inhaled chemical that continues to produce fumes or vapors (sodium azide) requires full respiratory protective equipment, whereas a patient exposed to a highly toxic inhaled chemical such as carbon monoxide requires no protection for ED personnel.

Patient Management

Patients from hazardous materials incidents may have one or a combination of the following: (1) chemical burns; (2) respiratory effects of inhaled toxins; (3) systemic effects; (4) trauma; (5) hysteria; and (6) contamination without apparent injury.[14]

Triaging Patients

Triage is the sorting of patients, based on the likelihood of survival given the resources available.[39, 90] The duty to one person is abandoned in favor of stabilizing many.[22, 64, 90] The initial triage decision focuses on the urgency and extent of decontamination in relation to treating life-threatening problems. Chemical identification and knowledge of human health risks will help with triage decisions. When the risk of toxicity and the likelihood of producing secondary contamination is low, urgent medical problems should be treated simultaneously with decontamination. The more toxic the substance, the more urgently decontamination should proceed.[91] A tremendous commitment of resources (personnel and supplies) may be required for decontamination. To use limited resources effectively, less seriously ill patients (even asymptomatic patients) may take priority over those more critically ill when contaminated with a highly toxic chemical.

Because of decontamination efforts at the scene, "load and go" transport is unlikely to occur. Instead, transport is likely to be delayed, resulting in critically ill patients not receiving treatment for long periods of time. On the other hand, improperly trained prehospital care providers or an overwhelmed EMS system may transport patients prematurely to the hospital prior to adequate decontamination, thus risking secondary contamination of themselves and ED staff.[55]

After decontamination decisions, triage should proceed as with any other mass casualty incident, concentrating on the ABCs.[39] However, thorough patient assessment, vital signs, and appropriate triage may be unreliable because vision and dexterity are impaired in full protective gear.[11, 32, 39, 42, 43, 97]

A wave of unannounced, noncritical patients arriving at the hospital is typical of many disasters.[90] All contaminated patients should be placed in a secure area until decontaminated. Those patients found to not need urgent treatment must be periodically reassessed because delayed toxic effects may occur.

Decontamination

The objectives of decontamination are to terminate exposure to toxins and to prevent secondary contamination. Toxic chemicals cause injury when inhaled or absorbed through the skin, open wounds, or mucous membranes. Airborne toxins account for most exposures in Haz-Mat incidents, and removal from the source may be all that is necessary to prevent further exposure.[91] Exposure to an inhaled toxin (e.g., carbon monoxide or arsine gas) typically poses little risk for secondary contamination, and decontamination is not required. However, toxic plumes may contain aerosolized chemicals, gases, or vapors that can condense on skin or clothing.[30] Skin irritation, burns, or deposits of liquid and solid materials on skin and clothing are clues to the presence of hazardous materials requiring decontamination.

Although data regarding decontamination is limited, principles of management can be found in military chemical battlefield studies and radiation accident protocols [54, 72, 76] Military doctrine suggests that decontamination occur as close to the site of exposure as possible to limit the spread of toxic agents and the delay to treatment.[15] In a Haz-Mat incident, decontamination is *always* best performed in the prehospital setting. A patient's condition is rarely too unstable to prohibit clothing removal and a brief decontamination performed in the field.

Decontamination should occur outside the ED unless a preplanned hospital protocol has been established. Contaminated patients must always be decontaminated before entry into the main emergency department. For many EDs it is most practical to perform decontamination outside. An expenditure of large amounts of money is not necessary for the safe, efficient management of patients. Provisions for inclement weather, lighting, privacy, and dealing with run-off must be considered with outside decontamination. Portable curtains will provide privacy. A warm water supply or a specially designed van or trailer are necessary for outdoor decontamination in cold climates. Portable decontamination stretchers allow for simultaneous decontamination and resuscitation, and containment tanks collect the effluent. Portable wading pools are an inexpensive means of containment for ambulatory patients.

Decontamination may occur inside the hospital in specially designed facilities equipped with a separate ventilation system that provides adequate air flow.[26] Air return from this room must never enter the hospital. Many specialized sites have floor drains leading to holding tanks that are easily accessed by contractors for toxin removal. An indoor decontamination area and used equipment may be returned to usual operation after inspection by an occupational hygienist.

Chemicals in contact with a patient's skin are analogous to unextinguished flames. Urgent steps are necessary to stop continual exposure. As long as a chemical remains in contact with the skin, the toxicity may potentially be worsening through direct injury as well as systemic absorption. Some toxins, such as caustics and solvents, directly damage the structural integrity of the skin, while other toxins (e.g., pesticides, hydrogen fluoride, and methemoglobin inducers) penetrate tissues, enter the circulation and cause systemic toxic effects.[37, 68, 79, 86] The duration of skin contact, concentration, surface area of contact, and physicochemical characteristics of the toxin determine the extent of injury and systemic absorption. Preexisting skin conditions may decrease the protective barrier effect of skin and allow enhanced absorption of toxic chemicals.[93, 94] Copious water irrigation will dilute a chemical and decrease its duration of contact with a patient's skin. Copious water irrigation within minutes of exposure, and definitely within the first hour, following a chemical burn is crucial in reducing direct corrosive effects (incidence of full thickness burns) and systemic toxic effects.[19, 31, 34, 50, 65] Associated ocular injuries are common with chemical burns.[10, 67, 75]

To reduce confusion and avoid delays, a universal substances decontamination protocol that is not specific for any chemical should be developed (Table 6).[49] Basic principles for decontamination of radiation exposures can be adapted to chemical decontamination.[49, 54] Contaminated clothing is a source of primary and secondary contamination and can enhance toxin absorption by acting as an occlusive dressing.[94] The removal of clothing will eliminate large amounts of contaminants. Once removed, the clothing should be placed in a plastic bag and handled as hazardous waste.[18] Any liquid or solid material on skin or clothing

Table 6. SUGGESTED DECONTAMINATION PROCEDURE

Establish "hot zone"
Don protective equipment
Assess and treat life-threatening conditions
Remove clothing and place in plastic bag
Remove solid or dry chemicals by gently scraping or brushing
Irrigate with copious, low pressure water*
Prioritize areas to be decontaminated
Contaminated wounds
Eyes
Mucous membranes
Skin and hair
Gently wash with soap or mild detergent
Contain water run-off
Determine toxin and use specific therapies if available
Decontaminate personnel and equipment

*Exceptions to water irrigation: elemental sodium, potassium, lithium, and magnesium.

should be removed promptly Prioritize decontamination to begin with the cleansing of contaminated wounds followed by the eyes, mucous membranes, skin, and hair. Emphasis should be placed on prompt first aid for the eyes including copious water irrigation and removal of contact lenses.[19, 58, 71] Copious, low-pressure, water irrigation is the initial approach for removal of nearly all toxins from the skin. A mild soap and gentle washing may aid removal of contaminants. Avoid hot water, strong detergents, stiff brushes, or vigorous scrubbing because the resulting vasodilation and skin abrasion may enhance toxin absorption.[93, 94] Do not allow irrigation runoff to contaminate clean skin. Occasionally detergents, dilute bleach, corn meal, or specific neutralizing agents may be recommended. Copious water irrigation should never be delayed searching for these additional agents. *If a patient cannot be safely decontaminated with available hospital resources, no protocol exists for decontamination, or decontamination procedures are unfamiliar to the ED staff, then the assistance of the fire department and Regional Poison Center should be sought.*

The physician will often not know "How clean is clean?" and will be forced to judge the effectiveness of decontamination without the benefit of objective criteria. Studies suggest that copious water irrigation and soap cleansing are highly effective in removing many chemical contaminants.[10, 13, 34, 52, 94] An animal model demonstrated that detergent and/or water removed a significant amount of dermal contaminants.[13] Lavoie and associates[49] evaluated the efficacy of a modified radiation decontamination protocol on chemically contaminated ED patients. Patients were swabbed before and again after decontamination (detergent/cornmeal wash of the skin followed by skin, eye, and oral mucosal water irrigation). The predecontamination skin swabs showed contamination of 10 patients, and all had negative swab analysis after cleansing and irrigation. The skin's stratum corneum is the protective barrier against penetration of many chemicals. Soap and water cleansing may mechanically remove the stratum corneum's upper layers where many chemicals are deposited.[93] Unfortunately, others have shown that those toxins penetrating the skin rapidly, such as pesticides, may be incompletely removed by washing.[28, 31, 94]

A few dermal toxins require special attention. An exception to irrigating with water is contamination with elemental metals (e.g., sodium, lithium). These metals explode on contact with water and should be covered with mineral oil before removal. Phenol is best removed with 200- to 400-molecular-weight polyethylene glycol or isopropanol.[12, 67] Small amounts of water can increase the dermal absorption of phenol, and "deluge" quantities of water are required when polyethylene glycol is not available. Hexavalent chromium should be treated with topical ascorbic acid to promote reduction to the trivalent (less toxic) state. White phosphorous will fume or flame spontaneously on contact with air.[46, 67] Therefore, before debridement the material should be covered with moistened gauze. Examination with a Wood's lamp will allow visualization of phosphorous in tissues. Copper sulfate irrigation will help visualize phosphorous within wounds. It should be avoided because it provides little benefit over a Wood's lamp examination and risks causing copper toxicity.

Medical Management for Hazardous Materials Toxicity

After decontamination, treatment of victims exposed to hazardous materials primarily involves symptomatic and supportive care. Close attention must be given to the airway, breathing, and circulation. Antidotes are useful in a minority of chemical exposures, such as cyanide or chemicals that induce methemoglobinemia (Table 7). Early endotracheal intubation is recommended in the presence of upper airway edema, central nervous system depression, hypoxia, hypoventilation, or excessive bronchial secretions. Administering supplemental oxygen is important because many hazardous materials can produce hypoxia. Hypotension should initially be treated with crystalloid fluids. Invasive monitoring should be considered when vigorous fluid resuscitation is required because many toxins have the potential to cause the adult respiratory distress syndrome. Vasopressors and inotropes are indicated after optimizing the intravascular volume status. Close attention must be given to possible concomitant trauma and other medical illnesses.

Acute pulmonary injury can occur along any part of the respiratory tract. Tracheobronchitis should be treated with beta-adrenergic agonist bronchodilators, frequent suctioning, and chest physical therapy. Parenchymal injury is best managed with oxygen, positive end-expiratory pressure, and avoidance of overhydration. Regarding the use of glucocorticosteroids, insufficient data exist to

Table 7. EXAMPLES OF ANTIDOTES FOR HAZ-MAT EXPOSURES AND SPECIFIC THERAPY FOR CUTANEOUS EXPOSURE

Haz-Mat Exposure	
Antidote	Toxin
Lilly Cyanide Antidote Kit	Cyanide
Oxygen/Hyperbaric Oxygen	Carbon Monoxide
Methylene Blue	Methemoglobin Inducers
Atropine/Pralidoxime	Organophosphates/Carbamates
Calcium	Hydrofluoric Acid
Chelators (BAL, DMSA, EDTA)	Heavy Metals (Lead, Mercury, Arsenic)
Specific Therapy for Cutaneous Exposure	
Treatment	Toxin
Ascorbic Acid	Chromium
Polyethylene Glycol/Isopropanol	Phenol
Moistened Gauze	White Phosphorus
Mineral Oil	Elemental Metals (e.g., Lithium, Sodium)
Calcium	Hydrofluoric Acid

support a beneficial effect on either upper airway or alveolar injury. Their use may be associated with an increased risk of pneumonia which is the most common late sequelae.[66] Thus, glucocorticosteroids should not be used in this setting. Likewise, there is no role for prophylactic antibiotics.

A limited number of antidotes are very effective in reversing specific intoxications. The cholinergic effects of organophosphate and carbamate insecticides are treated with atropine and pralidoxime. Respiratory failure secondary to bronchorrhea and hypoventilation is a common cause of death. Early intubation and the administration of high flow oxygen are essential, and atropine is titrated to dry pulmonary secretions. A dose of 1 to 2 mg (0.05 mg/kg pediatric dose) may be administered every 10 to 15 minutes until pulmonary secretions are dry.[85] Pralidoxime (2-PAM) should be administered in all patients treated with atropine. This drug reactivates acetylcholinesterase and acts synergistically with atropine to reverse the clinical effects of poisoning. The initial intravenous dose is 1 to 2 g (25 to 50 mg/kg pediatric dose).[85] Severe cases should be managed with repetative doses or may require a continuous infusion of 500 mg per hour.[27, 87] 2-PAM should be given early in the clinical course but may be effective if administered 48 hours or longer after exposure.[61] Therapy is based on clinical findings and must never be delayed pending serum cholinesterase analysis.

Many hazardous chemicals, such as chlorates, dinitrophenol, and nitrogen oxide, cause methemoglobinemia.[20, 35] Methemoglobin does not carry oxygen and thus interferes with oxygen delivery to tissues. A variety of central nervous system and cardiovascular symptoms develop depending on the methemoglobin concentration and the patient's underlying medical condition. Clinical symptoms or a methemoglobin level greater than 30% are indications for treatment.[20, 35] A 1% solution of methylene blue is given intravenously at a dose of 0.1 to 0.2 mL/kg (1 to 2 mg/kg) and may be repeated if symptoms persist. Methylene blue accelerates the efficient transfer of electrons from NADPH to ferric iron in the methemoglobin molecule, reducing it to hemoglobin.

The Lily cyanide antidote kit contains amyl nitrite pearls, sodium nitrite, and sodium thiosulfate for the treatment of cyanide toxicity. The generation of cyanomethemoglobin frees the electron transport chain and restores oxidative phosphorylation.[92] Cyanide is then slowly liberated and reacts with thiosulfate to form thiocyanate which is renally eliminated. Nitrites are potent vasodilators and must be infused slowly with close hemodynamic monitoring. Sodium thiosulfate has no significant toxicity and should be given early to all patients suspected of cyanide toxicity.

Calcium gluconate is an antidote for hydrofluoric acid (HF) exposure. HF is a corrosive that causes systemic and local toxicity through its strong affinity for calcium and magnesium ions. Concentrated HF exposure can be associated with profound hypocalcemia and rapid hemodynamic compromise.[68, 86] Intravenous calcium should be administered early in these cases to control arrhythmias and shock. Dilute HF (<20%) typically causes delayed pain and tissue injury which may present greater than 24 hours after exposure. Topical application of a 2.5% calcium gluconate gel and parenteral narcotics constitute the initial management of dermal injury. If this fails to relieve pain, calcium gluconate can be infiltrated into the wounds (except fingertips) at 0.5 mL/cm.[2] Severe hand wounds are best managed with an intraarterial infusion of calcium gluconate (10 mL of 10% solution mixed with 40 mL of 5% dextrose and infused over 4 hours) until the pain is resolved.[77, 88] If pain persists, the infusion should be repeated.

Special Risks to Rescue Personnel

In addition to the risk of secondary contamination, rescuers may be at risk for other injuries. Depending on ambient temperature and the physical condition of the rescuer, life-threatening heat illness can occur quickly when personnel are in fully encapsulated protective equipment.[16, 45] Traumatic injuries may occur during rescue operations. In addition to traumatic injuries, accidental disruption of the protective suit or respirator malfunction may lead to serious contamination. Psychologic stress may play a role in rescuer illnesses.[32, 78, 80] Rescue workers exposed to the toxin(s) also need debriefing sessions addressing such concerns.[5, 24, 25, 84]

PLANNING A HAZ-MAT RESPONSE

Planning a Haz-Mat response ideally should occur before any incident. Attempting to manage a Haz-Mat incident with minimal preparation and planning may prove disastrous. Unfortunately, most communities are only motivated to plan for disasters after an incident captures everyone's attention.[47] A recent Haz-Mat incident is an opportunity to motivate others to begin planning for the next one, but why wait?

Emergency physicians should view themselves as community leaders and recognize that their unique training and experience can make significant contributions to a community's preparedness plan. Federal law (Superfund Amendment and Reauthorization Act -SARA Title III) directs Local Emergency Planning Committees (LEPCs) to develop community response plans for Haz-Mat incidents. Joining the LEPC is an excellent way for an emergency physician to become involved in community planning. Surprisingly, a recent survey showed that most ED directors had never heard of SARA or LEPC, illustrating the need for Haz-Mat education and training in emergency medicine.[47] Prehospital planning and ED protocols for responding to chemical contamination require physician input. Detailed guidelines for prehospital and ED planning are discussed elsewhere.[2, 52, 70]

The goals for response planning from a medical standpoint should include the following: (1) assessing community risks to predict the most likely events; (2) teaching the public about potential risks; (3) planning a coordinated emergency response; and (4) testing the plan to better prepare for the future.[2, 60]

Effective planning requires one to "know the enemy." An investigation (risk assessment) of the types and amounts of chemicals in the community will help planners prepare for the most probable incident.[2, 6, 52] "Community Right-to-Know" laws allow the public access to information about chemicals stored in the community.[38, 53] Community risk assessment must include an inventory of chemicals from fixed facilities; railroad, highway, and water transportation routes; and airports. This information allows education of the public to potential risks and allows advanced preparation and training of EMS and hospital personnel.[58] Finally, this information can be used to estimate adequate amounts of antidotes necessary to meet the immediate needs of multiple casualties. Unfortunately, a plan must always prepare for the unknown because illegal storage and dumping of toxic materials will provide a constant element of uncertainty.

A coordinated response between all participating agencies is essential to an effective Haz-Mat response plan.[21] Organizations unfamiliar with each other will be forced to work together during a response. Medical disaster response planners must realize that medical care is only one mission of the many agencies involved in a response. The Incident Command System (ICS) for a community should be incorporated into a Haz-Mat response plan. A response plan must focus on managing information and resources. Mass evacuation contingency plans must be included.[41, 51] The plan must outline whom to contact for assistance and additional resources.

Communities with more than one hospital should designate a single health care facility to specialize in the care of chemically contaminated patients. A hospital designated to receive patients exposed to Haz-Mat should ideally have physicians skilled in emergency medicine, trauma and burn surgery, critical care, and pediatrics. Close communication with a medical toxicologist is essential. Regular didactic sessions for all members of the team (physicians and medical support services) should review the mechanisms of disease, protocols, and new advances in treatment. Other hospitals should play a supportive role in a Haz-Mat disaster; however, all hospitals should be prepared to receive contaminated patients if the designated hospital is overwhelmed with victims.

A Regional Poison Center can be effectively integrated into the response plan as an information management resource.[44, 69, 74, 89] An important principle of disaster management is assigning tasks to personnel which are similar to their usual daily routines.[90] Because Regional Poison Centers are 24-hour-a-day information resources, they can function to coordinate medical information flow for all agencies involved in the emergency medical response (Fig. 2). The Poison Center can help in chemical identification and provide information on the number of patients, advance notice of patient arrival, toxicity data, and specific decontamination and treatment recommendations to the scene and to local hospitals. Additionally, the Poison Center can function as a toxicologic information source to the media and public to ensure accurate information regarding the toxicity of chemicals. After the incident, the Poison Center can assist public health agencies in long term care and follow-up of patients.[44, 96]

Representatives from industry must take part in the design of the Haz-Mat plan for the community and hospital. Gaining the cooperation of industry before an incident is vital to facilitate an exchange of information. Industries may also serve as potential sources of funding for Haz-Mat preparations.

An annual drill must focus on common toxins in the community and include all agencies involved in the response plan.[48] Analysis of the plan following an incident or drill will pinpoint problems which require revision.[3] A written plan is an ongoing project which requires continual refinement and practice.[3]

Complying With the Law

Several federal mandates are important to ED personnel. The Hazard Communication Standard (Occupational Safety and Health Act [OSHA], 29 US Code, Section 654 Supp 1989) states that every worker has the right to be protected from potential work-related hazards. Other standards (29 Code of Federal Regulations, Section 1910.132, 1988) regulate the safety and health of any employee who responds to hazardous substances emergencies. Additionally, SARA title III requires training programs for local emergency response and medical personnel and training standards have been adopted by OSHA and EPA for those employees responding to hazardous waste/materials emergency incidents. Currently the effect of these laws on ED staff are unclear because most were written for emergency response or hazardous waste cleanup employees.[33] The well-being of all employees should be the ultimate goal of all policies and procedures concerning a hospital plan for a Haz-Mat response. At the very least, these federal

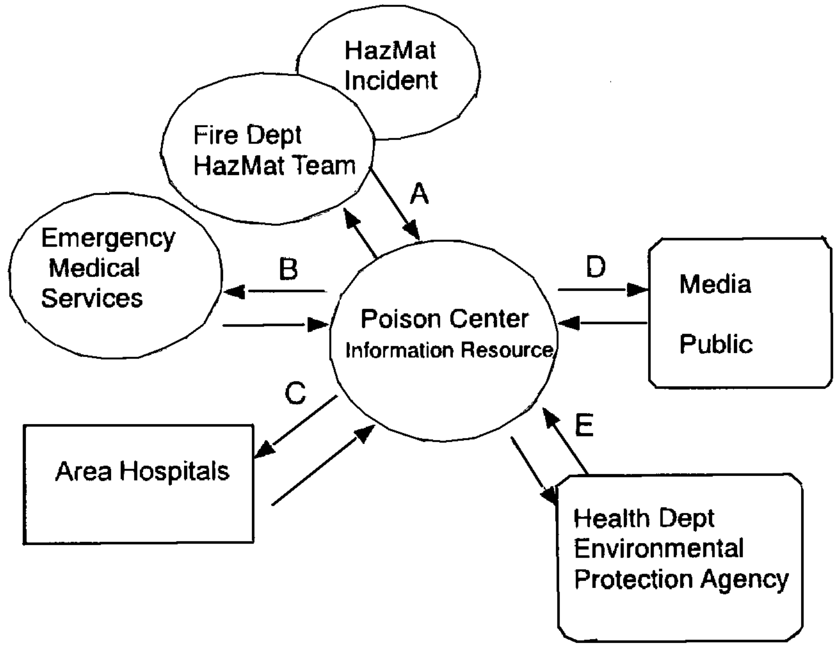

Figure 2. Role of the Regional Poison Center in Haz-Mat Response. Arrows illustrate the flow of information. *A*, Data from scene relayed to Poison Center (PC) to attempt chemical identification. PC provides data to scene about proper protective equipment, decontamination procedures, and evacuation recommendations. *B*, Paramedics report observed symptoms that may identify a toxidrome and provide clues to chemical identification. Treatment and decontamination recommendations can be given to on-scene treatment areas. *C*, Area hospitals can receive advanced notice of patients, expected symptoms, treatment recommendations, and sources of antidote supplies. Hospitals provide PC with observed toxic effects and patient information database. *D*, Accurate and timely information can be given to the public and media. Health care providers can delegate responsibility of media attention to PC. Allows timely response to public concerns and rumors. *E*, After an incident, the PC can advise public health officials of long-term effects, pregnancy risks, food and water contamination, and collect data for research and follow-up.

requirements should serve as guidelines for ensuring the safest environment for those employees involved in the care of chemically contaminated patients.

Ideally, hospitals should identify a core group of workers who are trained to use respiratory protection and who function as a team when the hospital receives chemically contaminated patients. Trained personnel for these teams must be available 24 hours a day. If specialized personal protection equipment such as encapsulated suits or respirators are to be used, each person must be fitted and trained in the proper use of this equipment.[2]

CONCLUSION

Advanced planning is essential to adequately respond to Haz-Mat incidents. The plan should prepare for likely events and emphasize management of information and resources. Regional Poison Centers should be used as an information resource during a Haz-Mat incident. Most important, advanced planning promotes familiarity between agencies that will work together during a Haz-Mat response. The underlying theme of all planning and policies is to do the greatest good for the greatest number without placing the staff or the facility, and ultimately the patients at risk of harm.

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