Injuries Caused by Hazardous Materials Accidents

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Study objective: To describe exposures that prehospital and ED personnel may encounter as a result of hazardous material incidents.

Methods: Retrospective analysis of hazardous material incident reports from six district hazardous material teams in Massachusetts from their inception through May 1996.

Results: The chemicals most frequently involved were various hydrocarbons and corrosive materials. Chlorine derivatives were involved in 18% of all incidents and 23% of all incidents resulting in victims. Victims were produced by 47 of 162 (29%) incidents. Respiratory exposures were the most frequent type of exposure and resulted in the largest number of victims transported to a hospital. Overall 24 of 26 (92%) incidents with chemical exposures resulted in symptomatic victims and 33 of 35 (94%) incidents produced victims requiring hospital transport. Respiratory symptoms were the most frequent, both in the number of incidents where they were observed and the total number of victims with symptoms.

Conclusion: Multiple victim transport to EDs from a single hazardous material incident is most likely to result from an inhalation exposure to a respiratory irritant. Information from descriptive studies should allow improved preparation for potential hazardous material victims.

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INTRODUCTION

Hazardous materials are defined as substances that are potentially toxic to living systems.[1] Human health effects associated with hazardous material releases are well known from such examples as Bhopal, India; Seveso, Italy; and Chernobyl in the former Soviet Union,[2] as well as the recent Tokyo subway sarin attack.[3] Many reviews have emphasized the need for emergency community and medical preparedness to minimize the adverse consequences of such incidents.[1,4-9] Recent articles in the *Annals* have discussed the use of materials safety data sheets as a clinical resource,[10] preparedness for chemical terrorism,[11] and presented the results of chemical exposures to emergency personnel generated during simulated patient decontaminations.[12]

On the other hand, relatively few studies have investigated hazardous material incidents in a systematic fashion.[13-17] We report hazardous material responses by six district hazardous material firefighter teams in Massachusetts from their inception through May 1996, focusing on the chemicals involved, the victims produced by these accidents, and these victims' exposures, symptoms or injuries, and requirements for hospital transport.

MATERIALS AND METHODS

The Metrofire Haz-Mat Team (formed June 1990) is made up of selected firefighters from 24 fire departments in the greater Boston suburban area and responds to hazardous material incidents within an area of 43 communities. Likewise, district teams are made up of firefighters from various local departments in the five other regions: Natick (May 1991), Lowell (November 1990), Bourne (November 1990), Chicopee (May 1991), and Pittsfield (September 1991).

A "hazardous material incident" included any situation responded to by a regional team. Fire department incident reports were obtained directly from the Metrofire Haz-Mat Team. The other five district teams submit a summary of each incident response to the *Haz-Mat Tech,* a newsletter for hazardous material technicians. Reports are usually completed within 48 hours of an incident. The hazardous material firefighter who was the team leader for that incident is responsible for the report.

A retrospective descriptive study was performed using incident reports. Information from these reports was extracted using a standard coding sheet. The coding sheet identified the local fire department and hazardous material response team; the site and type of facility involved; the chemicals or agents encountered; the mechanisms causing the release; and civilian, firefighter, or other public service personnel and hazardous material technician victims. A substance was classified as unknown if its identity remained "unknown" at the time of coding and no further information was available. "Civilians" were defined as residents or employees of the accident location, or other non-public service personnel. "Public service personnel" were defined as firefighters (other than hazardous material technicians), police, or ambulance personnel. "Spills" were defined to include any spill, leak, or other escape of hazardous material not resulting from fire or explosion. "Victims" were defined conservatively so as to include any human injury, exposure, symptomatic individual, or anyone transported to a health care facility. Information on the coding sheets was then entered into a database and updated to include all incidents through May 1996.

Reports from incidents that produced human victims (n=47) were further analyzed. This additional review extracted (1) the number of persons sustaining chemical exposure, and whether such exposures were by inhalation, dermal, mixed, or unspecified; (2) the number of symptomatic persons and the symptoms reported; (3) the number of persons sustaining motor vehicle crash or other physical trauma; and (4) the number of victims transported to a hospital.

RESULTS

The teams responded to a total of 165 incidents: 88 incidents from 1990 through February 1994 and 77 incidents from March 1994 to May 1996. For 3 of the 165 incidents (2%), information on substances was unavailable. In terms of absolute numbers, chlorine derivatives were the most frequently observed hazardous material in incidents with victims (11 incidents, 23% of 47 incidents with victims), followed by metals and metalloids (6 incidents, only 2 with chemical exposure victims) (Table 1).

On a percentage basis, pesticides were most frequently associated with chemical exposure victims (3/5, 60%). Three of four (75%) incidents involving a mixture of hazardous materials resulted in victims, although for one incident the injury was sustained from a motor vehicle crash. Other incidents resulting in victims involved sodium hydroxide (3/7, 43%), miscellaneous acids, bases, and corrosives (3/7, 43%), although for one incident the injury was sustained from a motor vehicle crash, and chlorine derivatives (11/29, 38%). Although victims were relatively frequent in gasoline-associated accidents (3/7, 43%), all were injured as a result of motor vehicle crashes and did not suffer from chemical exposure. Similarly, the single victim associated with an incident involving oil was the result of a vehicular accident.

Most hazardous material incidents did not result in victims (115/162, 71%). For 3 (2%) incidents, information on vic-

tims was unavailable. When injuries occurred they were more frequent among civilians than public service personnel. Civilian injuries occurred in 40 (25%) responses. Public service personnel were injured in 12 (7%) responses, and injuries to hazardous material team members were reported in only a single incident; only minor musculoskeletal injuries were involved.

Inhalation exposure was much more common than dermal exposure or incidents with no exposure: 50%, 20%, and 20% of incidents with victims, respectively (Table 2). Inhalation of hazardous substances occurred in 22 incidents involving civilians and 6 incidents involving public service personnel. Exposure in eight of the incidents among civilians and two among public service personnel was the result of a chlorine derivative.

Overall, 24 of 26 (92%) incidents with chemical exposures resulted in symptomatic victims, and 33 of 35 (94%) incidents resulted in victims requiring hospital transport (Table 2). Inhalation exposure resulted in the highest absolute number of victims requiring hospital transport followed by dermal exposure. The mean number of hospital transports per incident was also greater for inhalation than dermal exposure: 7.4 victims/incident (155/21) versus 2.7 victims/incident (24/9).

In nine incidents without exposures but with victims, motor vehicle crashes produced seven injuries in five incidents. The remaining four incidents involved minor musculoskeletal injuries, heat exhaustion, or cold injury.

Respiratory symptoms (respiratory irritation and shortness of breath) were the most common both in terms of the number of incidents and the absolute number of victims (Table 3). Although physical trauma was common, it produced only 1.4 victims per incident. The number of victims per incident for symptoms resulting from inhalation (respiratory irritation, shortness of breath, headache, dizziness, nausea, chest pain, smoke inhalation, and carbon monoxide poisoning) per incident was higher ranging from 2 for carbon monoxide poisoning to 37 per incident for chest pain. For dermal symptoms, the number of victims per incident was intermediate ranging from one for skin irritation to five for chemical burns.

Table 1.
Classes of hazardous materials associated with incidents that resulted in victims (n=162 incidents).

Class of Hazardous Material	Total No. (%) Incidents Involving Material*	No. Incidents With Victims (% of Incidents Involving Same Substance)	No. Incidents With Victims of Chemical Exposure (% of Incidents Involving Same Substance)
Chlorine derivatives	30 (18)	11/29 (38)†	11/29 (38)
Oil	22 (14)	1/22 (4)	0/22 (0)
Miscellaneous solvents	19 (12)	4/19 (21)	4/19 (21)
Metals and metalloids	17 (10)	6/17 (35)	2/17 (12)
Unknown	12 (7)	4/11 (36)†	4/11 (36)
Miscellaneous, otherwise not classified	12 (7)	4/12 (33)	4/12 (33)‡
Nitrates, nitrites, and nitric acid	12 (7)	1/12 (8)	1/12 (8)
Ammonia derivatives	11 (7)	2/11 (18)	2/11 (18)
Chemical asphyxients	10 (6)	3/10 (30)	3/10 (30)
Sulfates, sulfites, and sulfuric acid	10 (6)	3/10 (30)	2/20 (20)
Alcohols	8 (5)	2/8 (25)	1/8 (12)
Plastics and rubbers	8 (5)	2/8 (25)	2/8 (25)
Aromatic hydrocarbons	8 (5)	1/8 (12)	1/8 (12)
Gasoline	7 (4)	3/7 (43)	0/7 (0)
Sodium hydroxide	7 (4)	3/7 (43)	3/7 (43)
Miscellaneous acids, bases, and corrosives	7 (4)	3/7 (43)	2/7 (28)
Ethylene oxide	7 (4)	2/7 (28)	2/7 (28)
Pesticides	5 (3)	4/5 (80)	3/5 (60)
Mixture	4 (2)	3/4 (75)	1/4 (25)
Miscellaneous hydrocarbons (NOS)	4 (2)	1/4 (25)	0/4 (0)
Cleaning solution	4 (2)	1/4 (25)	1/4 (25)
Freon	4 (2)	1/4 (25)	1/4 (25)
Hydrogen	3 (2)	1/3 (33)	1/3 (33)

†Information on injuries missing for one incident.
‡Victims in one incident resulting from oxygen deficiency caused by malfunction of ventilation system (see reference 17 for details).
*Total is greater than 100% because more than one class of hazardous material may have been involved in each incident.

DISCUSSION

Chlorine derivatives, hydrocarbons, metals, petroleum-derived fuels, and various corrosives (acids and bases) were frequently involved in Massachusetts hazardous material incidents. Comparison with our original Massachusetts series[17] (inception through February 1994, 88 incidents) demonstrates similar relative frequencies of involvement of various hazardous substances and proportion of incidents with victims, suggesting some temporal stability in the types of Massachusetts hazardous material accidents. The greater frequency of responses during the period March 1994 to May 1996 may be the result of increased familiarity with the regional hazardous material teams by local fire departments.

The types of chemicals involved in our region appear similar to national data. Binder's[14] national study of hazardous material releases associated with deaths, injuries, or evacuations also found chlorine derivatives, petroleum-derived fuels, and various corrosives to be commonly involved, but not metals. The Agency for Toxic Substances and Disease Registry's hazardous substances emergency events surveillance (HSEES) system[15] found volatile organics, corrosives, chlorine, and metals to be frequently involved. The frequency of petroleum-derived fuels cannot be estimated because HSEES excludes petroleum products.

The majority of incidents in our study did not produce victims. This is similar to HSEES data[15] that found 85% of events cause no injury. In our series injuries were more common among civilians than public service personnel. Civilian injuries were also more common in the HSEES system.[16] We believe this is related to civilians' initial proximity to the accident or release of hazardous substances in addition to usual lack of protective gear.

Because our definition of a victim included any injury, exposure, symptomatic individual, or anyone transported to a health care facility, many of the victims may not have had serious effects. On the other hand, because fire department incident reports are not standardized, some victims may not be included by the firefighter compiling the report.

Frequently observed hazardous substances varied in their association with victims, especially chemical exposures. Chlorine derivatives were involved in 18% of all incidents and 23% of all incidents resulting in injuries. Although injuries resulting from inhalation or skin exposure to chlorine derivatives and other corrosives were common, injuries in hazardous material accidents associated with petroleum-derived fuels were less common and exclusively related to motor vehicle crashes.

Respiratory exposures were the most frequent type of exposure, produced the largest absolute number of victims transported to a hospital, and the highest number of victims per incident. These exposures were often due to chlorine derivatives. It is logical that an airborne release is more likely to expose a larger number of victims compared with a spill, splash, or even explosion involving a liquid or solid substance. Respiratory symptoms were also the most common both in terms of the number of incidents and the absolute number of victims. Respiratory irritation was also the most frequent injury observed in the HSEES system.[15,16]

Although respiratory exposure to chemicals was the most frequent cause of victims in our study and in the HSEES study, many discussions on hazardous material preparedness focus on the treatment of contaminated patients. In our series, incidents with only dermal exposure were associated with victims in nine incidents. In an additional three incidents, it could not be determined whether the exposure was dermal or inhalation. Situations resulting in dermal exposures often produced multiple victims, but not as many as inhalation exposures.

Table 2.
Medical consequences of 47 hazardous materials incidents with victims.

Type of Chemical Exposure	No./Total (%) Incidents With Exposure	No./Total (%) Incidents With Symptomatic Victims	No./Total (%) Incidents Resulting in Hospital Transports	No. Victims Transported to Hospital
Inhalation	23/46 (50)	17/17* (100)	20/21* (95)	155†
Dermal	9/46 (20)	5/7 * (71)	9/9 (100)	24†
Unspecified exposure	3/46 (7)	—*	3/3 (100)	9
Dermal and inhalation	2/46 (4)	2/2 (100)	1/2 (50)	1
No exposure	9/46 (20)	9/9 (100)	5/8* (62)	4†
Insufficient information	1/1 (100)	1/1 (100)	1/1 (100)	1
Total	37/46 (80)	34/36 (94)	39/44 (89)	194†

*Some reports with insufficient information to make a determination.
†Total is an underestimate because of unspecified number of transports in some incidents.

Most dermal exposures involved nonspecific irritants or corrosives, whereas three involved more dangerous substances: organophosphorus pesticides or elemental sodium metal. Dermal contamination with an organophosphate can potentially cause secondary contamination of rescue and medical workers, as well as ongoing absorption and toxicity in the victim. Although insecticide exposures were infrequent in our series and in HSEES data,[15] in both series they frequently produced victims.

In alkali metal burns (sodium, lithium, potassium, and so on), decontamination with water is specifically contraindicated. These metals react with water in a violent fashion releasing heat, hydroxide ion, and hydrogen gas. Proper treatment of alkali metal burns involves clothing removal and covering the affected area with mineral or cooking oil, followed by removal of any metal with dry forceps. Only then can the wound be irrigated with water and treated like other alkali burns.[18-20]

It is difficult to estimate the frequency of contaminated patients and the potential risk that their skin contamination poses.[1] Studies based on hazardous material teams may find few problems with contamination because of such teams' training and capacities for field decontamination. The Massachusetts district teams routinely perform decontamination after all incidents unless the hazard poses a threat only by pulmonary absorption (eg, carbon monoxide). Field decontamination of other firefighters or civilian victims is routinely done if there has been any possible exposure. It would be unusual for a patient who has undergone field decontamination to require additional decontamination after transport. There were no known episodes of secondary contamination of health care workers in this study.

On the other hand, EDs may have patients who arrive by private vehicle or via first responders with little hazardous material training. Lavoie and colleagues[21] reported on a 6-year experience with ED external decontamination involving 72 patients. None of these patients had received field decontamination. The proportion of ED patients with hazardous material exposure requiring decontamination is unknown but is not trivial. During the Tokyo sarin attack, some ED staff had symptoms of cholinergic excess, although none required pharmacologic treatment.[3] Thus, although contamination of patients may occur relatively infrequently, potential catastrophes could happen if emergency personnel are not prepared.[22]

Situations resulting in physical trauma were relatively common, but usually produced only a single victim per incident. Motor vehicle crashes were the most common cause of trauma. From the information in the reports, these transportation accidents appear to have been the cause and not the consequence of the hazardous material incident.

Most of the substances encountered in our series require only general supportive medical management. A few are capable of causing systemic intoxication or may require specific antidotes. These antidotes theoretically include atropine or pralidoxime for organophosphate and carbamate pesticides, cyanide antidote kit for cyanide or hydrogen sulfide, oxygen or hyperbaric oxygen for carbon monoxide, and methylene blue for methemoglobin-forming agents.[1,8] Four of these antidotes may be required in large quantities urgently because of mass exposure, but might not be readily available in large amounts. These are cyanide antidote kits, pralidoxime, atropine, and methylene blue.[23] Because cyanide and nerve gas poisonings may require emergent treatment, outside supplies of antidote would probably arrive too late to be useful unless locally stockpiled.[11,23]

One limitation of our study is the retrospective data collection. Because the incident reports contain almost exclusively prehospital information, the ultimate severity of illness was unknown. In addition, the delayed presentation of victims to health care facilities cannot be detected, nor can persistent or late sequelae of toxic exposures such as reactive airways dysfunction syndrome or cancer. Finally, the regional nature of our study is also a limitation. Certain industries, natural disasters, waste sites, transportation routes, and other unique factors may predominate in different geographic areas.

Respiratory exposure to hazardous materials was the most frequent cause of victims and produced the largest number of symptomatic persons and hospital transports. Chlorine

Table 3.
Medical effects encountered among victims of hazardous materials incident.

Type of effect	Incidents (No.)	Symptomatic victims (No.)
Respiratory irritation	11	108*
Shortness of breath	10	100
Physical trauma	8	11
Headache	5	38
Dizzy	3	25*
Chemical burn	3	15
Skin irritation	3	3
Chest pain	2	74
Nausea	2	9*
Smoke inhalation	1	4
Carbon monoxide poisoning	1	2
Heat stress	1	Unspecified
Cold injury	1	Unspecified
Numbness	1	Unspecified

*Total is an underestimate because of unspecified number of transports in some incidents.

derivatives are commonly involved in hazardous material incidents. The transport of multiple victims to an ED from a single hazardous material incident is most likely to result from inhalation exposure of a respiratory irritant such as chlorine.

In most situations, hazardous material exposures and injuries can be managed successfully by supportive care. Some exposures, however, may require advanced toxicologic knowledge, specific decontamination procedures, treatment, or antidotes. These victims may be difficult to manage appropriately without advance preparation and access to expert consultation such as a regional poison center and occupational and environmental medicine consultants.

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