

Mechanisms and Facility Types Involved in Hazardous Materials Incidents

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The purpose of this study was to systematically investigate hazardous materials (hazmat) releases and determine the mechanisms of these accidents, and the industries/activities and chemicals involved. We analyzed responses by Massachusetts' six district hazmat teams from their inception through May 1996. Information from incident reports was extracted onto standard coding sheets. The majority of hazardous materials incidents were caused by spills, leaks, or escapes of hazardous materials (76%) and occurred at fixed facilities (80%). Transportation-related accidents accounted for 20% of incidents. Eleven percent of hazardous materials incidents were at schools or health care facilities. Petroleum-derived fuels were involved in over half of transportation-related accidents, and these accounted for the majority of petroleum fuel releases. Chlorine derivatives were involved in 18% of all accidents and were associated with a wide variety of facility types and activities. In conclusion, systematic study of hazardous materials incidents allows the identification of preventable causes of these incidents. *Key words:* chemical accidents, chlorine, environmental exposure, ethylene oxide, hazardous substances, hospitals, petroleum, public health.

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The EPA has defined a hazardous material as any substance that "may present severe health hazards to humans following short-term exposure during a chemical accident or other emergency" (1). A hazardous materials (hazmat) incident may potentially occur at any point in the manufacture, storage, transport, sale, usage, or disposal of a substance (2). Approximately 60,000 chemicals are manufactured and used in the United States, and about 2,000 of these have been defined as hazardous by the Department of Transportation (DOT) (2).

Examples such as the methyl isocyanate release in Bhopal, India; the explosion involving dioxin in Seveso, Italy; the Chernobyl nuclear accident in the former Soviet Union (3); and the recent Tokyo, Japan, subway sarin attack (4) have emphasized that hazardous materials releases may cause substantial human morbidity and mortality. Many reviews (5-10) have addressed the need for emergency community and medical preparedness to minimize the adverse consequences of such incidents, and many communities have formed local emergency planning committees (LEPCs) and hazardous materials teams to cope with accidents. Yet, there has been little discussion in the literature directed at the primary prevention of such incidents.

We previously studied the first 88 hazmat responses by Massachusetts' six district hazmat firefighter teams, from their inception through February 1994 (11). In this paper, we report on all 165 hazmat responses by the same teams, from their inception through May 1996, focusing on the causes of

these accidents, the facility types involved, and the chemicals associated with specific facilities or activities.

Methods

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

A hazardous materials incident included any situation, incident, or accident to which one of the regional teams responded. Copies of incident reports were obtained directly from the Metrofire Hazmat Team. The other five district teams submit summaries of all of their incident responses to the *Hazmat Tech*, a newsletter for Hazmat technicians co-published by one of the authors (M.J.C.).

Information from each report was then extracted onto a standard coding sheet for each incident. This information included the local fire department and hazmat team responding to the incident; the site and type of facility involved; the chemicals or agents encountered at the episode; the mechanisms causing the release; and civilian, firefighter, and hazmat technician injuries. Spills were defined to include any

spill, leak, or other escape of hazardous material not resulting from fire or explosion. "No release of hazardous material" included those incidents where no spill, fire, or explosion occurred, such as responses to intact containers. Injuries were defined conservatively to include any injury, exposure, symptomatic individual, and/or anyone transported to a health care facility.

The original incident database contained information on all incidents from the teams' inceptions through February 1994 (11). It has subsequently been updated to include all incidents through May 1996. A detailed discussion of the types of injuries and the hazardous substances involved is presented elsewhere (12).

Results

During the study period, the six district hazmat teams responded to a total of 165 incidents. Table 1 shows the frequency of various causes of hazardous materials incidents and the number and percentage of these incidents resulting in injury. The vast majority of responses involved spills, leaks, or other escapes of hazardous materials. For three (2%) of the accidents, information on causes was unavailable. The totals exceed 100% because more than one cause was responsible for some of the accidents.

The proportion of incidents resulting in injury was highest for explosions, but was similar for other causes of accidents (fires, spills, and motor vehicle accidents), either alone or in most combinations. Explosion-associated injuries included inhalation expo-

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tures, explosion-related trauma, and chemical burns. Injuries sustained during vehicular accidents, with or without spills, were primarily due to the vehicular accidents and not to hazardous materials. Over 70% of injuries sustained during fires were due to inhalation exposures. Most spill-associated injuries were chemically associated: most frequently, inhalation; followed by dermal exposures; while trauma due to motor vehicle accidents occurred in five incidents.

Table 2 describes the facility type or activity at which hazardous materials accidents occurred. The majority of hazardous materials incidents occurred at fixed facilities; transportation-related incidents accounted for 31 of 157 (20%) incidents. When considering individual facility types, transportation-related incidents were the most common, followed by accidents occurring at industrial, commercial, health care, and residential sites. For 8 (5%) of the incidents, information on the facility type or location of the incidents was unavailable.

There were several specific locations involved in accidents more than once. There were two incidents at a company involved in the cleanup and transportation of waste; both of these incidents involved lead, and one each involved sulfuric acid and silver metal. A trucking terminal had two incidents involving spills. There were two incidents at a police headquarters due to a faulty heating system that filled the building with carbon monoxide on 2 consecutive days. There were two incidents at one chemical company involving fires and a mixture of materials, including neoprene, a synthetic rubber compound. Finally, there were two incidents at a university, both occurring in laboratories during experiments, which resulted in fires.

Table 3 displays the hazardous materials that were observed frequently in incidents at specific facility or activity types. Oil was involved in almost half of transportation-related incidents, and transportation-related incidents accounted for 15 of 22 (68%) accidents involving oil. Chlorine derivatives and gasoline were also observed in multiple transportation-related accidents.

The majority of hazardous materials accidents at hospitals involved ethylene oxide. Similarly, of the seven incidents involving ethylene oxide, five (71%) occurred at hospitals. Freon, which is mixed with ethylene oxide in gas canisters for use in sterilization, was involved in three of eight incidents at hospitals and in three of five (60%) incidents involving ethylene oxide.

Eight hazardous materials incidents occurred at schools. Chlorine derivatives were involved in half of these, and metals/metalloids were involved in another 25%.

Metals/metalloids were also observed repeatedly at chemical companies and other industrial sites and twice in waste-related accidents.

There were several facility types that were very strongly associated with specific hazardous materials. Cyanide was found in three of four incidents at electroplating operations, while three of five accidents involving cyanides were at electroplating facilities.

Of the three incidents involving cyanide that occurred at electroplating operations, two (66%) resulted in inhalation injuries. All three incidents that occurred at gas stations involved gasoline [three of seven (43%) accidents involving gasoline occurred at gas stations]. In both incidents at water treatment facilities, chlorine was the sole hazardous material involved.

Some frequently observed substances were associated with many different types of facilities and activities: chlorine derivatives were observed in 30 (18%) incidents involving 15 classes of facilities; ammonia derivatives were associated with 10 facility types in 11 incidents; metals/metalloids were observed at 8 facility types in 12 accidents; nitrites/nitrates were associated with 8 facility types in 12 accidents; and sulfites/sulfates were observed in 7 classes of facilities in 10 incidents.

Discussion

Spills (including other leaks and escapes) of hazardous materials, either alone or in combination, were the most frequent cause of hazardous materials accidents in this study and were involved in 76% of accidents. This is in agreement with our initial study [team inception through February 1994, 88 incidents; (11)], which found spills to be involved in 79% of Massachusetts hazardous materials incidents. Shaw et al. (13) found that leaks or drops from moving vehicles and vehicular accidents were common causes of hazardous

Table 1. Frequency of causes of hazardous materials incidents and number and percentage of those resulting in injury

Incident type	Number of incidents (%) ^a	Number of incidents with injury (%) ^b
Spill	123 (76%)	32 (26%)
Fire	27 (17%)	9 (33%)
Vehicular accident	26 (16%)	8 (31%)
Vehicular accident and spill	25 (15%)	8 (32%)
No release of hazardous material	17 (10%)	4 (24%)
Explosion	14 (9%)	6 (43%)
Fire and spill	13 (8%)	2 (15%)
Spill and explosion	4 (2%)	0 (0%)

Totals exceed 100% because more than one cause was responsible for some accidents.

^aPercent of total incident ($n = 165$).

^bPercent of that incident type.

materials incidents reported by the California Highway Patrol. The present results support the recommendations derived from these two studies (11,13) that tank and container construction, as well as worker education regarding the safe loading, handling, and disposal of hazardous materials, are appropriate targets for preventive interventions.

Table 2. Facility type and frequency of hazardous materials incidents

Facility type	Number of incidents (%) ^a	Number of incidents with injury (%) ^b
Transportation	31 (20%)	8 (26%)
Industrial	19 (12%)	5 (26%)
Commercial	15 (10%)	7 (47%)
Health care	10 (6%)	3 (30%)
Residential	9 (6%)	3 (33%)
School	8 (5%)	1 (12%)
Chemical company	7 (4%)	2 (28%)
Laboratory	7 (4%)	2 (28%)
Environmental ^c	6 (4%)	1 (17%)
Recreation	6 (4%)	2 (33%)
Truck terminal	6 (4%)	1 (17%)
Waste related	6 (4%)	4 (67%)
Warehouse	5 (3%)	2 (40%)
Electroplating	4 (2%)	2 (50%)
Office	4 (2%)	2 (50%)
Gas station	3 (2%)	0 (0%)
Dry cleaners	2 (1%)	0 (0%)
Police department	2 (1%)	0 (0%)
Water treatment related	2 (1%)	0 (0%)
Miscellaneous	5 (3%)	1 (20%)
Total	157 (100%)	46 (29%)

^aPercent of total incidents.

^bPercent of incidents at that facility type.

^cIncludes releases into areas such as parks and rivers.

Table 3. Hazardous materials frequently^a found at facility types and activity types during hazardous materials accidents

Facility or activity type	Hazardous material	Number of incidents (%) ^b
Transportation ($n = 31$)	Oil	15 (48%)
	Chlorine derivatives	4 (13%)
	Gasoline	3 (10%)
Hospital ($n = 8$)	Ethylene oxide	5 (62%)
	Freon	3 (38%)
School ($n = 8$)	Chlorine derivatives	4 (50%)
Laboratory ($n = 7$)	Chlorine derivatives	4 (57%)
	Sulfuric acid	3 (43%)
Chemical company ($n = 7$)	Metals/metalloids	4 (57%)
Electroplating ($n = 4$)	Cyanide	3 (75%)
Gas station ($n = 3$)	Gasoline	3 (100%)
Other industrial ($n = 19$)	Metals/metalloids	4 (21%)
	Solvents	3 (16%)

^aHazardous material was found three or more times at a facility or activity type.

^bNumber of incidents at that facility type involving the hazardous material and percent of incidents at that facility type with that material.

Petroleum-derived fuels, although they are not usually considered corrosives, should probably be transported in stronger tanks, given that these fuels accounted for over half of the transportation-related accidents in this series. Although most of these spills do not result in chemical exposure injuries, they may cause secondary motor vehicle accidents and present incendiary hazards. Even in the best case scenario, such spills still require cleanup and possibly environmental remediation. The frequent involvement of petroleum-derived fuels in hazardous materials accidents warrants reconsideration of their exclusion from programs such as the Massachusetts Toxic Use Reduction Program and the Agency for Toxic Substances and Disease Registry's (ATSDR) Hazardous Substances Emergency Events Surveillance (HSEES).

Releases of hazardous materials at industrial, commerce, warehouse, transport, residential, and disposal-related sites confirm that hazardous materials accidents can occur anywhere along the chain of production, distribution, storage, usage, and disposal. The vast majority of hazmat responses by Massachusetts district teams were to incidents occurring at fixed facilities, while transportation-related accidents made up a significant minority (20%). This is similar to our initial study in which 84% of accidents occurred at fixed facilities (11) and to HSEES data in which 23% of events were transportation-related and 77% were fixed-facility events (14). These studies contrast with data from Binder (15) and Shaw et al. (13), who reported 56% and 89% of hazmat incidents, respectively, to be transportation related. As we have previously noted (11), this marked difference is most likely due to the use of databases (California Highway Patrol and DOT) that are likely to be biased toward transportation-related incidents.

It is of concern that 11% of responses were to incidents at schools or health care facilities. This is similar to our initial study in which incidents at health care facilities and schools accounted for 15% of all responses (11). These accidents are especially worrisome because of the potential for toxic exposures to more susceptible populations: children and persons with various medical illnesses. School and hospital laboratories and hospital sterilization areas using ethylene oxide (EtO) should be targets for increased safety planning, awareness, and training in the safe use of chemicals.

Sullivan (16) has suggested that, although the use of EtO as a sterilization agent in the health care industry accounts for less than 5% of EtO production, the potential for EtO exposure is probably greater in the health care industry than in the chemical

industry. In this study, 71% of incidents involving EtO occurred at hospitals, while 62% of hospital accidents involved EtO. Although actual EtO exposures may have been small or even negligible during these incidents, the need for improvements in safety and engineering controls is obvious. If successful, such measures could eliminate the majority of hazardous materials accidents at Massachusetts hospitals.

The necessity to use hazardous chemicals in school laboratories should also be reconsidered. At present, hospitals, universities, and schools are not included in the Commonwealth of Massachusetts Toxic Use Reduction Programs. Their representation in hazardous materials accidents merits their consideration for future inclusion in such programs to reduce the use of hazardous substances.

Chlorine derivatives were involved in 18% of all incidents and were associated with releases from a wide variety of fixed facilities and transportation accidents. The companion study (12) demonstrated that chlorine derivative releases have a high propensity for causing injuries (accounting for 23% of all incidents resulting in injuries). Injuries occurred in 38% of chlorine derivative-associated hazmat accidents; therefore, prevention of these accidents should have a very high priority.

Several other classes of hazardous materials, in addition to chlorine, were also frequently involved in accidents, but were associated with a diversity of facilities and activity types. In these cases, preventive efforts by manufacturers and distributors are needed to reduce releases. Such efforts may include safer containers, greater precautions in transport, and a greater emphasis on education and safety warnings directed towards industrial, commercial, and retail consumers. Kilburn (17) has recently commented on the need for increased regulation of the transportation of hydrochloric acid.

Although the sample is relatively small and regional, most of the facility types and chemicals involved could be expected in most areas. Certain industries, natural disasters, hazardous waste sites (sites contaminated with or for disposal of hazardous materials), transportation routes, and other unique factors may predominate in different geographic areas and thus predispose to certain types of incidents and exposures. Regional data should be useful feedback to LEPCs in determining their prevention and accident contingency plans. Such information may also be useful to toxic use reduction programs in identifying target hazards for various types of industry and commerce. Specific companies and/or locations that have been involved in more than one hazardous materi-

als incident should draw increased attention and preventive efforts from LEPCs.

Comparison with our original Massachusetts series [inception through February 1994, 88 incidents; (11)] demonstrates similar relative frequencies of involvement of various causes, chemicals, and facility types consistent with some degree of temporal stability in the pattern of Massachusetts hazmat accidents. This temporal stability suggests that hazardous materials accidents are not random occurrences and that effective preventive measures, based on historical data for a specific region, could prevent some future accidents in that same area.

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