves 2 roles: It prevents further absorption of or injury from the chemical in question, and protects the health care worker from suffering injury from exposure to a contaminated patient. This cannot be emphasized enough, because secondary contamination resulting in adverse health effects in first responders and in health care workers caring for HAZMAT victims has been reported frequently in

the literature.[19–26] In addition, proper decontamination prevents off-gassing of chemicals from contaminated patients that can contaminate the hospital and render the ED inoperable.[20,25,27]

There is always the temptation to begin treatment to contaminated victims who arrive in extremis, without decontaminating the victim. However, this must be avoided unless proper protections are in place, because the first priority must be to keep the health care worker safe from becoming ill owing to secondary contamination. ABCs and emergency treatment should be performed only by ED personnel wearing appropriate PPE, and includes securing the airway, spinal precautions, controlling exsanguinating bleeding (by tourniquet or direct pressure), and use of premixed antidote autoinjectors in the case of nerve agent poisoning. Decontamination should then proceed and standard emergency care performed after decontamination has been completed.

Many patients arriving from a HAZMAT site will already have had their clothing removed by EMS personnel and already gone through decontamination procedures; they will not need to undergo repeat decontamination and can proceed directly into the ED for definitive examination and treatment.

Patients may arrive from a HAZMAT incident on foot or by private vehicle who have not undergone decontamination, and must be assumed to be contaminated. In these cases, simply removing a patient's clothing effectively removes significant portions of the contamination. Decontamination still needs to be performed, because exposed areas not covered by clothing and areas where chemicals have soaked through need to be removed.

The discussion herein of decontamination assumes victims are contaminated with liquid chemicals. However, some HAZMAT incidents may involve discharge of solid particles or powders, and many HAZMAT incidents involve only gases. Solid particles or dusts can be removed by vacuuming; battery-operated portable vacuums allow this to occur outdoors independent of power cords. In the case of exposures to gases, most victims will simply need removal from the source of the gas, and decontamination is not necessary. In instances where victims have been exposed to high concentrations of a highly water-soluble gas (eg, anhydrous ammonia), rinsing of eyes and mucous membranes may need to be performed if there is evidence of conjunctival injection or complaints of eyes burning. Rarely, high concentrations of highly water soluble gases or acid mists can also cause skin burning sensation, and therefore exposed skin should be washed in these cases.

Because most decontamination of ambulatory personnel will be in showers, decontamination with soap and water should begin with the head and proceed downward. Injury to the eyes and mucous membranes can be most devastating, and special attention should be directed to the eyes and any open wounds. Full-body showering with the soap and water, including hair, axilla, skin folds, and genital/buttocks area, effectively decontaminates the ambulatory HAZMAT victims. Supervision by same-gender hospital personnel must ensure victims do not neglect areas such as hands, feet, nails, and so on.

Generally, copious, tepid water flow adequately decontaminates most chemicals. The addition of a mild soap enhances removal of oily or non–water-soluble chemicals. Care must be made to not injure or abrade skin that may enhance absorption. This is especially true with elderly patients and young children. Also, a child's larger surface area to weight ratio allows a greater chance of systemic absorption of skin contaminants. All water run-off from the decontamination process should be collected for proper disposal and not allowed to contaminate local sewer systems.

In the nonambulatory HAZMAT victim who has suffered injuries, decontamination must proceed on a suitably designed decontamination stretcher with a surface sloped from head to toe. This allows the run-off to funnel into a drain nozzle to be captured in a drum for appropriate disposal.

Open wounds should be irrigated with copious amounts of physiologic solutions such as normal saline or Lactated ringers (plain water, being nonisotonic, can cause cellular swelling and tissue injury, but decontamination should proceed with plain water if sufficient isotonic solutions are not immediately available).

After open wounds, decontamination of the eyes and mucous membranes of the face should be undertaken next. Washing the eyes with isotonic saline is the preferred method. A frequently employed method involves attaching an oxygen nasal cannula to an IV line, and placing the cannula prongs over the bridge of the nose, directing 1 prong over the medial aspect of each eye. This allows irrigation fluid to proceed from medial to lateral, washing chemicals away from the nasal lacrimal duct. Irrigation and suctioning may be necessary for nasal and otic contamination. Moving down the body in a rostral–caudal direction, special attention must be directed toward skin fold areas such as neck, axilla, antecubital fossae, groin, popliteal region, and hands and feet. Commonly ignored or missed areas in skin decontamination are hairy areas (scalp, axillae, genitalia), skin creases and folds, and hands and feet, especially nails. Full inspection of the patient's body, including rolling the patient over to inspect the back, should be performed to ensure complete decontamination has occurred.

Decontamination of young children can be especially problematic, owing to their fear of the unknown. Families should be kept together for decontamination whenever possible. Alternatively, a nurse or attendant must stay with the child at all times for reassurance.[28]

After completion of decontamination, the victim will need to exit the decontamination area without recontamination and without spreading contamination. Once transferred to a clean area from the decontamination area, standard ED management of the patient's conditions can proceed, with hospital admission as indicated. Generally, the asymptomatic patient can be discharged home, providing no late effects from the chemical exposure are expected.

DECONTAMINATION AFTER RADIOLOGIC INCIDENTS

Radiologic contamination can occur as a result of a nuclear reactor accident, detonation of a thermonuclear weapon, or detonation of a radiologic dispersion device (or "dirty bomb"). Depending on the type of accident (unshielded fission vs coolant failure and meltdown/explosion) exposures at a nuclear reactor incident can be restricted to penetrating high-energy radiation (ie, gamma rays) in the case of unshielded fission exposure, or exposure can involve both high-energy waves and radionuclide particles in the case of a meltdown or explosion. Victims in the first scenario would not need decontamination, but the second would. This is why an accurate history of the incident is critical to offering efficient and effective response. By contrast, nuclear weapons involve fallout, and the very nature of an radiologic dispersion device (radionuclides placed in or on a conventional explosive such as dynamite, and exploded with the intent to disperse radioactive particles over a designated target site) will involve radiologic contamination of victims.

Health care facilities routinely involved with drills and emergency response to a local nuclear facility will often have a supply of PPE that is designated for radiation decontamination known as "Anti-C's". However, standard Level C PPE, like that described herein for chemical decontamination, is also acceptable PPE to be utilized to avoid

exposure and contamination of health care workers when caring for victims of a radiologic disaster. Like chemically exposed patients, those without life- or limb-threatening injuries should be appropriately decontaminated before ED entry.

The sequence for chemical decontamination outlined herein should also be used for the radiologically contaminated victim: Removal of clothing and jewelry (and double bagging and sealing them), followed by showering with water at high volume with low pressure, with gentle scrubbing as needed, in a rostral–caudal direction. As long as ED personnel are wearing proper PPE (Level D or C), emergent attention to the ABCs can proceed, followed by decontamination. After decontamination, standard medical care and full patient surveys can proceed.[29] The bagged belongings and wash run-off need special considerations for storage and disposal, however, owing to the radioactivity. Open wounds need special attention with radionuclide exposures, especially with alpha emitters, because once they are internalized, these isotopes have a greater potential to cause adverse health effects than gamma or beta emitters (see the article by Kazzi et al, elsewhere in this issue).

It is posited that most patients in the radiologic contamination scenarios will not have heavy enough radiation contamination from radionuclides to place health care workers at a significant health risk from their brief exposures to these patients when encountered before decontamination. Unless heavy, generalized radiologic contamination is demonstrated by Geiger–Müller surveys, most victims can be safely spot decontaminated by health care workers in level D PPE. Only the most heavily contaminated patients require full-body decontamination by health care workers using Level C PPE. Workers must also be reminded that victims of acute radiation sickness owing to massive gamma irradiation are not themselves radioactive and do not pose any risk to caregivers (just like a patient receiving radiation therapy for cancer is not a radiation risk to others). Only patients contaminated by radioisotopes pose a secondary contamination risk to ED staff. Radiation detectors (Geiger–Müller meters and similar devices), which are usually available in most hospitals that perform nuclear medicine studies, can be used to ensure proper decontamination of radionuclides from a patient, a luxury that is not available to ensure complete decontamination from a chemical spill.

SUMMARY

Accurate identification of the chemicals substances involved is the most important information necessary for proper care of the HAZMAT incident, but is often not available initially. Protection of the health and safety of the health care worker and maintaining the integrity of the hospital and ED must be the first priority in a HAZMAT incident, and is in the best interest in public health, to be able to properly care for the expected victims. Decontamination for both chemical and nuclear HAZMAT incidents are handled in a similar fashion by hospital personnel: Level C PPE is sufficient for worker protection, and decontamination using high-flow, low-pressure, tepid water, with a mild liquid soap if needed, washing from head to toe. Wounds and eyes should be decontaminated with physiologic solutions, and special attention must be directed to hairy areas and skin folds and hands and feet. Containment of run-off water must be assured, because this is considered hazardous waste. Emergent management of life- and limb-threatening conditions must only be performed by health care workers in proper PPE; once full decontamination is completed, standard evaluation and treatment can begin. Efficient patient flow will occur when proper protocols are followed and mock-up scenarios and drills have been practiced regularly by appropriate staff.

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