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Planning for a Transportation-Related Hazardous Material Spill in a Municipal Watershed

T. C. CRUSBERG, A. H. HOFFMAN, B. E. MURRAY, B. D. CULL, and C. E. BARNES

ABSTRACT

Because of urban sprawl, the formerly isolated water supplies of many municipalities are now exposed to transportation-related hazardous material spills. This study uses the water supply in Worcester, Massachusetts, as a model to identify factors associated with the risk of a transportation-related hazardous spill and to assess the current response to a spill. Business and industry within the watershed were surveyed to determine the most probable types of hazardous materials being transported. Local police records were used to identify sites with a high frequency of accidents. Local officials were surveyed to determine the probable response to a spill. It is concluded that governmental infrastructure problems may prevent an adequate response in those sections of the watershed outside the municipal boundaries. Recommendations are made to eliminate some of these deficiencies.

During the past quarter century urban populations have shifted into the suburbs and even more distant rural areas. Improved highway access, including construction of the Interstate highway system, has played a most important role in this decentralization. The ease of access to suburban and rural environments is often an important factor in siting new industries there.

The watersheds of many once-rural upland surface water supplies are now traveled by vehicles carrying a myriad of hazardous materials. Transportation-related accidental spills of hazardous materials pose an important threat to many potable water supplies (1-4), and there have been many instances in which drinking water was contaminated by hazardous material spills. Only recently have hazardous material spills begun to be properly reported. Since 1980 comprehensive records have been maintained by only one New England state, Connecticut. Based on Connecticut data, it was estimated that the Region I office of the U.S. Environmental Protection Agency (EPA) received reports of only 7 percent of all transportation-related hazardous material spills in New England during 1980-1981, although 60 percent of the severe spills (more than 100 gal) were reported (1).

In an attempt to determine the vulnerability of a surface water supply to an accidental transportation-related hazardous material spill, the watershed serving the city of Worcester, Massachusetts, was studied to identify possibilities for a transportation-related hazardous material spill, to determine the current response procedure to a hazardous material spill, and to recommend additional procedures that municipal agencies might take to prevent and minimize the environmental impact of a spill in a sensitive watershed. The study was carried out by the Water Quality Resource Study Group (WQRSG) (5), made up of environmental professionals from four city departments, regional environmental and planning groups, and faculty of the colleges and universities of the Worcester Consortium for Higher Education. Since 1972 the WQRSG has combined research, public service, and education to solve many water-related problems in central Massachusetts.

This study uses the Worcester watershed as an example to

1. Demonstrate the value of surveying the businesses and industries within the reservoir watershed in order to identify the types of hazardous materials likely to be used and thus transported within watershed boundaries;
2. Locate the most probable sites for possible transportation-related spills by studying traffic accident patterns;
3. Identify local, state, and federal experts and resources and to assess their abilities to react to the occurrence of a hazardous material spill;
4. Examine state and federal laws and regulations that affect the reporting, cleanup, and compensation for a hazardous material spill; and
5. Make recommendations that would serve to reduce the possibility of a spill in a watershed and to minimize the impact of such a spill once it had occurred.

THE WORCESTER WATERSHED

The Worcester watershed (Figure 1) encompasses approximately 40 miles^2 and is located almost entirely outside the jurisdictional limits of the central city in five surrounding communities (Holden, Paxton, Rutland, Princeton, and Leicester). For reference, the large body of water shown in Figure 1 north of Worcester and east of Holden is Wachusett Reservoir, which supplies Boston. The 10 reservoirs, each with a capacity between 15 million and 3 billion gal, store a total of 6.65 billion gal of water. The system is geographically separated into two distinct watersheds that adjoin each other. Chlorine disinfection is the only treatment to the water before it enters the distribution system. About 35 miles of state routes and major roadways are located within the watershed boundaries. In addition the watershed is traversed by numerous residential streets and private roads. There are no major industrial zones within the watershed. However, several commercial and small industrial users of hazardous materials such as plastic manufacturing plants, machine shops, gasoline service stations, and fuel oil distribution plants are located within the watershed.

USERS OF HAZARDOUS MATERIALS

Businesses in the Worcester watershed were identified by using the Directory of Massachusetts Manufacturers, 1980-1981, and the Yellow Pages of the central Massachusetts telephone directory. Groups of

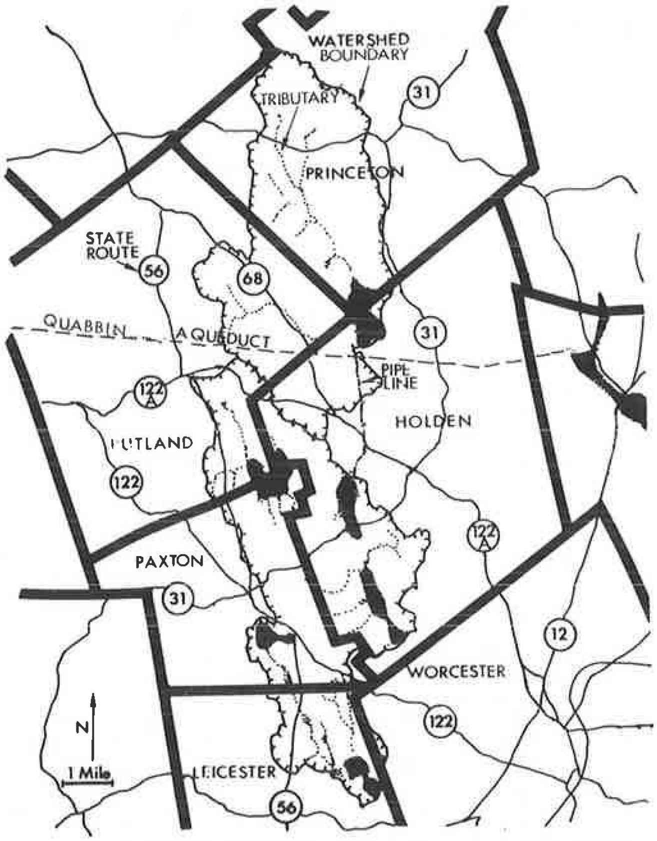

FIGURE 1 The Worcester, Massachusetts, watershed (bodies of water indicated by shading).

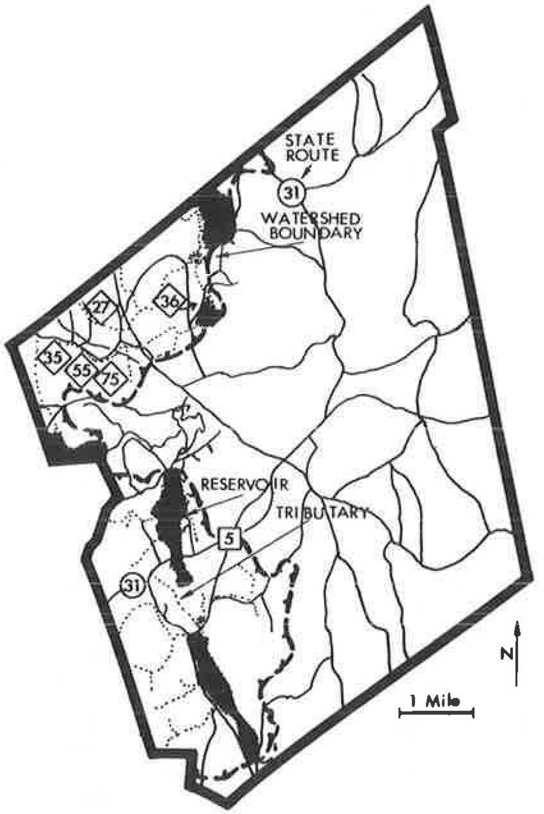

FIGURE 2 Worcester watershed in the town of Holden.

TABLE 1 Hazardous Material Use in Watershed

Town	SIC No.	No. of Businesses in Watershed	Possible Hazardous Material
Holden	27	2	Inks, dyes
	35, 36	7	Oils, plating wastes, sludges
	55, 75	1	Gasoline, diesel fuel, oil
Leicester		1	Fuel oil (dealer)
Paxton	17	4	Fuels and oils associated with construction machinery
	55, 75	2	Gasoline, diesel fuel, oil
Princeton		1	Fuel oil (dealer)
		1	Fuels and oils for buses
	36	1	Solvents, plating wastes, sludges
Rutland	17	1	Fuels and oils associated with construction machinery
	35	1	Oils, plating wastes, sludges, trichloroethylene
	75	1	Gasoline, oil, paint, trichloroethylene

chemicals likely to be used by those companies were obtained from the Directory of Massachusetts Manufacturers according to the standard industrial classification (SIC) code for each business. Eliminated from consideration were businesses that would not be likely to use chemicals or petroleum products in a sufficient quantity to pose the risk of a transportation-related spill (e.g., general contractors, dairy farms, coin laundries). Figure 2 shows this analysis for the town of Holden. The Worcester watershed occupies a substantial part of the eastern boundary of Holden. Within Holden a major service road and state routes 122A and 31 pass through the watershed. Businesses within the watershed likely to use hazardous materials are designated on the map by a diamond-shaped symbol containing the appropriate SIC number. The majority of hazardous materials include oils, plating wastes and sludges, gasoline and diesel fuel, and trichloroethylene. The single site with a high frequency of accidents in Holden is indicated by a square symbol in which the number of accidents that have occurred there is contained.

This procedure was repeated for each of the other four towns in which the watershed is located (Table 1). Based on SIC designations, the hazardous materials used by businesses in the watershed are likely to be fuel and diesel oil, gasoline, and solvents used in electronics and metal fabrication. The businesses use these materials in various manufacturing processes and also sell them commercially. Similar materials were used by businesses just outside the watershed boundaries.

Fuel oil storage and a town landfill were located within a few yards of the watershed boundary in Leicester. State route 56 is located within the watershed and close to several reservoirs in that town. In Paxton (Figure 3) three gasoline stations are located within the watershed, and three major state routes (122, 56, and 31) are located in the watershed. A fuel oil company and several industries (SIC code 36) are also situated within the watershed in the town of Princeton, and the Boston and Maine Railroad right-of-way bisects the watershed in that town. State routes 31 and 62 are also found in the watershed in Princeton. The most important feature in Rutland is state route 122A, which passes through the watershed.

Throughout the watershed in all communities, residential communities are found in large numbers. Thus virtually all roads in the watershed are traveled by fuel oil trucks.

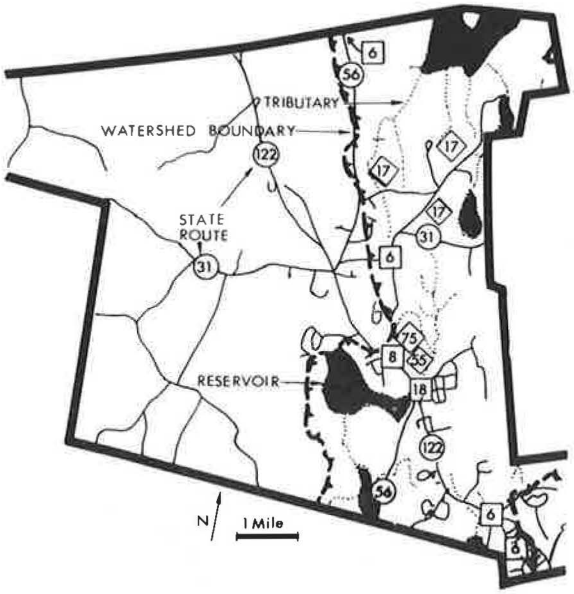

FIGURE 3 Worcester watershed in the town of Paxton (note six high-frequency accident sites).

TRAFFIC ACCIDENT FREQUENCY IN THE WATERSHED

A recent study of 123 traffic-related accidents occurring between 1972 and 1979 in which hazardous materials contaminated bodies of water in New England (6) revealed that a variety of industrial and agricultural chemicals were involved. These included petroleum products, caustic soda, dioctylphthalate, alcohol, ethylene glycol, fertilizers, latex, methyl methacrylate, acids, styrene, toluene, trichloroethylene, and xylene. Crusberg and Smith (1) recorded 306 similar events for New England for the years 1972-1981 using information obtained from EPA Region I. By comparing data obtained from Connecticut with that obtained from EPA, it was also estimated (1) that from July 1, 1980, to June 30, 1981, 77 percent of such spills were not reported to EPA. Applying the same underreporting ratio to the 1980-1981 EPA Region I data for transportation-related spills of hazardous materials in which some of the spill material entered surface waters, it was estimated that approximately 106 such incidents occurred throughout New England during that year. Such events are indeed common.

Traffic accidents involving carriers of hazardous materials represent a possible threat to the Worcester water supply because users of these materials have now been identified within the watershed. Traffic accident data were obtained from police departments in each of the five watershed towns. In most towns it was possible to obtain data for a 3-year period. For Leicester and Princeton, data were based on a 2-year period. When data were grouped by 3-month seasonal periods, the differences were not statistically significant. Data on the frequency of traffic accidents occurring in the Worcester watershed are as follows (average number of accidents per year, 74):

Town	No. of Accidents
Holden	14
Leicester	11
Paxton	23
Princeton	9
Rutland	17

The foregoing data show that traffic accidents occur relatively frequently within the Worcester watershed. To date, no accidents have occurred in which hazardous materials have been spilled in other than minor amounts. Paxton accounted for 31 percent of all accidents, and 23 percent occurred in Rutland. However, six of the nine sites with a high frequency of accidents (that had more than five accidents during the survey period) were in Paxton. Severe accidents have occurred in Paxton at the intersection of state routes 56 and 122, including seven fatalities in the last 10 years (Table 2 and Figure 3). Three of the nine sites with a high frequency of accidents are within 400 ft of a tributary to a reservoir. Four such sites in Paxton are located along state route 122. The site with the highest frequency of accidents is located only 600 ft from a major reservoir and directly adjacent to a tributary of that reservoir.

TABLE 2 Sites with High Frequency of Accidents in the Worcester Watershed

Town	No. of Accidents in 3-Year Period	Distance from Reservoir or Tributary (ft)
Holden	5	850 (R)
Leicester	9[a]	0 (T); 350 (R)
Paxton	18	0 (T); 600 (R)
Paxton	8	1,300 (R)
Paxton	6	1,300 (T); 6,600 (R)
Paxton	6	1,200 (T); 1,400 (R)
Paxton	6	1,650 (R)
Paxton-Rutland town line	6	1,700 (T); 4,000 (R)
Rutland	8	400 (T); 13,000 (R)

Note: R = reservoir; T = tributary.

[a] Based on a 2-year period.

Another location with a high frequency of accidents (nine accidents in 2 years) is in Leicester, immediately adjacent to a tributary and only 350 ft from a major reservoir. In Holden, five accidents have occurred at scattered locations on roads adjacent to reservoirs.

There are fewer accidents in Princeton, probably because of both the absence of major routes and a small population living in the watershed. The Boston and Maine railroad, which bisects the watershed in Princeton, is a route over which hazardous materials are transported. A derailment in the 1970s caused spillage of rock salt, but there was no substantial impact on the watershed.

REGULATIONS GOVERNING REPORTING OF SPILLS

There are several laws and regulations governing emergency response to hazardous material spills. The Water Pollution Control Act of 1970 (Public Law 91-224) requires reporting of spills of oils (Sec. 11B) and hazardous materials (Sec. 12 and 40 C.F.R. 117.3) to the federal government. First notice of pollution discharge must be made immediately, in accordance with 33 C.F.R. 153.203, to the National Response Center (NRC) (40 C.F.R. 1510) or alternatively to the nearest U.S. Coast Guard or EPA office. The Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) (Public Law 96-510), through Section 103(a), requires immediate notification to the NRC whenever there is a release of a "reportable quantity" of a hazardous substance into surface waters, navigable waters, drinking water supplies, land surfaces, and ambient air within the United States. Reportable quantities are specified in 40 C.F.R., Part 110, for oil and Part 117 for 297 other materials. Typical reportable quantities range from 1,000 lb for benzene to 10 lb for hydrogen cyanide and 1 lb for the insecticide DDT. Other reporting provisions are contained in 40 C.F.R. 171.15. A memorandum of understanding between the NRC and the Chemical Transportation Emergency Center (CHEMTREC) was signed in 1970, making information readily available to officials at the scene of a spill through a toll-free telephone number 24 hr a day.

The NRC also serves as initiator of a chain of notification steps that set federal response plans into action (7). Local response to a spill in New England is coordinated through the EPA Region I office for inland waters and the Coast Guard for navigable or marine waters. Criminal penalties exist for noncompliance.

Should a federal response be required, a regional response team (RRT) consisting in Massachusetts of officials of EPA and the Massachusetts Department of Environmental Quality Engineering (DEQE) and headed by one federal official (the on-site coordinator) must ensure proper removal of any spilled material. If necessary, federal money may be used to ensure that removal of hazardous materials is completed in the event that the responsible party cannot be identified or will not take appropriate action (Federal Water Pollution Control Act of 1972, Sec. 311, Subsection K; 33 C.F.R. 153.401-153.419). Under certain circumstances state or even local officials may also authorize removal of spilled materials and receive reimbursement. Costs of replacing or restoring resources damaged by pollution are not covered by this law.

In Massachusetts reporting of oil and hazardous material spills must be made in accordance with Chapter 21, Section 27, Clause 14 of the General Laws, which also provides criminal penalties for noncompliance. The discharger is liable to the Commonwealth for all costs incurred by the Commonwealth in containing and removing oil and hazardous material spills and also for the costs of restoring damaged areas to their original condition. Double damages may be assessed under Chapter 91, Section 59A of the General Laws against a party who negligently discharges oil onto or into the waters of another party. In Massachusetts cleanup of a hazardous material spill must be performed by a licensed contractor.

Related Massachusetts laws pertaining to response to hazardous material spills include Chapter 48, Section 59A, which encourages mutual aid, and Chapter 639 of the Acts of 1950, which established Civil Defense. Section 14 of that act also allows mutual aid in the event of a disaster.

LOCAL RESPONSE TO A HAZARDOUS MATERIAL SPILL

Interviews were conducted with the police and fire chiefs of all five towns in which the Worcester watershed is located to determine the response procedure that would be followed in the event of a spill. In each town, the fire chief identified himself as the person in charge of hazardous spills. Table 3 gives the responses to that interview, giving a tentative plan by each chief as to how he would proceed should a spill occur in the watershed area under his jurisdiction. None of the chiefs were aware of the precise boundaries of the watershed in their respective town. It is apparent that no common plan exists among the various town officials. The interviews revealed that all fire chiefs were trained in tactics of dealing with hazardous material spills. However, other firefighters may not be as aware of those tactics because of lack of training. Many of the local fire departments consist mainly or entirely of volunteers trained only in the essentials of firefighting. These interviews also revealed that equipment used to clean up spills was not available in the region. In addition only the city of Worcester had conducted simulation training for responding to a hazardous material spill. The Worcester fire department has protective clothing and air masks tethered to an emergency vehicle for use in these situations.

TABLE 3 Response Sequence Suggested by Fire Officials in Worcester Watershed Towns

	Town				
Response from Fire Official[a]	A	B	C	D	E
CHEMTREC	1	2	1	1	1
Massachusetts DEQE	3	1	2	—	2
Worcester water bureau	4	—	—	2	3
U.S. Coast Guard	—	—	—	4	—
Town highway department	2	—	—	—	—
Cleanup company	—	—	4	3	—
State police	—	—	—	5	—
Worcester fire department	—	3	3	—	—
Company responsible for spill	5	—	—	—	—

Note: Numbers indicate sequence in which each town would respond to a hazardous material spill.

[a] In order of contact.

The proper sequence of events following a spill would include notification of Massachusetts DEQE, which would send an Incident Response Team (IRT) to the scene of the accidental discharge. This team represents the state's contribution to the RRT. The identity of the responsible party is then made, and it is next determined whether that party will assume responsibility for cleanup; if not, the state intercedes and assumes that responsibility. The role of the RRT is advisory, because the local fire chief retains total control during the entire cleanup operation. Federal response would only be initiated for large spills. Usually state response in Massachusetts is quite efficient, because the state DEQE maintains four regional offices. However, there are also four separate phone numbers, and on holidays, nights, and weekends another phone number is used. In contrast, the states of Vermont and Maine maintain a single statewide emergency response telephone number 24 hr a day. The EPA Region I response is authorized from an office near Boston.

It was estimated that a minimum of 2 hr would elapse between the time a spill event occurred and arrival of a cleanup company at the scene (Table 4). An analysis of the Somerville, Massachusetts, spill of phosphorus trichloride (8) on April 3, 1980,

TABLE 4 Estimated Minimal Time for Response to Hazardous Material Spill in Watershed

	Minimal Time for Completion (min)	
Response	By Response	Cumulative
Accident reported	5	5
Fire chief arrives at site	10	15
Site inspection (hazardous materials identified)	5	20
CHEMTREC notified	5	25
Massachusetts DEQE and U.S. Coast Guard notified	10	35
Company responsible for spill notified	10	45
Cleanup company notified	10	55
Cleanup company arrives at site	60	115

demonstrated that 3 hr was required before cleanup could actually begin and that technical information provided to local authorities only aggravated the already dangerous conditions at the accident scene. A spill occurring near a reservoir or one of its tributaries would require an immediate response in terms of containment before cleanup. Unfortunately, at this time no resources are available in the Worcester region to effect such a response nor are trained personnel nearby to supervise and carry out such an effort. Storm drains in major roadways were designed to minimize turbidity entering the reservoirs, but no consideration was given to minimizing the impact of a hazardous material spill by retarding its passage with retention barriers.

DISCUSSION

Decades ago the city of Worcester and many other large communities in the United States built reservoirs and purchased lands to protect their drinking water supplies. The recent decentralization of the urban environment has led to extensive commercial, industrial, and residential development of once well-protected upland watersheds. This development has increased the possibility of transportation-related hazardous material spills within these formerly isolated watersheds. A serious governmental infrastructure problem exists in those cases in which the watershed lies outside the municipal boundaries.

This study identified several deficiencies in the emergency response that would occur if a hazardous material were spilled within the Worcester watershed. Officials from suburban or rural communities outside Worcester would be in charge of the cleanup operation. Although the officials in charge had received some training in handling the spills of hazardous materials, they did not appreciate the special problems that would arise in the case of a spill within the watershed. Many officials were unsure of the exact watershed boundaries or the types of hazardous materials transported through the watershed. They also had no contingency plans for dealing with an accident involving hazardous materials within the watershed. The majority of firefighters in the suburbs and rural towns surrounding Worcester are volunteers and may lack training in hazardous material spills. There is virtually no equipment that can be made available quickly to abate a spill in the watershed. Most fire chiefs indicated that they would rely on the state DEQE to obtain the necessary materials and equipment. It is clear that considerable time would pass before an adequate response was undertaken.

The Transportation Research Board (9) has noted unresolved issues related to hazardous material transport. One issue, which could not be considered in this study, was the need for adequate training of personnel involved in handling hazardous materials. Another issue, the knowledge of geologic conditions in the vicinity of a spill, should be the responsibility of both town engineers or public works officials and those city officials who must continuously monitor the watershed. Many suggestions have been made in the literature for dealing with hazardous material spills (10-13), and a contingency plan has been published by EPA (14). Canadian officials have also given much thought to hazardous material transport (15), and their observations and conclusions essentially parallel those of their U.S. colleagues.

In 1981 the city of Worcester developed, in outline form, a plan to give some direction in dealing with a transportation-related hazardous material spill within its own boundaries, but should a spill occur in its watershed, much of that plan would not apply.

The studies reported here indicate that it is relatively easy to identify the sites with a high frequency of accidents within the watershed at which a spill would pose an immediate threat to a reservoir. It would not be difficult to undertake contingency planning for each of these sites. In many cases relatively inexpensive road drainage reconstruction projects could provide temporary containment of hazardous material spills.

Identifying potential users of hazardous materials within a watershed is a valuable aid in identifying the type of materials likely to be spilled on local secondary roads. Traffic surveys on major routes would help identify materials routinely passing through the watershed. It is possible to estimate the amount of hazardous material released en route through the Worcester watershed by using the data and method of Abkowitz et al. given in another paper in this Record. Their results indicate that the expected fraction released per mile shipped ranges from approximately 1×10^{-8} to 8×10^{-6}, depending on the container class. These small amounts pose an interesting problem for a municipality trying to arrange its priorities for allocating resources. A catastrophic spill may be extremely rare and may even be virtually impossible to guard against in a remote rural watershed. Yet readiness through thoughtful planning may lessen the impact should a spill occur and threaten a public water supply.

It appears clear that the municipality deriving its water from the watershed must take the lead in solving the governmental infrastructure problem. The smaller surrounding communities have little incentive to use their resources to develop plans that would reduce the effect of a hazardous material spill on the larger municipality.

The central city must work with towns in which its watershed is located to establish a common plan of action regarding notification of central city officials, prevention, and cleanup of hazardous material spills. Exact locations of watershed boundaries should be made known to emergency personnel in all communities in which the watershed is located. Signs could be placed on local roads to identify watershed boundaries. Worcester may be unique in that virtually none of its reservoirs or watershed is under its own jurisdiction.

The central city should consider the purchase of supplies and equipment that could be used to abate any hazardous material spill immediately. Training in placement of such materials and operation of equipment and other aspects of mutual aid that could benefit all communities in which the watershed is located should be undertaken.

New road construction and road reconstruction projects within the watershed should include engineering measures that would prevent or contain hazardous material spills. Sites with a high frequency of accidents might be reconstructed solely for that purpose. Under certain conditions transport of hazardous materials across certain roads in a watershed might be prohibited.

On a larger scale, states should establish a single statewide emergency response telephone number that is available 24 hr a day.

CONCLUSIONS

Transportation-related spills of hazardous materials pose a small but nevertheless real threat to public drinking water supplies. Using the watershed of the city of Worcester as a model, numerous deficiencies have been identified that would prevent normal interception of a spill that could threaten a city water supply. Many of the deficiencies result from the need of the central city to rely heavily on other towns to respond to a threat to its water supply. Numerous remedies have been suggested to correct the deficiencies noted. This planning process and analysis of a municipal watershed model should have application to many other communities in which water supplies are subject to urban and suburban development.

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Hazardous Materials: Developing Transportation Safety Programs on a Limited Budget

DAVID J. FRIEND

ABSTRACT

The importance of moving hazardous materials safely requires that practical, low-cost ways be found to minimize the expense of transportation safety programs for such materials. Ideas are provided on how state and local officials can perform risk assessments, develop emergency response capabilities, establish vehicle inspection programs, and provide hazardous materials training programs economically. Emphasis is given to such practical solutions as maximizing the use of available federal, state, and local resources; consolidating hazardous materials transportation activities with other state and local programs; expanding the use of mutual aid arrangements; maximizing the use of part-time and volunteer staff; and encouraging greater local industry involvement in hazardous materials incident prevention and emergency response activities. Examples are provided of how different state and local agencies can share the costs of providing labor, equipment, and materials. Ways in which private industry has supported state and local hazardous materials transportation safety programs are also illustrated. State and local officials concerned with hazardous materials movements in and through their jurisdictions are encouraged to translate the cost-cutting measures and management practices identified here into practical solutions for their problems.

The responsibility for and cost of providing hazardous materials transportation safety programs have always been shared by a partnership of federal, state, and local government and industry. Historically, the federal government has provided the bulk of the resources for incident prevention, whereas local government and private industry have taken the lead in emergency preparedness activities and actual response to spills. State agencies provide some hazardous materials inspection and enforcement resources, targeted primarily at hazardous materials tank truck carriers. States also play a major role in coordinating the emergency response resources provided by others and (most recently) in providing for the cleanup of spills when federal and industry resources are not available (1,2).

Rapidly rising personnel and equipment costs, however, now jeopardize the combined ability of the public and private sectors to provide these important services. Public pressure to reduce the size of existing program budgets also threatens the existence of numerous federal, state, and local hazardous materials transportation safety efforts. No level of government or type of hazardous materials transportation safety program is immune from the effects of the shrinking dollar. These same economic pressures are preventing the establishment of new or expanded safety programs to address the growing concern with hazardous materials transportation.

The importance of moving hazardous materials (including waste) safely requires that practical, low-cost ways be found to offset rising costs. Considerable savings can result from

1. Maximizing the use of all available federal, state, and local agency resources;
2. Consolidating hazardous materials transportation activities with other state and local programs;
3. Expanding the use of mutual aid arrangements;
4. Maximizing the use of part-time or volunteer staff; and
5. Encouraging greater local industry involvement in hazardous materials incident prevention and emergency response activities.

Cost-cutting measures and improved management practices have been applied in hazards assessment and risk analysis, emergency response, vehicle inspection and enforcement, and training and education. State and local officials concerned with the movement of hazardous materials through their jurisdictions should be familiar with the range of cost-saving opportunities available and take steps to apply them to their particular problems.

PERFORMING A HAZARDS ASSESSMENT AND RISK ANALYSIS ON A LIMITED BUDGET

A hazards assessment and risk analysis is intended to provide an awareness of the problems that may arise during the transportation of hazardous materials. The preparation of a risk analysis requires (a) obtaining information on hazardous materials movement, population density, and environmentally sensitive areas; (b) mapping the data collected; (c) determining the types of hazards present; (d) identifying vulnerable areas; and (e) calculating the risks (3,4).

Typically, few data are available to indicate the amount of hazardous materials movement into, through, or from a region. Exhaustive surveys of transporters and of industries known to use hazardous materials are extremely expensive and time consuming. Few states or municipalities have conducted such extensive surveys. Where data are available, they usually relate to special materials moved frequently in small quantities (e.g., radioactive shipments) or movements of hazardous materials by select modes (e.g., rail).

Although there is often the temptation to try to prepare for every kind of hazardous materials emergency, valuable resources should not be committed until a hazards assessment has been performed and the problem is really understood. Moreover, risk analyses do not need to be extremely detailed and costly to be useful. Collecting precise information on every chemical and every movement in a region can easily exhaust a budget. Complicated risk analyses that rely on complex mathematical models and result in estimates of probabilities are expensive to perform because they require detailed data and (sometimes) the services of safety experts. A rough analysis or assessment can be as valuable in determining what to expect and where to look for potential problems with hazardous materials. In preparing such an assessment, local officials should

1. Focus on the general classes of materials (e.g., flammable liquids, corrosives, radioactive materials) being transported and not become overly concerned with specific chemicals unless large quantities are stored, shipped, or generated in the region;
2. Identify the major transport corridors and not become overly concerned with identifying the specific routes used by different modes, particularly movements by truck (local authorities may be able to supply this information);
3. Describe the risks in subjective terms (e.g., low, moderate, high) and not become overly concerned with estimating precise probabilities based on a complex mix of different factors; and
4. Use all of the information available from federal, state, and local agencies (Table 1 summarizes the type of information that can be provided by different agencies and organizations).

Adhering to these general guidelines will keep the costs of performing a hazards assessment low.

Costs can also be minimized by integrating a hazardous materials inventory effort with other ongoing data-collection or inspection programs. Although existing information is likely to provide all that is needed to identify the movements of hazardous materials by rail, air, water, and pipeline, additional information may be necessary on hazardous materials truck movements. A limited survey of the users and transporters of hazardous substances may need to be conducted.

To conduct this survey as inexpensively as possible, existing administrative structures and personnel should be used whenever possible. Local fire department personnel, for example, routinely inspect businesses and industries for compliance with state and local safety codes. Given the proper authority, the inspection of select industries could include the collection of transportation-related hazardous materials data, perhaps as part of an existing permit process. It may be possible to obtain detailed information if a nondisclosure agreement is established, which simply states that none of the detailed information collected will be released on a firm-by-firm basis. These agreements permit the use of the data collected in statistical summaries only. Officials should be aware, however, that some state or local statutes prevent the consolidation of certain program activities. Collective bargaining agreements may also prove to be a stumbling block.

If existing staff are unavailable to determine hazardous materials truck movements, the use of part-time or volunteer staff to conduct limited surveys should be explored. Volunteers can easily count the number of trucks traveling a particular roadway that display different hazardous materials placards. If volunteers cannot be found, local employment agencies or skill bureaus can provide relatively inexpensive labor who, with a minimum of training, can also perform truck counts.

Local industry may also be willing to provide funding and support. Private industry is well aware of the importance of a good hazards assessment. Many companies will offer to support efforts of this kind because they do not want

1. Scarce public monies wasted,
2. Taxes increased,
3. The public unnecessarily alarmed, or
4. State or local prenotification regulations enacted.

In addition, industry involvement in such programs enhances their public image. In Santa Clara, California, for example, local businesses pay a fee to support a special chemical division in the Santa Clara Fire Department. This chemical division in turn is responsible for implementing the Chemical Hazards Assistance Program, which includes conducting a chemical survey of every business in the city. Instead of contributing directly to a public agency, local industry could alternatively form an independent, nonprofit corporation to perform the hazards assessment. This approach has the advantage of overcoming the mistrust that the public may have of the industry.

MOBILIZING EMERGENCY RESPONSE RESOURCES WITH LIMITED FUNDS

First responders at the scene of a hazardous materials transportation spill require significant train-

TABLE 1 Hazards Information Commonly Available from Government Agencies and Industry

Source	Information
Materials Transportation Bureau, U.S. Department of Transportation	Accident data about hazardous materials in interstate transport
National Transportation Safety Board of Accident Investigation	Causes of specific accidents involving hazardous materials
U.S. Army Corps of Engineers	Hazardous materials movement by water
Civil Security Division, Federal Aviation Administration; also U.S. Air Transport Association	Movement of hazardous materials by air
U.S. Environmental Protection Agency	Hazardous waste dump sites (legal and illegal)
Nuclear Regulatory Commission	Movement of radioactive materials by truck
U.S. Geological Survey Distribution Branch; also U.S. Defense Mapping Agency	Topographic maps, aerial photographs
Bureau of the Census, U.S. Department of Commerce	Census tract maps, population and employment data
State agencies responsible for overseeing public utilities	Location of major pipelines
State environmental protection agency	Hazardous waste dump sites (legal and illegal); movement of hazardous wastes (manifests)
State office of planning	Population density data and maps
State department of transportation (highway)	Roadway network; identification of rail operators and rail lines
State motor vehicle department	Accident data
State department of environmental protection or ecology, public health department, department of agriculture, pesticide board, fish and game department	Topographic and other environmental data
Local fire department; local civil defense agency	Hazardous materials (disaster) emergency response plan
Local industry directories	Type and location of major storage sites of hazardous materials and waste

ing, need specialized equipment and materials, and must exercise more coordination than typically required in other emergency situations. Although large urban areas with full-time fire departments may have special teams and elaborate emergency response and communication vehicles, small volunteer fire departments often cannot afford such luxuries. Similarly, some departments may have ample supplies of a variety of chemical suppressants, whereas others have few or none.

It is not feasible or practical for every local fire, police, and emergency service organization to be fully equipped and staffed to respond to every conceivable hazardous materials emergency. In addition, it is difficult to justify spending large sums of money for special equipment and materials that are used infrequently. Nevertheless, a high level of emergency preparedness is desirable so that the potential destruction and injury from a spill can be minimized. There are a number of ways to supplement existing resources and maintain an adequate level of emergency response preparedness without spending large sums of money.

Federal, state, and local governments, as well as private industry, already have many programs in operation for responding to hazardous materials incidents. These programs may be able to fill the gaps in a community's emergency response effort. Knowing the capabilities of other agencies and industry also prevents wasteful duplication of effort. Table 2 summarizes the type of emergency response assistance commonly available from different agencies and organizations.

Local agencies are able to provide most of the equipment and materials necessary to respond to small spills of the most common hazardous materials. If a specific piece of equipment or material is not available in house, however, it can usually be obtained from other nearby sources. Having identified these sources, local officials should strive to set up a mutual aid arrangement to ensure that the necessary resources are in fact made available at the scene of a spill. A mutual aid program is an agreement among industries or government agencies or among both to share specific equipment, materials, or personnel in the event of a spill. Mutual aid programs have long been used to stretch emergency response resources and they take many different forms. The following are characteristics of mutual aid programs:

1. They can be among public agencies or private companies or among both.

Example: The Berkshire County (Massachusetts) Mutual Aid System is an informal mutual aid agreement between 28 police departments and 14 fire departments. As the result of this agreement, a communications center has been established to coordinate the notification of, and response to, emergencies in Berkshire County (population approximately 150,000).

2. They can be established to serve any size geographic area.

Example: The Northern Ohio River Industrial Mutual Assistance Conference (NORIMAC) consists of industries and utilities located along the Ohio River between Moundsville, West Virginia, and New Martinsville, West Virginia.

3. They can be concerned only with a certain kind of spill (e.g., oil) involving a specific transport mode (e.g., barge).

Example: The Channel Industries Mutual Aid (CIMA) organization was formed in 1955 to coordinate emergency response capabilities in the general vicinity of the Houston (Texas) Ship Channel. Composed of the Houston Fire Department, local industry, the Port Authority, the U.S. Coast Guard, the Harris County Sheriff Department, and various volunteer fire departments in the Ship Channel region, CIMA membership now totals 84, all of whom must agree to a number of conditions before being allowed to join the organization.

4. They can be formal (written) or informal.

Example: The Mississippi Gulf Coast Regional Disaster Services Mutual Aid Agreement exists as a formal, written mutual aid arrangement made between city and county officials to deal with hazardous materials and other disasters in the Gulf Coast region. Under the terms of this agreement, the involved parties agree to loan each other equipment and personnel and waive all claims for compensation that may arise from losses or damages incurred in providing assistance.

For a mutual aid arrangement to be successful, the participating parties should first agree--preferably in writing--on the financial terms. Mutual aid can be established on a cost-reimbursement basis or on a free-service basis. The issue of liability is also important (5). Unless otherwise specified, a

TABLE 2 Response Aid Commonly Available from Government Agencies and Industry

Source	Information
U.S. Coast Guard	Emergency resources for coastal incidents involving hazardous materials
U.S. Environmental Protection Agency	Emergency assistance for inland releases of hazardous materials
U.S. Department of Energy	Federal Radiological Monitoring and Assessment Plan (FRMAP): technical guidance for coping with radiation emergencies
State departments of emergency services, civil defense, and environmental protection or state police	Various emergency response equipment, personnel, and materials
Local fire, police, public works, civil defense, and public health departments	Various emergency response equipment, personnel, and materials
Local chemical companies	Equipment and personnel to respond to chemical spills
Oil refining and storage facilities	Capabilities to assist at spill of oil or gasoline
Construction companies	Heavy earth-moving equipment and operators
Transportation companies	Trained personnel and specialized equipment to deal with the hazardous materials they transport
Pollution cleanup contractors	Specialized equipment and trained cleanup experts
Chemical Transportation Emergency Center (CHEMTREC)	Advice on how to handle spill; liaison with shipper of materials involved
National Agricultural Chemicals Association (NACA), Pesticides Safety Team	Advice for incidents involving pesticides; on-site assistance if necessary
Chlorine Emergency Plan	Advice on how to handle chlorine emergencies; on-scene assistance if necessary

mutual aid responder if found to be negligent in some way can be held liable for the assistance lent during a hazardous materials incident. The participants in the agreement should also agree on the communications system and procedures to be employed in notifying one another. Regular meetings and mock drills are typically used to maintain the readiness of participants. Although mutual aid agreements can temporarily expand emergency response capabilities, their limitations should be known. Some firefighter unions are now using their bargaining powers to neutralize mutual aid pacts. For example, although most union contracts allow the use of apparatus belonging to other members of the mutual aid agreement, others will not allow apparatus to be used by volunteer or call departments unless it is their own.

A mutual aid agreement may not provide the pieces of equipment desired (or in the best location). If the proper equipment is still not available, converting currently underutilized equipment and outfitting it with inexpensive materials should be considered. The equipment and vehicles used to respond to a hazardous materials spill do not need to be new, elaborate, and expensive. The only essential requirement is that they be functional. Older, surplus equipment can often serve as well as new, custom-made equipment.

Many communities have used their know-how to develop an emergency response vehicle without large sums of money. The greatest cost savings have been realized through the purchase or conversion of a surplus vehicle. Additional smaller savings have been realized by adapting other pieces of equipment not originally designed for use in emergency situations, as in the following examples:

1. In Mt. Pleasant, South Carolina, a reserve pumper was converted into a foam truck with storage space for hazardous materials equipment, and an Army surplus jeep was purchased and repainted for use as a mobile command post.
2. In Normal, Illinois, the fire department modified a 1972 reserve pumper into a specialized response vehicle, using the town's public works department facilities to complete body work on the pumper and repaint it a high-visibility chrome yellow. Special care was taken in this case to modify the vehicle so that the unit could retain its certification as a pumper while also serving as the emergency response vehicle.
3. In Denver, Colorado, the fire department hazardous materials emergency response vehicle was fashioned from a 3/4-ton van customized by fire department repair and carpentry shop workers with shelving, insulation, and other adjustments.
4. The Springfield, Illinois, fire department converted a 1957 Ward LaFrance pumper with 4,000 miles of service into what is now known as Foam 1. The apparatus was completely rebuilt in the fire department shops and outfitted for less than $6,000 plus labor.
5. In St. Johns County, Florida, the hazardous materials team's chlorine kits actually belong to the local water department and are kept on the team's vehicle rather than at the waterworks. Patches and gaskets are made from scrap rubber, and a set of vice grips with a welded extension is used to close off leaking hose lines.

Local authorities can also save money by pooling resources with other communities and purchasing items in bulk quantities. To initiate this process, officials should meet with representatives of other agencies and make a list of the basic items that need to be purchased. These may include such items as breathing apparatus, uniforms, hose, tools, and first aid kits. Agreement should be reached on what the standards or specifications of the equipment should be. This has the advantages of (a) making the equipment interchangeable among all the communities, (b) making loans easier to obtain, and (c) ensuring that a person trained on one community's equipment is familiar with that of the next.

Metrofire, a mutual aid association made up of 25 communities and Massport in Greater Boston, Massachusetts, began its joint purchasing program with fire hose. Based on the success of that program, specifications and common purchase procedures were developed for turnout coats, helmets, rubber boots, gloves, and night hitches. Metrofire has also jointly purchased quantities of foam. These are stored in foam banks at centrally located member fire stations. Emergency supplies of foam can be quickly delivered to any emergency in any part of the district through the Metrofire Control Center.

Local expenses can be cut, in addition, by using volunteers and nonprofessionals to handle certain tasks (6). An emergency response team, for example, can be staffed with in-house firefighters. Engine or ladder personnel can be trained in hazardous materials problems, control techniques, and response equipment. This is cost effective when the expense of a full-time team would be prohibitive. Members of the community at large may also be willing to become members of the hazardous materials response team, either on a volunteer or salaried basis. Volunteer operations are increasingly attractive as the cost of paid firefighters rises. Volunteer dispatchers can be used to supplement full-time paid staff. Volunteers can also assist in setting up and administering a mutual aid system. Some firefighter unions, however, are now using their bargaining power to discourage use of volunteer services. The willingness of persons to assist on a volunteer basis should be taken advantage of, but only if they receive the proper training, are able to train regularly as a team, and do not upset current unionized operations. Also, one potential problem with the use of volunteers is that such personnel work when they want to, which makes scheduling difficult. Nonprofessionals can also reduce costs by serving as emergency medical technicians, clerks, or dispatchers.

If the foregoing measures fail to provide the needed equipment or materials, local industry assistance or loans can be sought. Industry is often willing to provide loans or donations of equipment or materials. Their assistance promotes public safety, enhances their image in the community, and helps to keep tax rates down. Arrangements for loans of equipment are quite common, as shown by the following examples:

1. In Guilford County, North Carolina, the county department of emergency services (DES) has direct access to a trailer loaded with absorbent material owned by Colonial Pipeline. Although the pipeline company has its own emergency response team, all of its equipment is available to the DES by simply hitching up Colonial's trailer and towing it to where it is needed.
2. In Memphis, Tennessee, the fire department's hazardous materials squad has the keys to the warehouse of a local distributor of fire and safety supplies. When materials are needed, squad members can enter the warehouse and take the materials needed. The company is reimbursed later. The team is spared the expense of keeping expensive inventory.

Local industry may also be willing to donate certain equipment items, particularly if the donation is tax deductible. If there is a question as to the tax status of a donation, a nonprofit tax-deductible charitable corporation can be set up to accept donations of emergency materials or funds. Donations have stretched the budgets of many hazardous materials teams.

PERFORMING HAZARDOUS MATERIALS INSPECTIONS WITH LIMITED RESOURCES

To prevent hazardous materials transportation incidents, the U.S. Department of Transportation (DOT) has developed a comprehensive regulatory program. Although most businesses affected by the federal hazardous materials transportation regulations--or by similar state regulations--comply with them, the complexity and changing nature of such regulations make it difficult for many to keep informed of all the requirements that affect them. A broad and continuing education program is needed to inform industry of the requirements it must meet. A good education program that reaches all of those potentially affected by the regulations will reduce the need for large inspection staffs. The threat of stiff penalties for noncompliance will also reduce the number of careless businesses. However, only a good inspection program backed by a strong enforcement program will minimize the number of hazardous materials safety violations.

The enormous size of the hazardous materials industry makes it virtually impossible for the federal government to carry out all hazardous materials inspection and enforcement activities. The federal government's inspection resources are most efficiently used if they focus on container manufacturers and shippers and those transportation modes that are predominantly interstate in nature--air, rail, barge, and pipeline (2).

State and local efforts are most efficiently directed toward the inspection of highway carriers of hazardous materials (7,8). State and local officials know best the traffic patterns and truck routes used in their regions. They can more efficiently mobilize inspection and enforcement forces than can the federal government. Some states may already have motor carrier safety or weight inspection personnel or both in the field.

It is not necessary to regularly inspect every vehicle carrying hazardous materials on every roadway. Extensive inspection surveys are impractical, unnecessary, and an inefficient use of resources. To save on inspection costs, state and local officials should consider the following measures.

First, inspection costs can be kept low by concentrating on bulk shipments of hazardous materials. Inspections can also be limited to a single high-risk hazardous material or restricted to a subset of hazardous materials (e.g., hazardous wastes).

Second, the size of the inspection staff can be minimized by conducting inspections at terminals and limiting the number of on-the-road inspections. Also, it is not necessary to inspect every vehicle at each terminal. Of course, inspections at terminals are aimed at the hazardous materials carriers domiciled in the region. Limited on-the-road inspections, therefore, are necessary to monitor the conditions of other carriers.

Third, officials should consider inspecting only a select list of critical hazardous materials safety items rather than performing a full inspection of every vehicle. From the standpoint of safety, it may be more effective to inspect a larger number of vehicles for a smaller number of items (more crucial to safety). A critical item inspection technique makes on-the-road and terminal inspections more efficient. It also increases respect by the carrier for the inspection process by minimizing the inconvenience caused by the inspection.

Finally, the inspection staff can be stretched by performing the hazardous materials inspections periodically and limiting the geographic regions--or roadways--that are covered. For example, only those vehicles that travel a given stretch of roadway could be inspected, and the inspection staff could be rotated to cover different regions throughout the year.

Inspection costs can also be minimized by integrating the hazardous materials inspection program with other ongoing inspection programs. In many states, truck hazardous materials inspections can be conducted in conjunction with, and using the facilities of, state weighing programs. The weigh stations provide a convenient, safe spot for pulling trucks over and inspecting them. In Utah, for example, 20 highway patrol officers work in two-person teams with a portable scale, weighing and inspecting trucks. These inspections concentrate on vehicle condition, proper placarding, and driver qualifications. A hazardous materials inspection program can also be combined with existing truck weighing or safety inspection programs. In Maryland, for example, the state's hazardous materials inspection activities have been integrated with the Maryland Truck Enforcement Division's truck weighing program, which both use personnel from the same department. Fire department personnel might also be trained to perform inspections at major truck terminals in the region.

There are deterrents to consolidation, however. Some state statutes prevent the consolidation of certain program activities. Collective bargaining agreements may also prove to be a stumbling block. Some fear that the use of existing fire or police personnel to conduct hazardous materials inspections will compromise their ability to perform their primary responsibilities.

To stretch inspection resources and eliminate the duplication of effort that typically results with the inspection of interstate carriers, state officials can consider coordinating inspection activities with those of neighboring states. For example, agencies in Oregon, Washington, Idaho, Colorado, Alaska, California, Utah, and Montana and in Alberta, Canada, have formed the Commercial Vehicle Safety Alliance (CVSA). Under the terms of this alliance, members agree to conform with minimum truck inspection criteria and to honor the inspection activities of one another. CVSA members inspect vehicles on highways and in terminals for compliance with a minimum number of critical items. Vehicles that pass the inspection are issued a CVSA decal valid for 3 months. All participating states and provinces use the same decals, which are color coded to denote the period in which they were issued. The system is a simple one: A vehicle inspected in one state that goes to another state or province with a valid decal is not reinspected, unless of course a defect is clearly visible. This coordination of inspection programs eliminates unnecessary duplication of effort, increases significantly the number of inspections that can be performed, and minimizes the costs and delays that inspections impose on the regulated industry.

State and local officials should also consider using part-time and volunteer staff to increase inspection staff but should exercise caution. Because hazardous materials regulations are complex and continually changing, personnel who are less than full time may be pressed to keep their knowledge and skills up to date. This potential problem can be minimized, however, if (a) the part-time worker or volunteer is trained to deal with hazardous materials regulations only and (b) training and responsibilities focus on inspection requirements only and not on administrative and enforcement procedures as well.

The development of industry self-inspection programs can also be encouraged. Industry self-inspection programs can ease considerably the burden placed on state and local inspection and enforcement teams (9-12). They require little government oversight to administer and reduce the need for large (and expensive) inspection staffs. Under the self-audit concept, firms are allowed to police themselves with a minimum of government supervision. To participate, firms must have good safety records and demonstrate that they can satisfy government-prescribed criteria. By incorporating industry self-audit programs as part of a formal inspection program, regulatory agencies can utilize their limited inspection resources more efficiently. Regulatory agencies also benefit from the improved relations that result from recognizing the self-inspection programs already ongoing in many companies.

Industry also benefits substantially from a self-inspection program. The loss of valuable material increases company insurance costs. A spill also raises the possibility of criminal or civil liability claims and significant litigation costs. A self-inspection program lessens the likelihood of these occurrences. Industry audit programs also result in the compilation of cause-and-effect data valuable in management planning and in complying with current Securities and Exchange Commission (SEC) regulations. SEC regulations require that publicly held companies disclose the cost of complying with existing regulations. A sound audit program also improves a company's public image.

Many large companies already inspect their vehicles and monitor their drivers carefully. A formal or voluntary industry self-inspection program gives their efforts the recognition they deserve. Other businesses, however, may not have the motivation or resources to establish self-inspection programs independently. If this is the situation, industry associations are urged to pool their resources and become involved in the administration of such programs. Industry and government agencies located in the region of the Houston Ship Channel have, in fact, included such a feature in their mutual aid arrangement. To belong to CIMA every member company must comply with a minimum number of conditions. As one of these conditions, each member agrees to perform an annual self-inspection, complete a CIMA self-inspection form, and file that form with the CIMA inspection officer. Further, each member agrees to cooperate fully with authorized inspections by the CIMA inspection officers.

OBTAINING HAZARDOUS MATERIALS TRAINING ON A LIMITED BUDGET

Training and education lie at the heart of every effective carrier inspection and enforcement program. Without proper training, hazardous conditions can go undetected and uncorrected. Training for response to hazardous materials transportation spills is equally important. Inadequate or improper training can destroy the best intentions and render the most up-to-date response equipment ineffective.

Many training courses and manuals have been developed by a variety of public and private groups. Yet proper training does not always reach those who need it, for a number of reasons:

1. The expense of sending staff to appropriate courses may be beyond an agency's budget.

2. Other job-related responsibilities may prohibit the attendance at training sessions. Part-time and volunteer personnel often cannot afford to take the time to attend training sessions.

3. The courses and materials available may not meet specific training needs. For example, some courses may not match a particular individual's actual job responsibilities. Similarly, many courses either do not provide field training drills or may use equipment and procedures that are quite different from those available in that region.

These obstacles can be overcome by taking a number of simple actions.

First, local officials need to define their training needs carefully. It is not advisable (or possible) to try to become an expert on everything. The hazardous materials training courses currently available differ significantly in their content and quality. To decide which (if any) of them is best, it is necessary to have a clear idea of what should be known and what skills should be acquired. To define training needs, matrices similar to those developed by the Puget Sound Council of Governments are helpful; they relate a number of different subjects and skills to a total of 48 different positions or occupations (13).

Second, officials should strive to attend only those training courses that are offered locally. The hazardous materials training opportunities offered by state fire academies and other state agencies should be considered only after the training opportunities offered locally have been investigated thoroughly. The hazardous materials training programs offered on a nationwide basis should only be considered if they can provide the specialized training and facilities desired. If it is necessary to travel a sizable distance, one person should be sent and that person should share the course material with other members of the agency, team, or company on his return. It is a highly efficient practice to train the trainer and then establish a training network that builds on the trained individual's knowledge. If the available budget cannot cover travel expenses, the costs can be split with other communities, industries, or organizations.

If the cost of sending personnel to training courses is still too high, officials should actively search out ways to inexpensively bring the training to them. There are several ways to accomplish this, depending on the kinds of skills that need to be acquired. If a good understanding of hazardous materials regulations and emergency response techniques is needed, the possibility of sponsoring a commercially available training course should be explored. Under certain conditions, course sponsors may be willing to conduct a hazardous materials course or seminar in a locality. Once again, contributions from others can be solicited if resources are not sufficient to cover instructor expenses, the cost of materials, and room rental fees. Other communities or organizations may be more willing to share expenses under this kind of arrangement than if, say, a firefighter, not trained as a teacher, were to be sent to an available course.

Other inexpensive ways to bring specialized hazardous materials training to a particular area include the use of videoteleconferences, self-produced videotapes (14), cable television (6), in-house computers (15), and commercially produced films, slide programs, and videocassettes (16). These communications technologies are useful but often underutilized teaching tools. They are particularly beneficial for training volunteer inspectors and emergency response personnel because they offer the freedom to schedule the training sessions. They also (a) eliminate transportation costs, (b) standardize training by assuring that the same information is presented to every student, and (c) allow for the training of new personnel quickly whenever there is a turnover in staff or change in responsibility.

Of course, computer simulations, commercial films, and video tapes cannot teach the fundamentals of teamwork. They also cannot provide the hands-on experience necessary to properly use the available equipment. Only facilities capable of simulating real-life emergency situations can provide this kind of training. Many state fire academies or training institutes have, or are developing, facilities where real-life drills for first responders can be conducted. These same state training programs are also providing their students with the tools necessary for intercommunity teamwork. In Massachusetts, for example, the state fire academy's training programs traditionally instructed firefighters on how to work with their own departments. There was little reason to teach intercommunity teamwork. Even when one community's apparatus went to the aid of another, firefighters tended to stay with their own departments. With recent manpower and equipment cutbacks, however, recruits are now being taught how to work with the firefighters and equipment from other communities. Conducting simulated drills and training medical personnel properly are also extremely important. The treatment of those exposed to certain toxic fumes and radiation requires skills and procedures not routinely used. The Joint Commission on Accreditation of Hospitals requires every hospital to perform two disaster drills every year in order to be accredited. If staged around mock hazardous materials incidents, these drills offer the opportunity to train medical personnel.

If there are no facilities capable of providing simulation-type training in a community, resources can be pooled and a regional training center can be established. A regional training center that teaches the foregoing skills and provides basic instruction may be a highly cost-effective way to provide hazardous materials training programs.

Designated emergency response personnel can economize further by relying heavily on self-help materials. There are a variety of self-help guides available from DOT, other federal agencies, and industry on a variety of topics.

Guest speakers from local universities and industry are often willing to lecture or give free classes. Local industries (chemical, trucking, etc.) are usually quite willing to donate their time and expertise to familiarize their neighbors with the hazardous materials they use, manufacture, and transport.

Finally, communities should explore the possibility of local industry funding and support. Many companies now provide their employees with comprehensive hazardous materials training as part of broader safety training programs. Local officials should determine the kinds of formal hazardous materials training programs available at industrial facilities in their locality and ask that their staff be allowed to attend. Industries that sponsor such training programs generally welcome the opportunity

1. To educate firefighters and other first responders on the types of chemicals they use and the hazards posed by these chemicals,
2. To familiarize local firefighters with their operations, and
3. To familiarize local emergency response personnel with specialized emergency equipment they have.

Communities can also encourage local industries to pool their resources and provide needed hazardous materials training. Several local industry associations have arisen across the country for the primary purpose of providing hazardous materials training, particularly for emergency responders. The South County Industrial Emergency Council (SCIEC) in California is a nonprofit educational organization dedicated to promoting cooperation between industry and emergency services. SCIEC is funded by membership fees, seminar fees, and donations. It provides its more than 160 member organizations with a variety of workshops, seminars, training sessions, and staged disaster drills designed to improve safety practices and emergency response capabilities.

CONCLUSION AND FUTURE DIRECTIONS

There is a tendency to view increased federal assistance as the cure-all for many hazardous materials transportation problems. However, the ideas presented in this paper--with their focus on how states and municipalities can help themselves--are as important a form of assistance as outright federal grants. DOT, EPA, the Federal Emergency Management Agency, or any one of a number of state and local advocacy organizations should initiate an outreach effort that actively promotes the widespread application of cost-saving measures and resource-sharing activities. Consideration could be given to the following:

1. A newsletter that identifies and describes recent examples of resource-sharing and cost-saving measures could be periodically prepared, published, and distributed and ultimately form the basis for a larger catalogue of practical ideas;
2. A film, videotape, or slide-tape show stressing the foregoing ideas could be produced and distributed to state and local officials via teleconferencing or other inexpensive communication methods; or
3. State and local demonstration projects--with the prime objective of applying as many resource-sharing ideas and cost-saving practices as possible--could be authorized and funded.

As part of a broader effort to provide state and local officials with the technical and other assistance they need, consideration might also be given to establishing a regional network or directory of hazardous materials transport experts. These experts would come from both the public and private sectors, would be versed in how to handle specific hazardous materials transportation problems, and would generally be available on request to assist state and local governments with their unique problems.

Last, it is timely to take steps now to examine more closely the potential for self-produced videotapes, videoteleconferences, cable television, and microcomputers as relatively inexpensive media for providing specialized hazardous materials training. Despite their potential, the application of these technologies to hazardous materials training has been quite limited to date. State and local public safety officials would benefit greatly from a study of the training and communications technologies available and their comparative costs and benefits. Demonstration or pilot projects that require the application and evaluation of alternative communications technologies to hazardous materials training could be used as the vehicle to gather the necessary information. Or detailed case studies of existing applications could be conducted based on the reconnaissance-level material contained in the Fire Service Resource Directory for Microcomputers prepared by the National Fire Protection Association, Inc. (15). Guidance materials could then be prepared and provided to local fire, police, and emergency service organizations describing the resources necessary to bring these important training tools to their communities.

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Risk of Multiple Small-Package Spills of Hazardous Substances

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ABSTRACT

The Materials Transportation Bureau (MTB) and U.S. Environmental Protection Agency (EPA) have agreed to regulate the transportation of hazardous substances only when they are shipped in larger than reportable quantities. This agreement simplifies the transportation regulations associated with hazardous substances and reduces the cost of complying with those regulations. However, it presents a potential risk of multiple small-package spills. A method is developed for assessing this spill risk by using data available from the Hazardous Material Incident Reporting System. Application of the data and methods revealed that the risk from multiple small-package spills was less than 0.5 percent of the risk of other regulated spills. Thus, the decision by EPA and MTB to regulate the transport of hazardous substances only when shipped in larger than reportable quantities is supported.

Section 311 of the Clean Water Act (CWA, Public Law 95-217) establishes a program for regulating hazardous substances. [CWA amends the Federal Water Pollution Control Act of 1972 (Public Law 92-500).] Pursuant to this legislation, 297 substances were designated as hazardous by the U.S. Environmental Protection Agency (EPA). These 297 substances were categorized into five groups based on their aquatic toxicity, and each group was assigned a reportable quantity (RQ). The groups and associated RQs are as follows: X, 1 lb; A, 10 lb; B, 100 lb; C, 1,000 lb; and D, 5,000 lb.

In cooperation with EPA, the Materials Transportation Bureau (MTB) of the U.S. Department of Transportation (DOT) incorporated these substances into its Hazardous Materials Table (49 C.F.R. 172.101). [For an excellent presentation of the regulations governing the transportation of hazardous materials, see Red Book on Transportation of Hazardous Materials (1).] Of the 297 substances, approximately 45 percent were already on the table by name. An additional 15 percent were already covered in general categories but not otherwise specified. The remaining 40 percent had not been previously covered. The Hazardous Materials Table has about 360 entries to cover the 297 substances, because many substances have different hazard classes or packing requirements or both, depending on the concentration and form. [For example, aldrin has six entries: aldrin, poison-B; aldrin, cast solid, ORM-A; aldrin mixture, dry (>65 percent aldrin), poison-B; aldrin mixture, dry ($\leq$65 percent aldrin), ORM-A; aldrin mix ture, liquid (>60 percent aldrin), poison-B; aldrin mixture, liquid ($\leq$60 percent aldrin), ORM-A.]

The MTB regulations on the transportation of hazardous substances require packages to be marked with the letters RQ when the package contains a reportable quantity or more of a hazardous substance. Packages containing less than a reportable quantity are not considered hazardous substances by MTB. (Note that they still fall under the regulation of CWA, however.) Further, the MTB requires reporting to the U.S. Coast Guard's National Response Center (NRC) when an RQ of a hazardous substance spills from a single package or, for bulk shipments, from a single transport vehicle.

These regulations present two categories of risk: First, a carrier could be involved in an incident in which many small unmarked packages spill and be unaware of the hazard because the packages were unmarked, and, second, multiple spills from marked packages could be unreported to the NRC because no single package spilled more than an RQ. The objective of this study is to assess these risks for X, A, and B hazardous substances where the chances of multiple shipments in a single vehicle are highest. The main source of data for the study is the MTB's Hazardous Material Incident Reporting (HMIR) System.

PROBLEM STATEMENT

The probability of a hazardous substance spill relative to the probability of a spill of a hazardous material is not a particularly meaningful estimate of relative risk for two reasons. First, not all hazardous substances are included in the commodity-specific HMIR data that have been extracted for analysis in this study. So the estimates of relative spill frequency from the HMIR data are likely to be inaccurate. Second, and most important, the damages that result from a spill of a hazardous material may be quite different from the damages from a hazardous substance spill. Risk should measure the expected hazard or damage. Expected hazard is the probability of the event multiplied by its severity or hazard level (2). So relative probability is a good measure of relative risk only when the damages from the events being compared are the same. For example, at the absurd level, if water were a hazardous material, it would greatly inflate the number of hazardous material spill reports and would dwarf the number of other spills in the file, but because the damage from a water spill is so slight compared with spills of hazardous substances like aldrin or parathion, the relative probability alone would be meaningless as a measure of relative risk. A more relevant example is wet electric storage batteries and paint when shipped in packages of less than 5 gal. These materials accounted for a large share of the spill reports, but after January 1, 1981, spills of these materials did not need to be reported to MTB.

With the foregoing points in mind, it has been decided to estimate the fraction of all hazardous substance spill incidents in which an RQ or more spills from multiple small unmarked packages. In this section, "small unmarked" and "unmarked" mean too small to require marking pursuant to the DOT-MTB regulations. Stated slightly differently, given that a spill incident involving an X, A, or B hazardous substance has occurred, what is the probability that an RQ has spilled from more than one small unmarked package?

There are two important characteristics of this approach that are worth noting:

1. The events whose probabilities are being compared (X, A, or B spill versus two or more small-package spills of X, A, or B substances) have similar consequences (note that because spill size is not the same, even this formulation of the problem does not completely reduce relative probabilities to relative risk).
2. The incomplete reporting to HMIR should not bias the measure of the relationship between spills of a collection of substances and multiple small-package spills of those substances. [Another approach to the analysis of risk in hazardous materials transportation is given in a report by Abkowitz et al. (3).]

The relative probability being estimated is the sum of (a) the probability that an RQ spills in an incident involving exactly two spills of the same X, A, or B substance; plus (b) the probability that an RQ spills in an incident involving three spills, two or more of the same X, A, or B substance; plus (c) the probability in four-spill incidents; and so on. The approach is to estimate the probability for two-spill incidents, then for three-spill incidents, and so on until the additions appear to be small enough to ignore.

For the two-spill case, the probability to be estimated is the probability that an incident occurs involving exactly two spills of the same hazardous substance where each of the two spilled packages contains less than an RQ but where the combined spill exceeds an RQ, given that an incident involving an X, A, or B hazardous substance spill has occurred. This probability can be stated precisely as follows:

$$\begin{aligned} P^{(2)} = \sum_{Y \epsilon S} & \Pr(t = 2, k_1 = Y, k_2 = Y, w_1 < RQ_Y, w_2 < RQ_Y, \\ & Q_1 + Q_2 \geqslant RQ_Y \mid t \geqslant 1, k_1 \text{ or } k_2 \epsilon S) \end{aligned} \qquad (1)$$

where

S = set of X, A, or B hazardous substances;
$Y \epsilon S$ = Y is an element of S;
k_1 = first spilled substance;
k_2 = second spilled substance;
t = number of packages spilled in the incident;
w_1 = weight of the first spilled package;
w_2 = weight of the second spilled package;
Q_1 = weight spilled from the first package;
Q_2 = weight spilled from the second package;
RQ_Y = reportable quantity for substance Y; and
$P^{(I)}$ = probability that an RQ of an X, A, or B hazardous substance spilled from unmarked packages in an incident involving exactly I spilled packages given that an incident involving an X, A, or B hazardous substance has occurred.

The HMIR data contain information on all these variables. So one approach would be to identify all incidents involving X, A, or B hazardous substances and then to identify the subset of incidents that meets the conditions specified in Equation 1. The relative frequency could be used as a measure of the relative probability. Unfortunately, there are only 1,531 X, A, or B hazardous substance spills in the HMIR data base covering 42 of the 92 hazardous substances covered by the CWA, too few to reliably measure the relative probability.

The approach taken to estimate $P^{(2)}$ is to reformulate Equation 1 into a set of factors that can be estimated from the data on hazardous material spill incidents by making some conservative approximations and some explicit assumptions. (There are 79,700 hazardous material spill incidents that were reported in the HMIR between January 1976 and August 1981, the period covered by the HMIR data used in this study.) This development is presented in the Appendix. The factors result from the definition of conditional probability (4) and from manipulations of the following form:

$$\begin{aligned} \Pr(A,B,C) &= \Pr(A,B \mid C) \Pr(C) \\ &= \Pr(A \mid B,C) \Pr(B \mid C) \Pr(C) \end{aligned}$$

The following five assumptions were used to reformulate Equation 1:

Assumption 1

$$\Pr(t = 2 \mid t \geqslant 1, k_1 = Y) = \Pr(t = 2 \mid t \geqslant 1)$$

Assumption 2

$$\Pr(k_2 = Y \mid t = 2, k_1 = Y) = \Pr(k_2 = k_1 \mid t = 2)$$

Assumption 3

$$\Pr(w_1 < 1 \mid t = 2, k_1 = Y, k_2 = Y) = \Pr(w_1 < 1 \mid t = 2)$$

Assumption 4

$$\Pr(w_2 < 1 \mid t = 2, k_1 = Y, k_2 = Y, w_1 < 1) = \Pr(w_2 < 1 \mid t = 2, k_1 = k_2, w_1 < 1)$$

Assumption 5

$$\begin{aligned} & \Pr(Q_1 \geqslant 1/2 \text{ or } Q_2 \geqslant 1/2 \mid t = 2, k_1 = Y, k_2 = Y, w_1 < 1, w_2 < 1) = \\ & \qquad \Pr(Q_1 \geqslant 1/2 \text{ or } Q_2 \geqslant 1/2 \mid t = 2, w_1 < 1, w_2 < 1) \end{aligned}$$

Equation 1 is then reformulated as follows:

$$\begin{aligned} P^{(2)} = {} & \Pr(t = 2 \mid t \geqslant 1) \Pr(k_2 = k_1 \mid t = 2) \\ & \text{x} \Big(\Pr(k_1 \epsilon S_X \mid t \geqslant 1, k_1 \epsilon S) \Pr(w_1 < 1 \mid t = 2) \\ & \text{x} \Pr(w_2 < 1 \mid t = 2, k_1 = k_2, w_1 < 1) \\ & \text{x} \{1 - [\Pr(Q < 1/2 \mid t = 2, w < 1)]^2\} \\ & + \Pr(k_1 \epsilon S_A \mid t \geqslant 1, k_1 \epsilon S) \Pr(w_1 < 10 \mid t = 2) \\ & \text{x} \Pr(w_2 < 10 \mid t = 2, k_1 = k_2, w_1 < 10) \\ & \text{x} \{1 - [\Pr(Q < 5 \mid t = 2, w < 10)]^2\} \\ & + \Pr(k_1 \epsilon S_B \mid t \geqslant 1, k_1 \epsilon S) \Pr(w_1 < 100 \mid t = 2) \\ & \text{x} \Pr(w_2 < 100 \mid t = 2, k_1 = k_2, w_1 < 100) \\ & \text{x} \{1 - [\Pr(Q < 50 \mid t = 2, w < 100)]^2\} \Big) \end{aligned} \qquad (2)$$

All of the assumptions involve independence of a component factor to variation with the specific substance considered. Note that assumptions 3, 4, and 5 depend on RQ and that only assumptions for X substances are shown. Similar expressions can be found in Equation 2 for A and B substances.

The first assumption states that the probability of a two-spill incident is independent of the material spilled. The second assumption states that the probability that the second material spilled in a two-spill incident is the same as the first material spilled is independent of the material spilled. The third assumption states that the probability that the first package spilled contained less than 1 lb (for X hazardous substances) is independent of the material in the shipment and of whether the two spilled materials are the same. The fourth assumption states that the probability that the second package spilled contains less than 1 lb (for X hazardous substances) is independent of the material spilled. Finally, the fifth assumption states that the probability that either spill is less than 1/2 lb (for X hazardous substances) is independent of the material spilled or the fact that the same material spilled from both packages.

In addition to these five assumptions, a conservative approximation was also used in the development of Equation 2. This approximation involves the probability that the sum of the two spills (Q_1 and Q_2) will exceed an RQ. Obviously either Q_1 or Q_2 must exceed 1/2 RQ if the sum is to exceed an RQ, but one could exceed 1/2 RQ while the sum was less than an RQ. The conservative approximation is as follows:

$$\Pr(Q_1 + Q_2 \geqslant \text{RQ}) = \Pr(Q_1 \geqslant 1/2 \text{ RQ or } Q_2 \geqslant 1/2 \text{ RQ})$$

The probability that the sum of the spills exceeds an RQ is approximated by the probability that one of the two spills exceeds 1/2 RQ. This is taken further in Equation 2 where the probability that one of the spills exceeds 1/2 RQ is replaced by 1 minus the probability that both spills are less than 1/2 RQ.

MEASURING THE FACTORS

Evidence of the validity of assumptions 1-5 will be presented later, but first the measures used to estimate each factor must be defined. The measures used for the factor probabilities in Equation 2 are as follows (similar measures are developed for A and B substances):

$$\Pr(t = 2 \mid t \geqslant 1) \cong (R_2/2)/[R_1 + (R_2/2) + (R_3/3)] \tag{3}$$

$$\Pr(k_2 = k_1 \mid t = 2) \cong R_{22}/R_2 \tag{4}$$

$$\Pr(w_1 < 1 \mid t \geqslant 1) \cong S_1/(R_1 + R_2 + R_3) \tag{5}$$

$$\Pr(w_2 < 1 \mid t = 2, k_1 = k_2, w_1 < 1) \cong G_1/H_1 \tag{6}$$

$$\begin{aligned} &\Pr(Q_1 \geqslant 1/2 \text{ or } Q_2 \geqslant 1/2 \mid t = 2, w_1 < 1, w_2 < 1) \\ &\quad \cong 1 - [\Pr(Q < 1/2 \mid t \geqslant 1, w < 1)]^2 \cong 1 - (F_1/S_1)^2 \end{aligned} \tag{7}$$

$$\Pr(k_1 \in S_X \mid t \geqslant 1, k_1 \in S) \cong X/(X + A + B) \tag{8}$$

where

R_1 = number of one-spill incident records (one record per incident),
R_2 = number of two-spill incident records (two records per incident),
R_3 = number of three-spill incident records (three records per incident),
R_{22} = number of two-spill incident records where the same material spills in both records,
S_1 = number of records where the shipment weight is less than 1 lb,
G_1 = number of records where the same material spilled in a two-spill incident and where both spills were from packages with a shipment weight of less than 1 lb,
H_1 = number of records that have shipment weights of less than 1 lb where the same material spilled in a two-spill incident,
F_1 = number of records where the shipment weight is less than 1 lb and less than half of the shipment spilled, and
X = number of category-X hazardous substance records.

Note that for each factor probability the numbers are defined over the set of spill records for which all necessary data were available. This permitted the largest sample of spills to be used in calculating each factor, but as a result the variables used are not precisely the same in each measure. For example, the R_1 used in estimating $\Pr(t = 2 \mid t > 1)$ is somewhat different from the R_1 used in estimating $\Pr(w < 1 \mid t \geq 1)$ because S_1 is not available for all spill records.

A conservative assumption has been introduced into the measurement of the probability that 1/2 RQ spills from one of the packages. Note in the definition of F_1 that instead of a 1/2 RQ spill a half shipment spill is used. This is equivalent to assuming that all shipments of less than an RQ contain exactly an RQ.

The variables used to measure the factor probabilities can be accumulated over a variety of sets of spill records. The largest set is the set of all hazardous material spills. The set of all hazardous substance spills is much smaller but also of interest. Further, the measures can be calculated for individual materials to examine how the estimates of the factor probabilities vary with material. This is a way of qualitatively testing the key assumption of independence of material that was used to develop Equation 2. Obviously, the smaller the sample the more the factor probability estimates will be influenced by the random noise or sampling error in the sample.

Table 1 presents estimates of the factor probabilities. Four estimates are presented. The first two are averages over all hazardous material and hazardous substance spill incidents. The next two estimates are selected from the commodity-specific factors. In the median estimate 50 percent of the commodities have factors of smaller size and 50 percent have factors of larger size. In the 90th-percentile case, 90 percent of the commodities have factors of smaller size and only 10 percent have larger factors. In these last two sets of estimates each estimate is selected separately, so different commodities are used for each factor. If a factor probability is nearly constant over the four columns, as in the case of the first factor, the corresponding assumption is supported. If the factor is not constant over the columns, the assumption is more doubtful, although at least part of the variation is caused by random noise or sampling error.

The similarities between the estimates of the factors calculated over all hazardous substance incidents and over all hazardous material incidents suggest that, in aggregate, spill incidents involving hazardous substances and hazardous materials are similar. In percentage terms, the largest discrepancies arise in factors involving shipment size $[\Pr(w_1 < \text{RQ} \mid t \geq 1)]$. The dominance of anhydrous ammonia in the hazardous substance incidents probably accounts for the discrepancy, because it is transported in large shipments.

The similarities between the average and median estimates for the hazardous materials indicate that a few unusual hazardous materials are not dominating the spill data. The 90th-percentile estimates give an indication of the range of factor values that can be expected. As mentioned earlier, some of the differences between the median and 90th-percentile estimates are due to random noise or sampling error, which results from the small number of spills over which the factors are calculated. Some of the difference is undoubtedly due to real differences in the way specific materials are shipped and their susceptibility in spill incidents.

RESULTS

The factor probabilities can be used in Equation 2

TABLE 1 Estimates of the Factor Probabilities

	Factor Estimate			
	Avg for All X, A, or B Hazardous Substance Spill Incidents	For All Hazardous Material Spill Incidents		
Measure		Avg	Median	90th Percentile
$\Pr(t = 2 \mid t \geq 1)$	0.0406[a]	0.0606[b]	0.0605[c]	0.0804[c]
$\Pr(k_2 = k_1 \mid t = 2)$	0.4870[a]	0.3886[b]	0.2917[c]	0.7225[c]
$\Pr(w_1 < 1 \mid t \geq 1)$	0.0000[d]	0.0009[e]	0.0000[c]	0.0024[c]
$\Pr(w_2 < 1 \mid t = 2, k_1 = k_2, w_1 < 1)$	1.000[f]	1.000[f]	1.000[f]	1.000[f]
$1 - [\Pr(Q < 1/2 \mid t \geq 1, w < 1)]^2$	1.000[f]	0.9600[g]	1.000[f]	1.000[c]
$\Pr(w_1 < 10 \mid t \geq 1)$	0.0198[d]	0.0315[e]	0.0234[c]	0.1121[c]
$\Pr(w_2 < 10 \mid t = 2, k_1 = k_2, w_1 < 10)$	1.000[f]	0.5385[e]	1.000[f]	1.000[f]
$1 - [\Pr(Q < 5 \mid t \geq 1, w < 10)]^2$	0.8457[d]	0.8209[e]	0.7934[c]	1.000[c]
$\Pr(w_1 < 100 \mid t \geq 1)$	0.0989[b]	0.1547[e]	0.1383[c]	0.3578[c]
$\Pr(w_2 < 100 \mid t = 2, k_1 = k_2, w_1 < 100)$	1.000[f]	0.6531[e]	0.5106[g]	1.000[g]
$1 - [\Pr(Q < 50 \mid t \geq 1, w < 100)]^2$	0.3485[d]	0.4813[e]	0.4861[c]	0.7256[c]

[a] Calculated over the 1,416 X, A, or B hazardous substance spill incidents.
[b] Calculated over the 79,700 hazardous material spill incidents.
[c] Measured over the 72 materials with more than 100 incidents.
[d] Calculated over the 1,145 X, A, or B hazardous substance spill incidents with good spill and shipment size data.
[e] Calculated over the 44,699 hazardous material spill incidents with good spill and shipment size data.
[f] Sample did not contain adequate information. Upper bound of 1.0 used.
[g] Measured over the 31 materials with more than 10 matching-material, two-spill incidents.

along with the portion of all X, A, or B hazardous substance spills that belongs to each category $[\Pr(k_1 \in S_X \mid k_1 \in S)]$ to estimate $P^{(2)}$. Table 2 gives these estimates of $P^{(2)}$ along with estimates of the probability that a multiple-small-package incident releases an RQ, given an X, an A, or a B hazardous substance spill. For the first three sets of factor estimates the estimates of $P^{(2)}$ are similar. $P^{(2)}$ given an X hazardous substance spill is the only exception. The extremely low frequency of shipments weighing less than 1 lb resulted in no observations in the average hazardous substance sample and none for the median hazardous material either. All other estimates are quite close, within a factor of 2. These results again suggest that using the average hazardous material factors produces reasonable estimates of hazardous substance spill probabilities. In the remainder of the paper, the focus will be on the analysis of probability estimates developed from the average factors calculated from the set of all hazardous material spills.

The 90th-percentile factor estimates produce estimates of $P^{(2)}$ that are substantially higher than the other three estimates. The 90th-percentile factor estimates should be interpreted as estimates of the range of the commodity-specific spill probabilities that are consistent with the average estimate. Table 3 shows the same 90th-percentile estimates of $P^{(2)}$ as in Table 2 but also shows the highest estimates of $P^{(2)}$ developed for single materials. These estimates are developed from the factors for a single material. Ammonium hydroxide has the highest $P^{(2)}$ of all hazardous materials, which is about the same as the 90th-percentile estimate. This is a little misleading, however, because 1.0 was used as the factor $[\Pr(w_2 < RQ \mid t = 2, k_1 = k_2, w_1 < RQ)]$ for all materials because most of the single-material samples were too small to estimate this factor. Calcium hypochlorite is the X, A, or B hazardous substance with the highest estimate of $P^{(2)}$.

The estimates of $P^{(2)}$ in Table 2 suggest that the probability of an RQ spill from more than one unmarked package is small (10^{-3}). However, the probability of three, four, and more spills must be added to the estimates of $P^{(2)}$ to obtain the full probability. $P^{(3)}$ and $P^{(4)}$ cannot be ignored a priori because there are two factors that change in different directions and influence the probability

TABLE 2 Probability of RQ Spills from Two-Spill Incidents

	$P^{(2)}$, Probability That an RQ Spills from Two Unmarked Packages Given			
Factor Estimate	X Spill	A Spill	B Spill	Spill of Some X, A, or B Substance
Avg for all hazardous substance spill incidents	0.0	3.3×10^{-4}	6.8×10^{-4}	5.7×10^{-4}
For all hazardous material spill incidents				
Avg	2.0×10^{-5}	3.3×10^{-4}	1.1×10^{-3}	9.3×10^{-4}
Median	0.0	3.3×10^{-4}	6.1×10^{-4}	5.1×10^{-4}
90th percentile	1.4×10^{-4}	6.5×10^{-3}	1.5×10^{-2}	1.2×10^{-2}

TABLE 3 Possible Variations in Probability with Material

	$P^{(2)}$, Probability That an RQ Spills from Two Unmarked Packages Given			
Factor Estimate	X Spill	A Spill	B Spill	Spill of Some X, A, or B Substance
90th percentile[a]	1.4×10^{-4}	6.5×10^{-3}	1.5×10^{-2}	1.2×10^{-2}
Highest single hazardous material (ammonium hydroxide, < 45 percent ammonia)				1.1×10^{-2}
Highest single X, A, or B hazardous substance (calcium hypochlorite mixture)				1.2×10^{-3}

[a] Each factor used in calculating the probability was chosen so that 90 percent of the hazardous materials had factors with lower values.

of a larger number of spills. First, incidents with more spills are much rarer than two-spill incidents. However, when more packages spill, an RQ spill is more likely to result. Table 4 presents the contributions of two-, three-, and four-spill incidents to the total estimated probability that a hazardous substance spill will be an RQ spill from more than one unmarked package. The factors used to calculate these probabilities are presented in a study by Hoxie and Woodman (5).

TABLE 4 Contribution of Number of Spills

	Probability That an RQ Spills from More Than One Unmarked Package Given			
$P^{(1)a}$	X Spill	A Spill	B Spill	Spill of Some X, A, or B Substance
$P^{(2)}$	2.0×10^{-5}	3.3×10^{-4}	1.1×10^{-3}	9.3×10^{-4}
$P^{(3)}$	3.1×10^{-6}	5.3×10^{-5}	2.1×10^{-4}	1.7×10^{-4}
$P^{(4)}$	8.6×10^{-7}	1.5×10^{-5}	6.7×10^{-5}	5.4×10^{-5}
Total	2.4×10^{-5}	4.0×10^{-4}	1.4×10^{-3}	1.2×10^{-3}

[a] Averaged over all hazardous material spills.

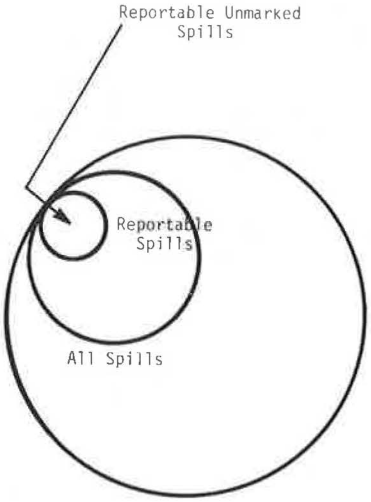
As the data in Table 4 indicate, three- and four-spill incidents add only about 30 percent to the $P^{(2)}$ estimate, and the contribution drops off by about a factor of 5 with each increase of 1 in the number of packages spilled in the incident. Incidents of five spills or more can safely be ignored.

The total probability (1.2×10^{-3}) is very small. The 42 X, A, or B hazardous substances reported in the HMIR were involved in 1,531 spills over the period January 1976 through August 1981. Over this 5.5-year period, then, it would be expected that there would be roughly two spills of an RQ from multiple-spill incidents involving unmarked packages of these 42 hazardous substances. Actually, none were reported.

Only half of the X, A, or B hazardous substances designated under the CWA are in the HMIR data, and without knowledge of the total spills of the unreported half, an estimate of the total number of RQ spills from unmarked packages cannot be made. Further, new designations of hazardous substances by EPA under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) (Public Law 96-510) will also increase the number of X, A, or B hazardous substance spills. With the increases in hazardous substance spills, the expected number of RQ spills from unmarked packages will increase in a ratio of about 800 to 1; that is, of every 800 hazardous substance spills, one is expected to be an RQ spill from small unmarked packages. As the proportion of X, A, or B hazardous substance spills that falls into each category changes from the 0.1109X, 0.1135A, or 0.7756B found in the HMIR data, the expected rate of increase in RQ spills from unmarked packages will also vary. The 1.2×10^{-3} estimate is $(0.1109 \times 2.4 \times 10^{-5}) + (0.1135 \times 4.0 \times 10^{-4}) + (0.7756 \times 1.4 \times 10^{-3})$; $1.2/1{,}000 \approx 1/800$.

OTHER MEASURES

Without being able to estimate the total number of RQ spills from unmarked packages, an important statistic in attempting to judge the acceptability of these spill probabilities is the fraction of reportable incidents that would go unreported because the spill came from more than one unmarked package. ("Reportable" means spills of more than an RQ. The regulations currently require reporting to the NRC only when an RQ spills from a single package.) This fraction is different from the 1.2×10^{-3} cited earlier because not all hazardous substance incidents result in spills of an RQ. In fact, only 0.266 of the incidents spill more than 100 lb, 0.533 spill more than 10 lb, and 0.898 spill more than 1 lb. (These values are calculated over all spill reports in the HMIR data and cover all hazardous materials.) The foregoing values are used with the probabilities in Table 4 to calculate the fraction of reportable incidents that would go unreported because the spills were from unmarked packages. Figure 1 shows these relationships for B hazardous substances and the following tabulation gives the results for X, A, and B hazardous substances:



$$1.\quad \frac{\text{Reportable}}{\text{All}} = .27$$

$$2.\quad \frac{\text{Reportable, Unmarked}}{\text{All}} = 1.4\text{x}10^{-3}$$

$$3.\quad \frac{\text{Reportable, Unmarked}}{\text{Reportable}} = \frac{1.4\text{x}10}{.27} = 5.3\text{x}10^{-3}$$

FIGURE 1 Relationship among all spills, reportable spills, and reportable spills from unmarked packages for B hazardous substance.

	Probability That an RQ Spills from More Than One Unmarked Package Given an RQ Spill of		
	X	A	B
Avg over all spills	2.7×10^{-5} (1 in 37,000)	7.5×10^{-4} (1 in 1,300)	5.3×10^{-3} (1 in 190)

Roughly 1 in 37,000 reportable X hazardous substance spills, 15 in 20,000 reportable A hazardous substance incidents, and 5 in 1,000 reportable B hazardous substance incidents would be from unmarked packages. All of these fractions are small and are probably much smaller than the fraction of incidents that are not reported for other reasons.

One of the reasons for nonreporting could be that a spill of less than an RQ from a marked package is added to a spill from an unmarked package. In this case the operator of the vehicle would know that a hazardous substance had spilled but he would be unaware that an RQ had spilled. Table 5 presents estimates of the fraction of reportable spills that results from spills of less than an RQ from a marked

TABLE 5 Fraction of Reportable Two-Spill Incidents That Might Not Be Reported Because No Single Package Spilled an RQ

Type of Two-Spill Incident[a]	Fraction of X Spills	A Spills	B Spills
One marked and one unmarked package	2.4×10^{-6}	5.4×10^{-4}	3.6×10^{-3}
Two marked packages	2.7×10^{-3}	1.8×10^{-2}	2.1×10^{-2}
Total	2.7×10^{-3} (1 in 370)	1.9×10^{-2} (1 in 50)	2.1×10^{-2} (1 in 40)

[a] In which less than an RQ spills from each package but the sum of spills exceeds an RQ.

package and a spill from an unmarked package. These fractions are roughly the same size as the fraction of reportable spills from multiple spills of unmarked packages.

Table 5 also presents the fraction of reportable spills that are from multiple spills of marked packages where less than an RQ spills from each package. Under the MTB's regulations these incidents do not need to be reported even though an RQ spilled in the incident. This fraction is much larger than the fraction from a marked and an unmarked package or that from two unmarked packages. The factors used to calculate the fractions reported in Table 5 are given in the report by Hoxie and Woodman (5).

CONCLUSIONS

Table 6 shows estimates of the fraction of incidents in which an RQ or more spills for the two categories of risk. The estimates were derived from the MTB's HMIR data and the probability equation developed in the foregoing and in the report by Hoxie and Woodman (5). The results indicate that less than 0.53 percent of all B hazardous substance spills of an RQ or more are from incidents involving multiple spills from unmarked packages. Further, the comparable fraction is even smaller for A hazardous substances and smaller still for X hazardous substances.

TABLE 6 Summary of Multiple-Spill Risk

Type of Incident	Fraction of RQ Spills of X Substance	A Substance	B Substance
Unmarked and unreported (multiple[a] spills from unmarked packages)	2.7×10^{-5}	7.5×10^{-4}	5.3×10^{-3}
Unreported			
One spill of unmarked package and one spill of less than an RQ from a marked package	2.4×10^{-6}	5.4×10^{-4}	3.6×10^{-3}
Two spills of less than an RQ from marked packages	2.7×10^{-3}	1.8×10^{-2}	2.1×10^{-2}

[a] Includes incidents with two, three, and four spills.

The results are somewhat less complete for incidents spilling more than an RQ that are unreported because no single spill exceeds an RQ. Only two-spill incidents are included in the analysis, but the risk calculations indicate that such cases compose less than 3 percent of all incidents in which an RQ or more of B hazardous substance spills. Further, this fraction is dominated by the spills from marked packages, and because only the letters RQ are marked on the package, it seems likely that these spills would be reported (overreported) even though reporting is not required by current regulations. They would be reported because the marking does not indicate the category of hazardous substance or the RQ threshold, so as long as the package spilled more than 1 lb, it could potentially be an RQ.

These results are based on several assumptions. Because the probabilities were estimated from hazardous material spill data, the most important assumption is that hazardous substances are shipped and spill in ways that are the same as those for hazardous materials. An analysis of the spill data for the 42 X, A, or B hazardous substances contained in the HMIR data base supports the validity of this assumption. Other assumptions involve the independence of probability factors across substances and the degree to which the HMIR data are representative of all hazardous material spills.

APPENDIX

The objective of this Appendix is to show how assumptions 1-5 are used to develop an upper bound on the probability of an incident in which two packages containing the same hazardous substance spill when each package contains less than an RQ but more than an RQ spills, given that an incident involving a hazardous substance has occurred. Obviously another goal of the development is to reduce the probability to a set of probabilities each of which can be estimated by using the HMIR data.

The probability of interest $[P^{(2)}]$ is as follows:

$$P^{(2)} = \sum_{Y \epsilon S} \Pr(t = 2, k_1 = Y, k_2 = Y, w_1 < RQ_y, w_2 < RQ_y, Q_1 + Q_2 \geqslant RQ_y \mid t \geqslant 1) / \sum_{Z \epsilon S} \Pr(k_1 = Z \text{ or } k_2 = Z \mid t \geqslant 1) \quad (9)$$

where the symbols are as defined for Equation 1.

Examine the numerator:

$$\begin{aligned} C(Y) &= \Pr(t = 2, k_1 = Y, k_2 = Y, w_1 < RQ_Y, w_2 < RQ_Y, Q_1 + Q_2 \geqslant RQ_Y \mid t \geqslant 1) \\ &= \Pr(t = 2, k_2 = Y, w_1 < RQ_Y, w_2 < RQ_Y, Q_1 + Q_2 \geqslant RQ_Y \mid t \geqslant 1, k_1 = Y) \times \Pr(k_1 = Y \mid t \geqslant 1) \\ &= \Pr(k_2 = Y, w_1 < RQ_Y, w_2 < RQ_Y, Q_1 + Q_2 \geqslant RQ_Y \mid t = 2, k_1 = Y) \\ &\quad \times \Pr(t = 2 \mid t \geqslant 1, k_1 = Y) \times \Pr(k_1 = Y \mid t \geqslant 1) \end{aligned} \quad (10)$$

Assume that the probability of a two-spill incident is independent of the material spilled (assumption 1). Then

$$C(Y) = \Pr(k_2 = Y, w_1 < RQ_Y, w_2 < RQ_Y, Q_1 + Q_2 \geqslant RQ_Y \mid t = 2, k_1 = Y) \times \Pr(t = 2 \mid t \geqslant 1) \times \Pr(k_1 = Y \mid t \geqslant 1) \quad (11)$$

$$C(Y) = \Pr(w_1 < RQ_Y, w_2 < RQ_Y, Q_1 + Q_2 \geqslant RQ_Y \mid t = 2, k_1 = Y, k_2 = Y) \times \Pr(k_2 = Y \mid t = 2, k_1 = Y) \times \Pr(t = 2 \mid t \geqslant 1) \times \Pr(k_1 = Y \mid t \geqslant 1) \quad (12)$$

Assume that the probability that the second material spilled in a two-spill incident is the same as the first material spilled is independent of the first material (assumption 2). Then

$$C(Y) = \Pr(w_1 < RQ_Y, w_2 < RQ_Y, Q_1 + Q_2 \geqslant RQ_Y \mid t = 2, k_1 = Y, k_2 = Y) \times \Pr(k_2 = k_1 \mid t = 2) \times \Pr(t = 2 \mid t \geqslant 1) \times \Pr(k_1 = Y \mid t \geqslant 1) \quad (13)$$

Recall that

$$
\begin{aligned}
P^{(2)} &= \sum_{Y \epsilon S} C(Y) \Big/ \sum_{Z \epsilon S} \Pr(k_1 = Z \text{ or } k_2 = Z \mid t \geqslant 1) \\
&= \sum_{Y \epsilon S} [\Pr(w_1 < RQ_Y, w_2 < RQ_Y, Q_1 + Q_2 \geqslant RQ_Y \mid t = 2, k_1 = Y, \\
&\quad k_2 = Y) \times \Pr(k_2 = k_1 \mid t = 2) \times \Pr(t = 2 \mid t \geqslant 1) \\
&\quad \times \Pr(k_1 = Y \mid t \geqslant 1)] \div \sum_{Z \epsilon S} \Pr(k_1 = Z \text{ or } k_2 = Z \mid t \geqslant 1)
\end{aligned} \tag{14}
$$

This expression can be rewritten as follows:

$$
\begin{aligned}
P^{(2)} &= \Pr(t = 2) \mid t \geqslant 1) \times \Pr(k_2 = k_1 \mid t = 2) \\
&\quad \times \sum_{Y \epsilon S} [\Pr(k_1 = Y \mid t \geqslant 1) \Big/ \sum_{Z \epsilon S} \Pr(k_1 = Z \text{ or } k_2 = Z \mid t \geqslant 1)] \\
&\quad \times \Pr(w_1 < RQ_Y, w_2 < RQ_Y, Q_1 + Q_2 \geqslant RQ_Y \mid t = 2, \\
&\quad k_1 = Y, k_2 = Y)
\end{aligned} \tag{15}
$$

The first two terms can be moved out of the summation because they are constant, unaffected by the material.

Examine the following:

$$
D(Y) = \Pr(k_1 = Y \mid t \geqslant 1) \Big/ \sum_{Z \epsilon S} \Pr(k_1 = Z \text{ or } k_2 = Z \mid t \geqslant 1) \tag{16}
$$

$\Pr(k_1 = Z$ or $k_2 = Z \mid t \geq 1)$ is short for $\Pr(t = 1$ and $k_1 = Z$; or $t = 2$ and $k_1 = Z$; or $t = 2$ and $k_2 = Z \mid t \geq 1)$. However, because $t = 2$ only 0.06 of the time that $t \geq 1$ and because $k_1 = Z$ some of the time when $k_2 = Z$, this expression can be approximated by $\Pr(k_1 = Z \mid t \geq 1)$. (This term should also cover the situation in which $t = 3, 4, \ldots$, and a complete statement of this approximation would include $k_3, k_4, \ldots = Z$. However, the arguments made when $t = 2$ apply for the $t = 3, 4, \ldots$ cases as well.) So

$$
\begin{aligned}
D(Y) &= \Pr(k_1 = Y \mid t \geqslant 1) \Big/ \sum_{Z \epsilon S} \Pr(k_1 = Z \mid t \geqslant 1) \\
&= \Pr(k_1 = Y \mid t \geqslant 1, Y \epsilon S)
\end{aligned} \tag{17}
$$

Thus, the original probability becomes

$$
\begin{aligned}
P^{(2)} &= \Pr(t = 2 \mid t \geqslant 1) \times \Pr(k_2 = k_1 \mid t = 2) \sum_{Y \epsilon S} \Pr(k_1 = Y \mid t \geqslant 1, \\
&\quad Y \epsilon S) \times \Pr(w_1 < RQ_Y, w_2 < RQ_Y, Q_1 + Q_2 \geqslant RQ_Y \mid t = 2, \\
&\quad k_1 = Y, k_2 = Y)
\end{aligned} \tag{18}
$$

Now $S = S_X + S_A + S_B$, where S_X, S_A, and S_B are the subsets of X, A, or B hazardous substances and $RQ_Y = 1$ lb for $Y \varepsilon S_X$, $RQ_Y = 10$ lb for $Y \varepsilon S_A$, and $RQ_Y = 100$ lb for $Y \varepsilon S_B$. So $P^{(2)}$ can be rewritten as follows:

$$
\begin{aligned}
P^{(2)} &= \Pr(t = 2 \mid t \geqslant 1) \times \Pr(k_2 = k_1 \mid t = 2)[\sum_{Y \epsilon S_X} \Pr(k_1 = Y \mid t \geqslant 1, \\
&\quad Y \epsilon S) \times \Pr(w_1 < 1, w_2 < 1, Q_1 + Q_2 \geqslant 1 \mid t = 2, k_1 = Y, k_2 = Y) \\
&\quad + \sum_{Y \epsilon S_A} \Pr(k_1 = Y \mid t \geqslant 1, Y \epsilon S) \times \Pr(w_1 < 10, w_2 < 10, Q_1 \\
&\quad + Q_2 \geqslant 10 \mid t = 2, k_1 = Y, k_2 = Y) + \sum_{Y \epsilon S_B} \Pr(k_1 = Y \mid t \geqslant 1, \\
&\quad Y \epsilon S) \times \Pr(w_1 < 100, w_2 < 100, Q_1 + Q_2 \geqslant 100 \mid t = 2, \\
&\quad k_1 = Y, k_2 = Y)]
\end{aligned} \tag{19}
$$

Examine the second factor in the first sum in the brackets [call it F(Y)]:

$$
F(Y) = \Pr(w_1 < 1, w_2 < 1, Q_1 + Q_2 \geqslant 1 \mid t = 2, k_1 = Y, k_2 = Y) \tag{20}
$$

$$
\begin{aligned}
F(Y) &= \Pr(w_2 < 1, Q_1 + Q_2 \geqslant 1 \mid t = 2, k_1 = Y, k_2 = Y, w_1 < 1) \\
&\quad \times \Pr(w_1 < 1 \mid t = 2, k_1 = Y, k_2 = Y)
\end{aligned} \tag{21}
$$

Assume that the probability that the first package spilled contained less than 1 lb is independent of the material in the shipment and of whether the two spilled materials are the same (assumption 3). Then

$$
\begin{aligned}
F(Y) &= \Pr(w_2 < 1, Q_1 + Q_2 \geqslant 1 \mid t = 2, k_1 = Y, k_2 = Y, w_1 < 1) \\
&\quad \times \Pr(w_1 < 1 \mid t = 2) \\
&= \Pr(Q_1 + Q_2 \geqslant 1 \mid t = 2, k_1 = Y, k_2 = Y, w_1 < 1, w_2 < 1) \\
&\quad \times \Pr(w_2 < 1 \mid t = 2, k_1 = Y, k_2 = Y, w_1 < 1) \\
&\quad \times \Pr(w_1 < 1 \mid t = 2)
\end{aligned} \tag{22}
$$

Assume that the probability that the second package spilled contains less than 1 lb is independent of the material spilled (assumption 4). Then

$$
\begin{aligned}
F(Y) &= \Pr(Q_1 + Q_2 \geqslant 1 \mid t = 2, k_1 = Y, k_2 = Y, w_1 < 1, w_2 < 1) \\
&\quad \times \Pr(w_2 < 1 \mid t = 2, k_1 = k_2, w_1 < 1) \\
&\quad \times \Pr(w_1 < 1 \mid t = 2)
\end{aligned} \tag{23}
$$

Examine the first factor of F(Y):

$$
G(Y) = \Pr(Q_1 + Q_2 \geqslant 1 \mid t = 2, k_1 = Y, k_2 = Y, w_1 < 1, w_2 < 1) \tag{24}
$$

Certainly either Q_1 or Q_2 must be larger than 1/2 lb if $Q_1 + Q_2$ is to be larger than a pound. So

$$
\begin{aligned}
G(Y) \leqslant H(Y) &= \Pr(Q_1 \geqslant 1/2 \text{ or } Q_2 \geqslant 1/2 \mid t = 2, k_1 = Y, \\
&\quad k_2 = Y, w_1 < 1, w_2 < 1)
\end{aligned} \tag{25}
$$

Assume that the probability that either spill is less than 1/2 lb is independent of the material spilled or the fact that the same material spilled from both packages (assumption 5). Then

$$
H(Y) = \Pr(Q_1 \geqslant 1/2 \text{ or } Q_2 \geqslant 1/2 \mid t = 2, w_1 < 1, w_2 < 1) \tag{26}
$$

If it is assumed either that Q_1 is independent of Q_2 or that if it is not independent, they are positively associated, an estimate of an upper bound on H(Y) can be made:

$$
H(Y) \leqslant 1 - [\Pr(Q \leqslant 1/2 \mid t = 2, w < 1)]^2 \tag{27}
$$

(By positively associated it is meant that larger values of Q_1 are on the average associated with larger values of Q_2 and similarly smaller values of Q_1 are associated with smaller values of Q_2. By assuming that Q_1 and Q_2 are either positively associated or independent it is assumed that they are not negatively associated. That is, it is assumed that smaller values of Q_1 are not on the average associated with larger values of Q_2.) So

$$
G(Y) \leqslant 1 - [\Pr(Q \leqslant 1/2 \mid t = 2, w < 1)]^2 \tag{28}
$$

and an upper bound on F(Y) is

$$
\begin{aligned}
F(Y) &= \{1 - [\Pr(Q \leqslant 1/2 \mid t = 2, w < 1)]^2\} \\
&\quad \times \Pr(w_2 < 1 \mid t = 2, k_1 = k_2, w_1 < 1) \times \Pr(w_1 < 1 \mid t = 2)
\end{aligned} \tag{29}
$$

Recall that the first summation in the last expression for $P^{(2)}$ is

$$
J(Y) = \sum_{Y \epsilon S_X} \Pr(k_1 = Y \mid t \geqslant 1, Y \epsilon S) F(Y) \tag{30}
$$

Substituting in the upper bound on F(Y) yields

$$
\begin{aligned}
J(Y) &= \sum_{Y \epsilon S_X} \Pr(k_1 = Y \mid t \geqslant 1, Y \epsilon S) \times \Pr(w_2 < 1 \mid t = 2, \\
&\quad k_1 = k_2, w_1 < 1) \times \Pr(w_1 < 1 \mid t = 2) \\
&\quad \times \{1 - [\Pr(Q \leqslant 1/2 \mid t = 2, w < 1)]^2\}
\end{aligned} \tag{31}
$$

Because only the first factor depends on the material, this expression can be rewritten as follows:

$$
\begin{aligned}
J(Y) &= \Pr(w_2 < 1 \mid t = 2, k_1 = k_2, w_1 < 1) \times \Pr(w_1 < 1 \mid t = 2) \times \{1 \\
&\quad - [\Pr(Q \leqslant 1/2 \mid t = 2, w < 1)]^2\} \times \sum_{Y \epsilon S_X} \Pr(k_1 = Y \mid t \geqslant 1, \\
&\quad Y \epsilon S)
\end{aligned} \tag{32}
$$

Now the final summation in J(Y) can be restated:

$$\sum_{Y \epsilon S_X} \Pr(k_1 = Y | t \geq 1, Y \epsilon S) = \Pr(k_1 \epsilon S_X | t \geq 1, k_1 \epsilon S) \quad (33)$$

and

$$J(Y) = \Pr(w_2 < 1 | t = 2, k_1 = k_2, w_1 < 1) \times \Pr(w_1 < 1 | t = 2) \times \{1 - [\Pr(Q \leq 1/2 | t = 2, w < 1)]^2\} \times \Pr(k_1 \epsilon S_X | t \geq 1, k_1 \epsilon S) \quad (34)$$

Similar logic can be used to develop upper bounds on the other two summations in the final expression for $P^{(2)}$. The result is

$$\begin{aligned} P^{(2)} = {} & \Pr(t = 2 | t \geq 1) \times \Pr(k_2 = k_1 | t = 2) \\ & \times \Big(\Pr(k_1 \epsilon S_X | t \geq 1, k_1 \epsilon S) \times \Pr(w_1 < 1 | t = 2) \\ & \times \Pr(w_2 < 1 | t = 2, k_1 = k_2, w_1 < 1) \times \{1 - [\Pr(Q \leq 1/2 | t = 2, \\ & w < 1)]^2\} \\ & + \Pr(k_1 \epsilon S_A | t \geq 1, k_1 \epsilon S) \times \Pr(w_1 < 10 | t = 2) \\ & \times \Pr(w_2 < 10 | t = 2, k_1 = k_2, w_1 < 10) \times \{1 - [\Pr(Q \leq 5 | t = 2, \\ & w < 10)]^2\} \\ & + \Pr(k_1 \epsilon S_B | t \geq 1, k_1 \epsilon S) \times \Pr(w_1 < 100 | t = 2) \\ & \times \Pr(w_2 < 100 | t = 2, k_1 = k_2, w_1 < 100) \times \{1 \\ & - [\Pr(Q \leq 50 | t = 2, w < 100)]^2\}\Big) \end{aligned} \quad (35)$$

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Estimating the Release Rates and Costs of Transporting Hazardous Waste

MARK ABKOWITZ, AMIR EIGER, and SURESH SRINIVASAN

ABSTRACT

In the United States more than 160 million metric tons of hazardous waste are generated annually, and there has been concern over the management of these wastes and their impact on the population and environment. Responding to this issue, policy makers have begun to examine the risks and costs associated with hazardous waste treatment, transport, and disposal. The focus of this paper is the expected releases and costs associated with the transportation of hazardous waste by truck. Expected release rates are derived for eight container classes that may be used in the transport of hazardous materials and waste. The results indicate that the expected fraction released per mile shipped ranges from approximately 10^{-8} to 10^{-6}, depending on the container class. Expected released fractions at terminal points range from 10^{-6} to 10^{-3}. Thus, the expected released fractions during transport are potentially as large as the corresponding released fractions at disposal sites and treatment facilities. A review is also conducted of previous studies of the cost of hazardous waste transport. Several deficiencies are noted, particularly assumptions related to shipment characteristics and the lack of a comparison of actual rates charged by waste haulers. To overcome these deficiencies, new formulas are derived for estimating the cost of waste transport by tanker and stake (flatbed) truck. Cost estimates based on these formulas are subsequently compared with quoted industry rates. A conclusion is reached that the revised procedure is representative and can be used in policy analysis.

In the United States more than 160 million metric tons of hazardous waste are generated annually (1). In response to a growing concern over the management of these wastes and their impact on the population and environment, policy makers have begun to examine the risks and costs of treatment, transport, and disposal of hazardous waste.

The U.S. Environmental Protection Agency (EPA) has taken a leading role in assessing the trade-offs between various aspects of the disposal and treatment problem. In 1981 EPA's Office of Solid Waste began development under the Resource Conservation and Recovery Act (RCRA) of a Risk/Cost Analysis Model to assist in the development of regulations and standards for hazardous waste treatment, storage, and disposal facilities.

The RCRA Risk/Cost Analysis Model consists of an array of possible ways to treat and dispose of the hazardous wastes generated in the United States (2). Three main factors are considered in the model's formulation of possible ways to manage hazardous waste:

1. The type of waste (and its hazardous chemical constituents);
2. The types of technologies used to treat, transport, and dispose of the waste; and
3. The environmental settings in which the wastes are treated, transported, and disposed.

The model forms all possible combinations of a list of wastes, technologies, and environmental settings, or WET cells. It then calculates the risks and costs involved in each WET cell. In this fashion, the relative merits and drawbacks of various hazardous waste management strategies can be identified.

The focus in this paper is on the development of fraction release estimates for the transport technology component of the RCRA Risk/Cost Analysis Model. A secondary topic is the derivation of cost estimates of transporting hazardous waste. This includes a review of existing work directed at estimating the cost of transporting hazardous waste and modifications to existing methods based on hazardous waste shipment characteristics and current economic reasoning. The new cost formulas are subsequently compared with quoted industry rates to ascertain whether the revised approach can be used reliably in policy analysis. Because 90 percent of all hazardous waste is currently transported by truck (3), the models described in this paper are restricted to truck transport.

RELEASE MODEL DEVELOPMENT

Four general types of risk estimation methodologies have thus far evolved and been applied to the various aspects of transport risk analysis. [For an overview of this topic, see TRB Special Report 197 (4) and NCHRP Report 103 (5).] These methodologies are statistical inference, fault-tree modeling, simulation modeling, and subjective estimation. Each of these techniques has advantages and disadvantages, which must be evaluated in any given case. For example, the primary limitation of statistical estimation techniques is that one must assume the process generating the accident or incident frequencies to be stationary. Otherwise the estimates obtained from past data could not be used to predict future occurrences. Unlike statistical estimation methods, fault-tree analysis attempts to model the incident occurrence process in great detail. Although this has scientific appeal, there are difficulties associated with the acquisition of data for predicting basic event probabilities and the uncertainty that all significant event sequences have been considered. Nevertheless, fault-tree analysis as applied to the estimation of the risk of transporting hazardous materials has been used in several studies, among which are those by Rhoads (6), Bercha (7), and Geffen (8). Other studies relevant to the evaluation of risk in hazardous material transport include those by Gaylor (9), Jones et al. (10), and the National Transportation Safety Board (NTSB) (11). The reader is referred to a comprehensive bibliography on this subject provided by Russell et al. (12). Of the various techniques discussed in the literature, statistical estimation was considered to be the most appropriate for this study in terms of the overall project objectives. The results of other researchers were used to check the credibility of the estimates.

Incidents involving release of hazardous waste during transport result from any of a number of causes (failure modes) and can occur at shipment terminal points or en route. Of those that occur en route, a certain proportion result directly from truck accidents. Thus, three types of incidents are defined:

1. Container failures due to vehicular accidents en route,
2. Container failures occurring en route due to causes other than vehicular accidents, and
3. Failures at the shipment terminal points.

In developing the transport release model, certain postulates were made concerning the three types of incidents defined earlier:

1. The probability of a truck accident in which a release occurs is independent of the waste being shipped and the container type used in shipment.
2. The probability of occurrence of an incident at any point along the route is a nonzero constant that, exclusive of the truck accidents, depends on the container type used.
3. The probability of occurrence of an incident at a shipment terminal point depends only on the container type used.
4. The expected amount released as a result of an incident depends on the container type used and the specific cause of the release (failure mode). It does not depend on the location of the incident.

The transport release model is formulated as follows:

$$\begin{aligned} R_{tr} &= \underline{R} \times \underline{\Lambda} \times d \text{ (expected fraction released en route)} \\ & \underline{R} \times \overline{\underline{\theta}} \text{ (expected fraction released at terminal point)} \end{aligned}$$

where

R_{tr} = expected released fraction,
$\underline{R}$ = vector of parameters corresponding to the expected fraction released for each defined failure mode,
$\underline{\Lambda}$ = probability vector corresponding to incidents en route for each defined failure mode,
$\underline{\theta}$ = probability vector corresponding to incidents at terminal points for each defined failure mode, and
d = distance shipped.

For each container type considered, it is necessary to estimate the vectors $\underline{R}$, $\underline{\Lambda}$, and $\underline{\theta}$. Thus, the total number of parameters to be estimated depends on the number of container types and failure modes defined. The primary source of data for estimating the incident probability and fraction released vectors was the 1981 Hazardous Material Incident File (HAZMAT) maintained by the U.S. Department of Transportation's Materials Transportation Bureau (MTB). The HAZMAT file is a compilation of nationwide data regarding incidents involving hazardous material spills. As such, it contains information relating to frequency and circumstances (container involvement, failure mode, etc.) surrounding these incidents. This file allows the coding of up to 334 container types and 23 failure modes. Analysis of the data resulted in the identification of the following eight container classes with reasonably uniform physical characteristics and incident involvement rates:

1. Cylinders,
2. Cans,
3. Glass,
4. Plastic,
5. Fiber boxes,
6. Tanks,
7. Metal drums, and
8. Open metal containers.

For each of these eight container classes, expected release estimates were derived, as described in the following sections.

INCIDENT OCCURRENCE MODEL

Given the previous assumptions that the probability of an incident is constant along all points on a given route, it follows that the probability of occurrence of an incident somewhere along the route is directly proportional to the length of the route. Thus, for the first two incident types (incidents en route), the total transport distance is the exposure. For incidents at shipment terminal points, the number of shipments is the exposure because distance is not a factor. Given the foregoing conditions for each container class and failure mode, it can be shown that the limiting probability distributions for each of the incident types and failure modes are given as follows:

Container Failure During Vehicular Accident:

$$P\{n_1 | S, \lambda, \mu_d\} = \exp(-\lambda \mu_d S)(\lambda \mu_d S)^{n_1}/n_1! \tag{1}$$

Container Failure En Route:

$$P\{n_j | S, \lambda_j, \mu_d\} = \exp(-\lambda_j \mu_d S)(\lambda_j \mu_d S)^{n_j}/n_j! \qquad j = 2, 23 \tag{2}$$

Container Failure at Terminal Point:

$$P\{m_j | S, \theta_j\} = \exp(-\theta_j S)(\theta_j S)^{m_j}/m_j! \qquad j = 1, 23 \tag{3}$$

where

S = number of shipments,
μ_d = mean shipment distance, and
λ and θ = corresponding incident rates for the particular container class.

Direct estimation of the incident rates (λ_j and θ_j) requires knowledge of the number of shipments (S) and the mean shipping distance (μ_d) for each container class. Because the former is not available and cannot be reasonably estimated, the incident-rate estimators (excluding vehicular accidents) were derived in terms of a releasing truck accident rate, which is to be independently assessed. The releasing truck accident rate is some fraction of the overall truck accident rate, accounting for the fact that not all truck accidents result in a material spill. Thus,

$$\tilde{\lambda}_j = [(n_j + 1)/n_1]\hat{\lambda} \qquad j = 2, 23 \tag{4}$$

$$\tilde{\theta}_j = [(m_j + 1)/n_1]\hat{\lambda}\tilde{d} \qquad \text{for all } j \tag{5}$$

where

$\hat{\lambda}$ = estimate of the accident rate for trucks in which releases occur [$\hat{\lambda} = 2.8 \times 10^{-7}$ (13)];
$\tilde{d}$ = estimate of μ_d, determined from the HAZMAT data; and
n_j and m_j = incident frequencies for the container class obtained from the HAZMAT file.

FRACTION-RELEASED MODEL

The fraction-released model is made up of two submodels: one for the fraction of containers failed given an incident and the other for the fraction spilled given failure. These are henceforth referred to as the failure and spill models, respectively. Given the assumed dependence of the fraction-failed and fraction-spilled variables on both the container type and failure mode, linear models are constructed as follows:

$$F = \alpha_0 + \alpha_1 X_1 \ldots + \alpha_7 X_7 + \beta_1 Y_1 + \ldots + \beta_{22} Y_{22}$$

$$P = \gamma_0 + \gamma_1 X_1 \ldots + \gamma_7 X_7 + \delta_1 Y_1 + \ldots + \delta_{22} Y_{22} \tag{6}$$

where F and P denote the fraction failed and fraction spilled and the X's and Y's are binary variables denoting the container classes and failure modes, respectively. For example, an observation corresponding to container class 1 and failure mode 6 would have $X_1 = 1$ and $Y_6 = 1$ and the remaining independent variables would be zero.

The full regression models contain 29 binary variables (needed to define the 8 container classes and 23 failure modes), with the assumption that the interaction terms are not significant. The regression coefficients in the models were estimated by using the spill data in the HAZMAT file.

Let F_j, P_j, and R_j denote the random variables fraction failed, fraction spilled, and fraction released for failure mode j; the means are μ_{fj}, μ_{pj}, and μ_{rj}, respectively. Thus, $R_j = F_j P_j$. Assuming that F_j and P_j are independent, $\mu_{rj} = \mu_{fj}\mu_{pj}$. Denoting by r_j the estimate of μ_{rj}, one obtains

$$r_j = f_j p_j \tag{7}$$

where f_j and p_j are the mean response estimates obtained from the models of Equation 6.

Recall that λ_j and θ_j denote the probabilities of incident occurrences by failure mode j en route and at the terminal points, and $\tilde{\lambda}_j$ and $\tilde{\theta}_j$ are their estimators. Let μ_r and μ_{rt} denote the mean fraction released per mile shipped and at terminal points, respectively. Let r and r_t denote the respective estimators. Then

$$r = \sum_{j=2}^{23} r_j \tilde{\lambda}_j + r_1 \lambda' \tag{8}$$

$$r_t = \sum_j r_j \tilde{\theta}_j \tag{9}$$

where λ', corresponding to the failure mode of a releasing vehicular accident, is considered an input variable. Several values for λ' will be given below for different highway types, of which the composite rate ($\hat{\lambda}$) was used in the estimation of the incident probabilities ($\tilde{\lambda}_j$ and $\tilde{\theta}_j$).

PARAMETER ESTIMATION

In the previous section, estimators of the expected fraction released were derived based on the failure and spill models. Table 1 gives the computed estimates for each of the container classes both for incidents en route and at terminal points.

TABLE 1 Estimates of Fraction Released by Container Class

Container Class	Expected Fraction Released per Mile Shipped	Expected Fraction Released at Terminal Points
1	$1.3 \times 10^{-6} + (0.13\lambda')$	1.4×10^{-4}
2	$2.6 \times 10^{-6} + (0.12\lambda')$	4.0×10^{-4}
3	$1.7 \times 10^{-6} + (0.27\lambda')$	2.6×10^{-4}
4	$4.1 \times 10^{-6} + (0.14\lambda')$	5.2×10^{-4}
5	$1.3 \times 10^{-6} + (0.12\lambda')$	6.1×10^{-5}
6	$4.2 \times 10^{-8} + (0.19\lambda')$	7.6×10^{-6}
7	$2.4 \times 10^{-6} + (0.10\lambda')$	2.9×10^{-4}
8[a]	7.5×10^{-6}	1.2×10^{-3}

[a] Estimate associated with the released fraction during accident is not reliable.

Note in the table that the expected fraction released per mile shipped has been expressed in terms of λ', a rate for truck accidents in which a release occurs. From an independent analysis of data on truck accident rates (13) and the work of Vallette et al. (14) and of others (15-23), the following estimates of accident rates (releasing accidents per million truck miles) for three different highway types have been derived:

Highway Type	Accident Rate
Interstate	0.13
U.S. and state (rural)	0.45
Interrupted flow due to intersections (urban)	0.70
Composite	0.28

In computing the foregoing estimates, it is necessary to take into account that not all truck accidents result in a release. An estimate of 0.2 for the fraction of truck accidents in which a spill occurs was derived. This was based on the following factors. First, the 1982 FRA Accident/Incident Bulletin (24) indicates that in 601 train accidents consisting of 2,770 cars carrying hazardous materials, 109 cars released. Second, previous work by Geffen (8) indicates that tank trucks involved in accidents are approximately 10 times more likely to spill than rail tank cars. These two factors yield an estimate of 0.4, which was adjusted downward to compensate for the higher damage threshold for an FRA reportable accident than the threshold used in the HAZMAT file. It is emphasized that the releasing accident rates reported here are suggested values that in a given situation should be replaced by more accurate estimates if they are available.

In order to evaluate the results, estimates for tanks in Table 1 were compared with the results of the Bercha study (7) for tank trucks and vacuum trucks and the Pacific Northwest Laboratory (PNL) studies (6,8) for tank and tank-trailer combination trucks. The PNL studies report incident probabilities in a 130-mile (210-km) shipment of 3.68×10^{-5} and 3.57×10^{-5} for propane- and gasoline-carrying trucks, respectively. These values translate to an incident probability per mile of 2.8×10^{-7}, which compares favorably with the current estimate for the fraction released per mile of 1×10^{-7}. The Bercha study reports fractions released per mile of 2.02×10^{-7} and 1.68×10^{-7} for vacuum trucks and tank trucks, respectively. In addition, Bercha reports estimates of the fraction released during loading and unloading of 4.6×10^{-4} and 2.4×10^{-4} for vacuum trucks and tank trucks, respectively. The current results for incidents en route are in general agreement with those of Bercha. For incidents at terminal points, however, they are two orders of magnitude lower. This apparent discrepancy could result from underreporting of HAZMAT small spill incidents at terminals. After the small spills have been removed from the Bercha analysis, the resulting fractions released during loading and unloading for both vacuum and tank trucks become 2.4×10^{-5}. These are still three times higher than this study's estimate of 7.6×10^{-6}.

ERRORS OF THE ESTIMATES

There are several sources of error that affect the release estimates in Table 1. These can be categorized as modeling errors and estimation errors. In this section, only the estimation errors and their implications are discussed.

Recall that in Equations 4 and 5, there are three factors to be estimated: λ, the accident rate for trucks in which releases occur; μ_d, the mean shipping distance for the container class; and the incident frequency ratios. In view of the functional form of the estimators, the errors in the aforementioned factors are multiplicative. That is, a 10 percent error in $\hat{\lambda}$ and a 10 percent error in $(n_j + 1)/n_1$ yields a 21 percent error in $\tilde{\lambda}_j$. The error in $\hat{\lambda}$, in turn, is multiplicative in the errors in the accident rate estimates and the estimates of the fraction of accidents that release. In order to gauge the total error, each of the factors is considered separately.

The frequency ratios derived from the HAZMAT data could be affected by underreporting of incidents. There is strong evidence to suggest that this occurs. However, if the underreporting is uniform across all failure modes, the estimates are not affected. It is the authors' view that accidents are not as likely to go unreported as are other incidents (particularly at terminals) and this would lower the estimates.

The estimates of the truck accident rates derived in this study are within the range of previously reported findings. As an average of rates representing varied highway and traffic volume conditions, the composite rate used in the analysis is lower than what was used in the PNL (6,8) and Bercha (7) studies. This again would tend to lower the estimates.

With regard to the estimate of the fraction of accidents that release, it may be argued that the estimate of 0.2 is high. For example, it has been suggested that one can use the fatality rate as a proxy for the releasing accident rate. From data reported by NHTSA (23), 8.6 percent of single-vehicle truck accidents result in a fatality. NHTSA also reports injury rates of 24 percent. Thus, a factor in the range of 0.08 to 0.24 appears reasonable.

There are other factors the errors of which affect the computations of the final estimates of the fraction released. These include sampling errors in the estimates of the fraction spilled given an accident and errors in the estimation of the shipping distances by container types. The magnitude of these errors is given by the standard error of the estimates and is less than 20 percent.

As an illustration of the overall error effects, consider the possibility that the accident rate was underestimated by 25 percent, the fraction of releasing accidents was overestimated by 100 percent, the shipping distance was overestimated by 20 percent, and the frequency ratio at terminals was underestimated by 20 percent. For the foregoing situation, the net error in the incident probability estimates would be approximately 44 percent.

ESTIMATING THE EXPECTED AMOUNT RELEASED

From the model parameters described previously, the following procedure is used to estimate the expected fraction released during transport in a given application:

1. Identify shipment characteristics (e.g., number of shipments, volume per shipment, trip distance, and container type),
2. Identify roadway characteristics (highway type),
3. Select appropriate values of the parameters for the fraction released for the container type being considered,
4. Select appropriate λ',
5. Determine fraction released en route and at terminal points,
6. Multiply fraction released en route by total trip miles and fraction released at terminal points by the number of shipments,
7. Add these values to arrive at total expected fraction released, and
8. Multiply this by the total volume to obtain the total expected amount released.

To illustrate this procedure, consider the problem of estimating the expected amount released given that two hundred 55-gal drums are being shipped a distance of 100 miles on Interstate highways.

The accident rate for Interstates has been given as $\lambda' = 0.13$ releasing accident per million truck miles. The expected amount released en route and at the terminal points is obtained by using the information from Table 1 as follows:

E (release en route) = $(2.4 \times 10^{-6} + 0.10 \times 0.13 \times 10^{-6}) \times 100 \times 200 \times 55 = 2.6$ gal.

E (release at terminals) = $2.9 \times 10^{-4} \times 200 \times 55 =$ 3.2 gal.

Total expected release = 5.8 gal = 0.05 percent of total shipment.

ESTIMATION OF TRANSPORT COST

Literature Review

During the literature review process, seven studies were identified as having treated the issue of estimating the cost of transporting hazardous waste by truck. (Several other cost studies of truck transport exist that do not explicitly focus on hazardous waste transport.) In all cases, this issue was considered within the larger scope of addressing the total cost and risk of hazardous waste treatment at a regional level. The subsequent discussion describes the methodology adopted in each study.

In a report to the Environmental Council of Alberta concerning the risks of transportation of hazardous waste substances, Bercha (7) addressed the cost of hazardous waste transportation by segmenting according to trip length (1 km = 0.6 mile):

	Cost	
Trip Length (km)	Canada ($/tonne-km)	United States ($/ton-mile)
0-100	0.120	0.176
>100	0.080	0.117

Bercha did not differentiate by truck capacity and material carried. Although not reported, it is assumed that trip length corresponds to one-way trip distance and that the costs of deadheading back to the trip origin are embedded in this cost structure. It is also assumed that the trip length segmentation was established to reflect the decrease in costs per ton mile that will occur with longer trips as fixed costs are distributed over a larger base.

A study by Booz-Allen and Hamilton (25) addressed transport costs as part of an assessment of hazardous waste generation and treatment capacity. Booz-Allen assumed that all hazardous waste would be transported by either 6,000-gal tank trucks or flatbed trucks carrying 80 drums. It was implied that trucks would be traveling at full capacity. On the basis of interviews with facility operators, three different rules of thumb were established:

Method	Cost ($)
Flat rate per hour	30.00-40.00
Flat rate per mile, round trip	1.50-3.00
Fixed cost plus variable cost (usually applied to shorter trips)	100.00-150.00 minimum charge and 1.00-1.50 per mile

The Booz-Allen study did not indicate the conditions under which each costing method is most appropriate. The study also assumed that the costs are similar for transporting waste by tank or drum, and it did not recognize the expected decrease in per-mile costs associated with longer trips. Finally, the assumption that trucks travel at full capacity is not supported by analyses that have been conducted on hazardous waste shipment characteristics (13). As a result, the estimated costs are likely to be biased toward underreporting the actual cost of transport.

In their study of the New York State hazardous waste management program, Camp et al. conducted telephone interviews with haulers operating within the state (26). Cost estimates were solicited for a 75-mile one-way trip by using 4,000-gal tank trucks. The cost estimates (including all fees, tolls, gas, and wages) ranged from $1.14 to $4.80 per trailer mile depending on distance, waste type, and quantity. For their purposes, Camp et al. used an average cost of $1.25 to $1.50 per mile.

The importance of this study is not what Camp et al. adopted for their use (which suffers from the deficiencies described previously in the discussion of the Bercha and Booz-Allen studies), but in the information obtained in conversing directly with operators. The operators themselves identified trip distance, shipment size, and waste type as being important factors in determining transport cost.

Transport cost was treated quite generally in a study of hazardous waste management in Massachusetts

(27). It was assumed that waste would be transported in either 80-drum trucks or 4,400-gal tanker trucks, and it was further assumed that trucks only travel at capacity. Costs were estimated at \$1.00 to \$3.00 per truck mile (one-directional travel), which is equivalent to \$0.06 to \$0.18 per ton mile. The Massachusetts study adopted a rate of \$0.12 per ton mile for their purposes. No additional insights can be gained from reviewing this costing approach. Beyond assuming that shipments are only made at full capacity, the methodology suffers from assuming that per-mile costs remain constant irrespective of trip length and material carried.

In contrast to the variable cost structure established in the previously described studies, Arthur D. Little, Inc. (ADL), developed a more sophisticated approach in their assessment of hazardous waste management facilities in New England (28). In this study it was recognized that the real cost of transporting waste consists of a fixed cost (capital amortization, insurance, taxes, salaries, fringe benefits, supervision, and general and administrative costs) independent of the shipment activity and a variable cost (fuel, tires, lubrication, maintenance), which is likely to be a function of trip distance.

To arrive at their cost formulas, ADL assumed that a truck is in service 2,000 hr per year and during the time that the truck is in service and on the road, the average travel speed is 40 mph. It was further assumed that the truck operates at capacity when a shipment is made and returns empty to the trip origin. Tank trucks and stake trucks with 6,000-gal capacity that can carry thirty 55-gal drums were examined.

With this information, cost functions were derived of the following form:

$$\text{Tanker } C_T = (0.084 + 2.45)/d \tag{10}$$

$$\text{Stake truck } C_T = (0.237 + 11.01)/d \tag{11}$$

where C_T is the cost in dollars per ton mile and d is the one-way trip distance in miles.

The major advantage of the ADL approach is the detail given to components that are part of the cost of providing transport service and the recognition that some costs are fixed whereas others are variable in nature. This methodology accounts for different truck types and unit costs that decrease as a function of trip distance. The drawbacks of this work are as follows:

1. The estimates of capital and operating costs were not validated against actual records,
2. It was assumed that trucks were at full capacity during transport, and
3. It was assumed that trucks were constantly in demand and available for service.

These assumptions contribute a bias toward underestimating the real transport cost per shipment.

A revised costing procedure was developed by ADL for their study of hazardous waste quantities and facility needs in Maryland (29). The primary modifications to their earlier methodology were

1. The assumption that trucks were in service 80 percent of the time,
2. Inclusion of a line item for profit (5 percent of non-capital-related expenses plus general and administrative expenses),
3. Consideration of a roll-off container truck with capacity for eighty 55-gal drums, and
4. An update to the component costs to account for inflation and other changing market conditions.

For the Maryland study, ADL did contact several operators in the United States to verify the plausibility of the cost assumptions.

Estimates of the cost per ton for one-way trip distances of 50 and 100 miles for tank trailers and roll-off containers (using a stake truck) were made. ADL also developed generalized cost formulas in their study.

This approach resolves many of the criticisms raised in the review of previous methodologies. The major remaining problems are the assumption of fully loaded trucks and, although operators were consulted on the component cost estimates, the failure to examine actual cost records for the purposes of establishing the representativeness of the entire costing procedure.

For the EPA RCRA Risk/Cost Analysis Model, ICF, Inc., examined the costs of transporting waste by 6,000-gal tank trucks for one-way trip distances of 25 and 250 miles (30). It was assumed that on-site transportation costs were included in treatment and disposal costs, which appears to be an implied assumption in the other studies that have been reviewed.

ICF's approach was to formulate a procedure similar to that developed by ADL. Notable differences in the two approaches are the absence in the ICF formulation of the following: supervisory labor, interest on capital, insurance, tax, general and administrative costs, and profit. The ICF procedure suffers from the same deficiencies as the ADL Maryland methodology and, in addition, is not as comprehensive. For these reasons, the ICF approach appears less suitable.

In summary, the methodologies reviewed fall into two major categories: variable-cost models and total-cost (fixed plus variable) models. The total-cost models are more sophisticated in their treatment of component costs and are likely to be more representative of the real cost of operating service. Of the total-cost models, the ADL Maryland approach appears to be the most complete, although some deficiencies still remain. In the following section a revised procedure is described that was developed to address these deficiencies.

Revised Procedure

The revised costing procedure was developed based on ADL cost assumptions with the following modifications:

1. Costs are updated into 1983 terms by using the consumer price index (CPI) where appropriate,
2. Average trip distances and shipment sizes are assumed based on the results of an analysis of hazardous waste shipment characteristics by using manifest data from several states (13), and
3. The revised cost formulas are compared with actual price quotes from waste haulers for purposes of establishing the accuracy of the revised procedure.

Transport costs are estimated for 6,000-gal tankers and 18-ton stake trucks. As in the case of the ADL study, costs are segmented into fixed and variable costs, as described in Table 2.

Average-Cost Approach

Tanker (6,000-gal)

Analysts often require average-cost information in

TABLE 2 Cost Assumptions for Revised Procedure

Type of Cost	Costs ($) Tanker (6,000-gal)	 Stake Truck (18-ton)
Fixed		
Capital[a] amortization (8 yr at 12 percent = 0.201)	18,170	16,402
Noncapital fixed (1983[b])		
Driver's salary ($14.64/hr x 2,000)	29,280	29,280
Supervision ($2.93/hr x 2,000)	5,860	5,860
Insurance ($2.10/hr x 2,000)	4,200	4,200
License and tax ($2.00/hr x 2,000)	4,000	4,000
Total capital and noncapital fixed	61,510	59,742
General and administrative at 10 percent	6,151	5,974
Profit at 5 percent	3,383	3,286
Total fixed	71,044	69,002
Variable[c]		
Fuel and oil	0.23	0.23
Tires, maintenance, and repair	0.14	0.14
General and administrative at 10 percent	0.04	0.04
Profit at 5 percent	0.02	0.02
Total variable	0.43	0.43

[a] Capital cost for 6,000-gal tanker = $90,400; for 18-ton stake truck = $81,600.

[b] Using consumer price index (CPI) figures for urban wages, the inflation rate has been as follows: 1981 = 10.4 percent, 1982 = 6.1 percent.

[c] Per mile.

order to make policy decisions when detailed information on shipment characteristics is not available. This can be facilitated by assuming an average shipment size and trip length for a typical shipment. The following analysis examines average costs for tanker transport where it is assumed that the tanker is carrying liquid materials.

The analysis assumes an 80 percent utilization rate (in service 1,600 hr per year), time on the road is based on an average speed of 40 mph, and the loading and unloading time per shipment is 2 hr. Based on the analysis of hazardous waste shipment characteristics, the mean trip length is 84.2 miles and the average shipment size is 3,171 gal, or equivalently, 13.21 tons (<u>13</u>). These inputs, coupled with the information in Table 2, yield the following results:

Average time per shipment = [(84.2 x 2 miles)/40 mph] + 2 hr = 6.21 hr.

Average trips per year = 1,600 hr/6.21 hr = 257.65.

Average fixed cost per trip = $71,044/257.65 = $275.74.

Average variable cost per trip = $0.43 x (84.2 x 2 miles) = $72.41.

Average total cost per trip = $275.74 + 72.41 = $348.15.

Average cost per loaded mile = $348.15/84.2 = $4.14.

Average cost per loaded ton mile = $4.14/13.21 = $0.31.

Thus, the average cost per loaded mile of tanker transport is $4.14 and the average cost per ton mile is $0.31.

Stake Truck (18-ton)

The time, distance, and quantity assumptions remain the same as in the previous case, with the following exceptions:

1. Loading and unloading time is assumed to be 3 hr and
2. Average shipment size is 11.63 tons (<u>13</u>).

The analysis proceeds as follows:

Average time per shipment = [(84.2 x 2 miles)/40 mph] + 3 hr = 7.21 hr.

Average trips per year = 1,600 hr/7.21 hr = 221.9.

Average fixed cost per trip = $69,002/221.9 = $310.96.

Average variable cost per trip = $0.43 x (84.2 x 2 miles) = $72.41.

Average total cost per trip = $310.96 + $72.41 = $383.37.

Average cost per loaded mile = $383.37/84.2 = $4.55.

Average cost per loaded ton mile = $4.55/11.63 = $0.39.

The average costs per loaded mile and loaded ton mile are larger for stake trucks than for tankers. This is because of the smaller loads associated with stake trucks.

Deriving Cost Formulas

It is extremely useful to have formulas available to estimate the cost of transport when details on specific shipments are available. These formulas are derived for tankers and stake trucks in the following discussion. The average cost per loaded mile (clm) in dollars per loaded mile can be expressed as follows:

$$\text{clm} = \{F/[1{,}600/(0.05X + Z)]\}(1/2X) + (0.43 \times 2) \tag{12}$$

where

F = annual fixed cost,
X = one-way shipment length (miles),
Y = shipment size (tons), and
Z = loading and unloading time (hr).

For tankers, F = $71,044 and Z = 2. Therefore,

$$\text{clm}_{\text{tanker}} = 3.08 + (88.8/X).$$

The cost per loaded ton mile (ctm) in dollars per loaded ton mile for tankers is

$$\text{cltm}_{\text{tanker}} = (3.08/Y) + (88.8/XY).$$

For stake trucks, F = $69,002 and Z = 3. Therefore,

$$\text{clm}_{\text{stake}} = 3.02 + (129.38/X).$$

The cost per loaded ton mile for stake trucks is

$$\text{cltm}_{\text{stake}} = (3.02/Y) + (129.38/XY).$$

<u>Comparison with Actual Charges</u>

The cost estimates using the revised costing procedure were compared with actual rates charged by haulers to determine the accuracy of the costing procedure. Information on actual rates was obtained from a study of transportation costs of hazardous waste haulers conducted by Temple, Barker and Sloane, Inc., (TBS) in May 1983 (31).

In their study, TBS contacted 10 companies involved in the treatment, disposal, and transportation of hazardous waste to gather cost information on drum and bulk waste transport activities. TBS experienced considerable difficulty in obtaining cost information that could be used to directly compare one operation with another. In fact, companies varied in terms of type of truck, vehicle capacity, area of service, average haul distance, quoted rates, and units to establish rates. Nevertheless, TBS attempted to establish a uniform scale by converting all rates to dollars per loaded mile.

For 5,000- to 6,000-gal tankers, quoted rates ranged from \$2.75 to \$4.50, with an average of \$3.40. The average cost per loaded mile using the revised costing procedure is \$4.14, which is toward the upper bound of what most shippers are charging. However, the lower costs in the range were quoted for one-way trips of 200 to 300 miles, well above the average trip distance used to compute the average cost per mile in the costing procedure. Using the cost formula for tankers with a one-way trip distance of 300 miles, the estimated average cost is \$3.38 per loaded mile, which is consistent with the amount operators are reportedly charging for a 300-mile one-way trip.

For stake trucks capable of handling 70 to 88 drums, the rate per loaded mile ranged from \$2.10 to \$4.00, with an average of \$3.30 as compared with the estimated average of \$4.55. Again, the lower rates were associated with longer trips. Using the cost formula for stake trucks, the estimated cost per loaded mile for a 300-mile one-way shipment is \$3.45, which compares rather favorably with reported rates.

In conclusion, the cost formulas appear to be representative of quoted rates in the hazardous waste transport industry, particularly for the long-haul market. The average-cost figures, however, should be treated more carefully and should only be employed when information is not available on shipment size and trip distance.

SUMMARY

In this paper the results of a study are reported in which expected release rates are derived for the truck transport of hazardous materials and wastes. The results indicate that in terms of order of magnitude, the expected fractions released per mile shipped range from 10^{-8} to 10^{-6}, depending on the container used in transport. Expected release fractions at terminal points ranged from 10^{-6} to 10^{-3}, also depending on the container class.

The computed estimates indicate that

1. The release rates for tanker trucks are much lower than those for other container types,
2. The expected amount released at terminal points is one to three orders of magnitude higher than the amount released en route (depending on trip length), and
3. The release rates during transport are potentially as high as the corresponding rates at disposal sites and treatment facilities, which range from 10^{-7} to 10^{-3} for routine spillage and 10^{-5} to 10^{-3} for accidental spillage (2).

The implication of the reported findings for policy analysis is that the transportation-related aspects of the hazardous waste disposal problem deserve considerable attention.

In this paper methods for estimating the cost of transporting hazardous waste by truck were also reviewed. Previous work has varied from gross estimates of the unit cost of transport to more sophisticated derivations of cost based on fixed and variable components. Several deficiencies were noted in previous work, particularly assumptions related to shipment characteristics and a lack of comparison with actual rates charged by waste haulers.

A revised procedure was developed with the objective of overcoming these deficiencies. Based on this approach, new cost formulas were derived for estimating the cost of waste transport by tanker and stake truck. Cost estimates based on these formulas compared quite favorably with industry quotes. Consequently, it is believed that these formulas can be adopted for use in policy analysis.

Taken together, the release and cost models described in this paper can be used to address several levels of policy analysis involving hazardous waste management. This includes the development of optimal truck routing based on minimizing risk and cost over the network or identifying the optimal location of hazardous waste disposal and treatment facilities based on transport, treatment, and disposal considerations.

ACKNOWLEDGMENT

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Chemical Spill Response Information System of the Association of American Railroads

G. E. MEIER

ABSTRACT

Many information sources present worthwhile data concerning hazards of and responses for accidental chemical spills. Most sources, however, consider only the acute effects of a spilled substance and provide little information concerning the long-term cleanup, which is typically considered unrelated to the emergency response. This concept is erroneous and costly. To combat this problem, the Association of American Railroads has undertaken a program to bridge the gap between the first response and the longer-term environmental cleanup. Two information systems have been developed and targeted at two basic levels of spill response. The Emergency Action Guides are intended for the first responder. These are printed commodity-specific pamphlets designed to assist those who are first on the scene until chemical or technical assistance can be obtained. To support chemical or technical decisions, a computerized system, the Industrial Chemical Accident Response Information System (ICARIS), was developed and integrated with a series of environmental and mathematical models to allow real-time assessment of chemical release problems. The design considerations inherent in both systems promote the evaluation of the long-term consequences associated with emergency spill response activities. The current capabilities of the computer information system as well as the design and development of the Emergency Action Guides are described.

The first-response actions used to control a chemical spill may have a profound impact on the long-term cleanup of the spill. Information generally available to first responders is limited in scope and usually presents little information with which to evaluate long-term cleanup problems. An even greater limitation of many information sources is their being tied to one or two spill situations with no provisions accounting for the uniqueness of an individual spill.

When an accident occurs, the first group on the scene with responsibility for handling the release is usually the local police or fire service. The level of training and equipment they obtain is usually related to the size of the community and the local emphasis placed on the relative danger of a chemical release. At the community level, training and equipment priorities may not include hazardous material spills.

This is a sensible approach. It is easy to spend several thousand dollars in training costs alone to establish a special-response team. In many communities the likelihood of using that team may be so remote that several groups would be trained and equipment shelf lives exceeded before an accident occurred. When the number of other emergencies is considered in comparison with a chemical release, the potential chemical accident often becomes insignificant.

In a number of publications the guidelines for first response to a chemical accident are discussed. Hazardous Materials; Emergency Response Guidebook of the U.S. Department of Transportation (1), Emergency Handling of Hazardous Materials in Surface Transportation (2) of the Association of American Railroads (AAR), manuals issued by the U.S. Coast Guard from their Chemical Hazards Response Information System (CHRIS) data base, and others are widely distributed. These sources, however, provide information for first response only and do not consider any problems beyond the acute threat of the substance.

DESCRIPTIVE DATA

In 1979 AAR began an intensive collection of information describing those commodities commonly carried nationally by rail. During the data-collection phase, two primary user groups were identified. Group 1 includes the railroad response personnel, chemists, biologists, and others with an environmental or chemical background. Group 2 was identified as the first responders, generally firefighters and police. Because of the variability in training received by first responders nationally, this group was assumed to have knowledge relating only to the identification of commodities via placards or shipping documents but little training in the characteristics of spilled chemicals.

To accommodate these two groups, two separate methods of data presentation were pursued, a computer communication system and a printed information source. The data collected by AAR for presentation to both user groups consists of 180 descriptive entries per commodity, grouped into four major categories:

1. General information, which includes 48 elements to identify the chemical, including synonyms, trade names, the different codes [that of the Intergovernmental Maritime Consultive Organization (IMCO), the Standard Transportation Commodity Code (STCC), and the United Nations code (UN)], useful shipping information, and some physical constants;
2. Chemical information, which includes 35 elements that describe the properties of each chemical;
3. Health and hazard information, which consists of 40 data elements describing the hazards of an uncontrolled release of the chemical, including response guidelines, health hazards, and protective clothing needed; and
4. Environmental effects information, which includes 52 data elements, including toxicity, pollution effect, and interreaction data.

Each data point listed in Table 1 was collected from current and reliable sources. Each entry is referenced back to the original data to allow the

TABLE 1 Data Fields

1 Commodity Name
2 Other Shipping Names
3 Synonyms and Tradenames
4 Chemical Formula
5 Molecular Weight
6 Constituent Components (% Each)
7 49 STCC
8 CAS Registry Number
9 OHM-TADS Accession Number
10 Standard Industrial Code
11 IMCO Designation
12 UN Designation
13 CHRIS Identifier
14 Manufacturers
15 Common Uses
16 Percentage Shipped by Rail
17 Usual Containers
18 DOT Placard and Form Number
19 Physical State as Shipped
20 Physical State as Released
21 Shipping Temperature
22 Color
23 Odor Characteristics
24 Threshold Odor Concentration
25 Absolute Odor Threshold
26 Median Recognition Threshold
27 Upper Recognition Threshold
28 Population Perception Threshold
29 Population Identification Threshold
30 Individual Perception Threshold
31 Threshold Odor Number
32 Odor Index
33 Taste Characteristics
34 Lower Taste Threshold
35 Median Taste Threshold
36 Upper Taste Threshold
37 Flash Point
38 Lower Flammable Limit
39 Upper Flammable Limit
40 Lower Explosive Limit
41 Upper Explosive Limit
42 Explosiveness
43 Autoignition Temperature
44 Burning Rate
45 Toxic Combustion Products
46 Behavior in Fire
47 Electrical Ignition Hazard
48 Stability
49 Specific Gravity (Liquid)
50 Specific Gravity (Vapor)
51 Density
52 Density at Shipping Temperature
53 Vapor Pressure
54 Vapor Pressure at Shipping Temperature
55 Solubility in Water
56 Solubility in Other Chemicals
57 Solution Color
58 Melting Point
59 Freezing Point
60 Melting/Freezing Behavior
61 Boiling Point
62 Boiling Behavior
63 Heat Capacity (Constant Pressure)
64 Heat Capacity (Constant Volume)
65 Heat of Combustion
66 Heat of Decomposition
67 Heat of Solution
68 Latent Heat of Vaporization
69 Latent Heat of Fusion
70 Latent Heat of Sublimation
71 Thermal Conductivity
72 Thermal Conductivity at Shipping Temperature
73 Surface Tension
74 Interfacial Tension With Water
75 Viscosity
76 Viscosity at Temperature
77 Saturation Concentration
78 Saturation Concentration at Shipping Temperature
79 Diffusivity
80 Diffusivity at Shipping Temperature
81 Polymerization Potential
82 Heat of Polymerization
83 Reactivity With Water
84 Reactivity With Other Chemicals
85 Toxic Reaction Products
86 Vapor Weight-Volume Conversion Factor
87 Emergency Resources
88 Emergency Telephone Numbers
89 Notification Requirements
90 Public Health Hazards
91 Evacuation Guidelines
92 Incompatible Materials
93 Conditions to Avoid
94 Unusual Hazards
95 Corrosiveness
96 NAS Hazard Classification
97 NFPA Hazard Classification
98 Field Detection, Identification, and Quantification Techniques
99 Field Detection Limits
100 Laboratory Detection, Identification, and Quantification Techniques
101 Laboratory Detection Limits
102 Containment Techniques for Airborne Materials
103 Containment Techniques for Ground Contamination
104 Containment Techniques for Surface Water Contamination
105 Containment Techniques for Ground Water Contamination
106 Neutralization Materials
107 Neutralization Techniques
108 Extinguishing Materials
109 Extinguishing Techniques
110 Symptoms of Inhalation
111 First Aid for Inhalation
112 Symptoms of Percutaneous Absorption
113 First Aid for Percutaneous Absorption
114 Symptoms of Ingestion
115 First Aid for Ingestion
116 Aspiration Potential
117 Nonspecific Symptoms
118 Nonspecific First Aid
119 Time to Onset of Symptoms
120 Routes of Entry
121 First Aid Equipment Required
122 Respiratory Protection Required
123 Protective Clothing Required
124 Location of Primary Hazard
125 Safe Handling Procedures
126 Precautionary Actions
127 Short-Term Exposure Limits (Maximum Time/Maximum Concentration)
128 Freshwater Species
129 Saltwater Species
130 Animal Species
131 Avian Species
132 Plant Species
133 Human Toxicity
134 Bioaccumulation Potential
135 Food Chain Concentration Potential
136 Threshold Limit Value
137 Other Standards
138 Recommended Drinking Water Limit
139 Inhalation Toxicity Index
140 Maximum Pool Radius/Spill Size
141 Diameter at Base of Solid Pile/Spill Size
142 Fugitive Dust or Particulate Emissions
143 Maximum Downwind Extent of Vapor Cloud/Bounding Effect/Spill
144 Maximum Crosswind Extent of Vapor Cloud/Bounding Effect/Spill
145 Total Hydrocarbon Emissions
146 General Air Pollution Information
147 Downstream Concentration Factor
148 Sinking Velocity
149 PH of Aqueous Solution
150 Biological Oxygen Demand
151 BOD impact on Biodegradation
152 Biodegradation Rate
153 Chemical Oxygen Demand
154 Theoretical Oxygen Demand
155 Total Organic Carbon
156 Industrial Water Fouling Potential
157 Effects on Water Treatment Process
158 General Water Pollution Information
159 General Soil Chemistry
160 Soil Penetration Depth/Soil Type/Soil Dosage
161 Minimum Soil Sterilization Concentration
162 Estimated Half-Life in Soil/Soil Type/Soil Dosage
163 Estimated Diffusion in Soil/Soil Type/Soil Dosage
164 Absorption Materials/Absorption Techniques/Absorption
165 Adsorption Materials/Adsorption Techniques/Adsorption
166 Activated Carbon Dosage/% Reduction by Activated Carbon Adsorption
167 Gelation Materials/Gelation Techniques/Gelation Effectiveness
168 General Cleanup Information
169 Availability of Countermeasure Materials
170 In-Situ Amelioration Techniques/In-Situ Amelioration Effectiveness
171 Onsite Disposal Limitations
172 Chronic Hazards
173 Synergistic Materials (Toxicity)
174 Antagonistic Materials (Toxicity)
175 Environmental Fate
176 Toxic Daughter Products
177 Sampling Locations
178 Disposal Techniques/Disposal Effectiveness
179 Required Agency Coordination
180 General Disposal Information

user to identify which of the more than 40 sources was used for that item of information.

The commodities characterized (listed in Table 2) were restricted to those moved in bulk quantity. Selection was based on the number of car loadings in decreasing order. The list now includes 134 commodities that represent more than 98 percent of the chemical traffic on the railroads.

COMPUTER COMMUNICATION

The computer medium was selected to provide the swiftest method of communicating large volumes of data as well as state-of-the-art predictive information to trained responders on the scene. This system, known as the Industrial Chemical Accident Response Information System (ICARIS), is designed to mesh up-to-date chemical data with state-of-the-art predictive modeling to provide the user with a dynamic method for assessing the adequacy of their response activities. ICARIS is housed on AAR's IBM 370 system and can be accessed by remote terminal over the telephone network.

The principal advantage of this system is that it allows a site-specific analysis of a spill situa-

TABLE 2 Commodities Listing

1. Acetaldehyde
2. Acetic Acid, Glacial
3. Acetic Anhydride
4. Acetone
5. Acetone Cyanohydrin
6. Acrolein
7. Acrylic Acid
8. Acrylonitrile
9. Adipic Acid
10. Allyl Chloride
11. Ammonium Hydroxide
12. Ammonium Nitrate Fertilizer
13. Anhydrous Ammonia
14. Aniline Oil, Liquid
15. Arsenic Trioxide
16. Asphalt
17. Benzene
18. Bromine
19. Butadiene, Inhibited
20. Butene
21. Butyl Acetate
22. Butyl Acrylate
23. Butyl Alcohol
24. Butyraldehyde
25. Calcium Carbide
26. Carbolic Acid or Phenol
27. Carbon Bisulfide
28. Carbon Dioxide, Liquefied
29. Carbon Tetrachloride
30. Chlorine
31. Chlorobenzene
32. Chloroform
33. Chloroprene
34. Chlorosulfonic Acid
35. Chromic Acid
36. Creosote
37. Cresol
38. Cyclohexane
39. Di-N-Propylamine
40. Dichlorodifluoromethane
41. Diisobutylene
42. Dimethylamine, Anhydrous
43. Epichlorohydrin
44. Ethyl Acetate
45. Ethyl Acrylate, Inhibited
46. Ethyl Alcohol
47. Ethyl Chloride
48. Ethylene
49. Ethylene Glycol Monoethylether
50. Ethylene Glycol Monoethylether Acetate
51. Ethylene Oxide
52. Ferric Chloride Solution
53. Formaldehyde
54. Fuel Oil No. 1
55. Fuel Oil No. 2
56. Fuel Oil No. 4
57. Fuel Oil No. 5
58. Furfuryl Alcohol
59. Gasoline
60. Hexamethylene Diamine
61. Hexane
62. Hydrochloric Acid
63. Hydrocyanic Acid, Liquefied
64. Hydrofluoric Acid, Anhydrous
65. Hydrofluosilicic Acid
66. Hydrogen Chloride
67. Hydrogen Peroxide, Solution
68. Isobutyl Acetate
69. Isobutyraldehyde
70. Isopentane
71. Isoprene
72. Isopropanol
73. Liquefied Petroleum Gas
74. Maleic Anhydride
75. Meta Nitrochlorobenzene
76. Methanol
77. Methyl Bromide
78. Methyl Chloride
79. Methyl Ethyl Ketone
80. Methyl Isobutyl Ketone
81. Methyl Mercaptan
82. Methyl Methacrylate
83. Monochlorodifluoromethane
84. Monoethanolamine
85. Monomethylamine, Anhydrous
86. Motor Fuel Antiknock Compounds
87. Nitrating Acid
88. Nitric Acid, Fuming
89. Nitrobenzene
90. Octanol
91. Oleum
92. Ortho Nitroaniline
93. Ortho Nitrochlorobenzene
94. Para Nitrochlorobenzene
95. Pentane
96. Petroleum Naphtha
97. Phosphatic Fertilizer
98. Phosphoric Acid
99. Phosphorus Pentasulfide
100. Phosphorus
101. Phosphorus Trichloride
102. Potassium Hydroxide Solution
103. Potassium Nitrate
104. Propionaldehyde
105. Propionic Acid
106. Propyl Acetate
107. Propylene Oxide
108. Rosin Solution
109. Silicon Chloride
110. Sodium Chlorate
111. Sodium Cyanide, Solid
112. Sodium Hydrosulfide
113. Sodium Hydrosulfite
114. Sodium Hydroxide
115. Sodium Metal
116. Sodium Nitrate
117. Spent Caustic Soda Solution
118. Spent Sulfuric Acid
119. Styrene Monomer, Inhibited
120. Sulfur Chloride
121. Sulfur Dioxide
122. Sulfuric Acid
123. Tetrahydrofuran
124. Thorium Ore
125. Titanium Tetrachloride
126. Toluene
127. Toluene Diisocyanate
128. Trichloroethylene
129. Trimethylamine
130. Uranium Hexafluoride
131. Vinyl Acetate
132. Vinyl Chloride
133. Vinylidene Chloride, Inhibited
134. Xylene

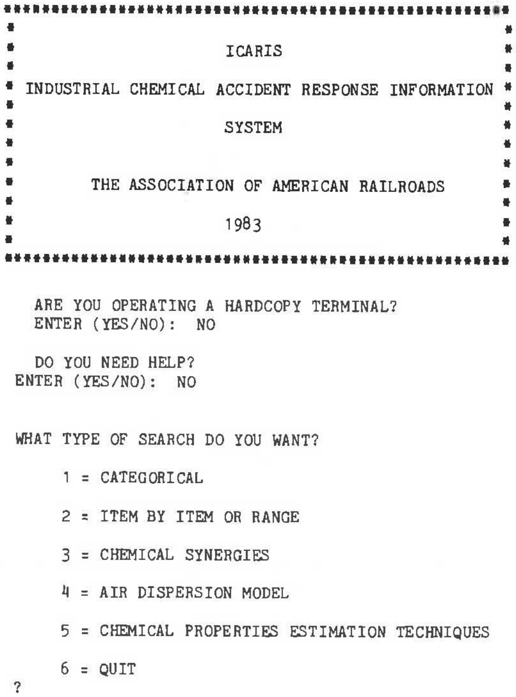
tion. The complex environmental interactions are discussed not in terms of broad generalities, but rather in terms of the specific peculiarities of the location of the spill. This method allows a more complete and specific evaluation of the individual situation.

The major limitation of the system is tied directly to the current understanding of chemical and environmental interactions. The number of environmental variables that affect chemical behavior is quite large, and this interaction is very complex. Hence, the use of spill models, at least now, must be considered in light of the assumptions intrinsic to each model. This requires expertise and training not generally available to the first-response community.

ICARIS now performs three basic functions. These include data retrieval, air dispersion modeling, and chemical property estimation.

The design of the computer program is straightforward and requires a minimum of computer training for operation. Generally, the system is menu driven, presenting the user with a question and a fixed set of choices. The main menu (Figure 1) allows the user to select from among the five major packages currently on line. Selection 1 is a search that allows the user to print data organized into prearranged categories of information for each commodity requested. Option 2 allows the user to print individual items of information as needed. Option 3 allows the user to select any number of chemicals and receive a chemical-by-chemical printout of all the reaction information contained in the data base. Option 4 involves the evaporation air dispersion model and allows the calculation and subsequent plotting of the vapor dispersion for a given region. The model currently in use is the Shell Development Corporation's Spills Model, written by M.T. Fleischer. Option 5 allows the user to select from among 19 techniques for calculating various chemical properties.

The estimation techniques in option 5 were included because many of the properties contained, such as rate of hydrolysis, carbon absorption ratios, thermal diffusivity, and volatility from soil, are either site dependent or not reported in the literature. These data are often necessary for the prediction of a chemical's behavior in air, water, or soil.



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****************************************************
*                                                  *
*                      ICARIS                      *
*                                                  *
* INDUSTRIAL CHEMICAL ACCIDENT RESPONSE INFORMATION *
*                                                  *
*                      SYSTEM                      *
*                                                  *
*                                                  *
*        THE ASSOCIATION OF AMERICAN RAILROADS     *
*                                                  *
*                       1983                       *
*                                                  *
****************************************************

   ARE YOU OPERATING A HARDCOPY TERMINAL?
   ENTER (YES/NO):  NO

   DO YOU NEED HELP?
 ENTER (YES/NO):  NO

 WHAT TYPE OF SEARCH DO YOU WANT?

      1 = CATEGORICAL

      2 = ITEM BY ITEM OR RANGE

      3 = CHEMICAL SYNERGIES

      4 = AIR DISPERSION MODEL

      5 = CHEMICAL PROPERTIES ESTIMATION TECHNIQUES

      6 = QUIT
 ?
```

FIGURE 1 ICARIS main menu.

The last option allows the user to terminate processing within ICARIS.

Future enhancements to ICARIS will be of three basic types:

1. Increase in commodity coverage,
2. Increase in data describing each commodity, and
3. Increase in the number and reliability of environmental models.

Items 2 and 3 are dependent on basic research into the behavior of chemicals in the environment. The use of ICARIS as a planning and training tool is also being explored.

EMERGENCY ACTION GUIDES

The most dangerous and critical aspect in handling a chemical release is the initial response. A system such as ICARIS would be ideal in a first-response situation; however, the expense at the community level to purchase terminals and train personnel hardly justifies its use.

The ultimate cost of a spill is highly dependent on the adequacy of the first response. Because railroads generally rely on local agencies for that response, the AAR has developed the Emergency Action Guides (EAGs). The design of the EAGs was the result of an intensive review of past accidents as well as currently available information resources.

Definitions

Two major definitions evolved from the accident review. The first is the definition of "first response," which in the context of the EAG is the time in an accident's chronology beginning when a unit or agency with equipment and manpower is summoned to the scene of an accident for the purpose of mitigating the effects of the accident until the time when that unit or agency obtains specialized assistance in handling the accident. Inherent in this definition is the assumption that outside expertise will be required to successfully handle the accident.

The second definition is that of "first responder." Again in the context of the EAG, a first responder is a unit or agency with equipment and manpower arriving first on the scene of a chemical spill for the purpose of mitigating the hazards associated with the spill, whose training in chemical spill response may be limited solely to commodity identification techniques. This definition assumes that first responders are acquainted with the concept that chemicals may pose a threat to life and health.

These definitions served to limit the intended scope of the EAGs.

Accident Chronology

The next part of the developmental process was to analyze the chronology of a chemical spill by looking at reports of past accidents as well as the experiences of personnel within the AAR's Bureau of Explosives. Within this chronology, information requirements were outlined. Further review of past incidents indicated what information was available at

ACRYLONITRILE
Flammable Liquid
RQ 100/45

General Information

Acrylonitrile is a clear colorless liquid with a strong pungent odor. It is used in insecticides and to make plastics, fibers, and other chemicals. It has a flash point of 32°F. It may polymerize if contaminated with strong bases or if the container is subject to heat as in fire conditions. Prolonged exposure to the vapors or skin contact may result in death. It is lighter than water and is soluble in water. Its vapors are heavier than air. Toxic oxides of nitrogen are produced during combustion of this material. It weighs 6.7 pounds per gallon.

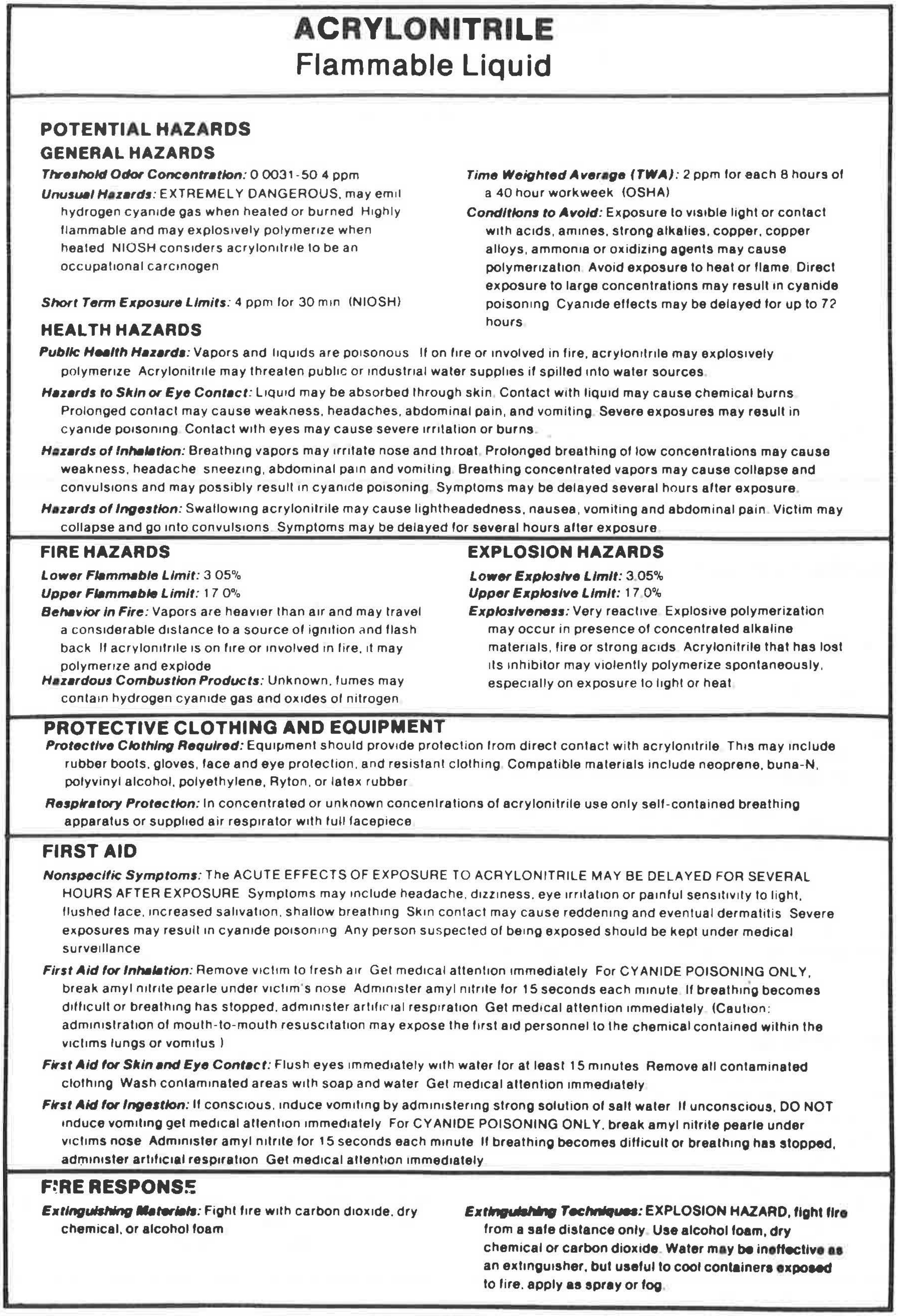
CHEMICAL/PHYSICAL DATA

Solubility in Water: Soluble in water, 7.35 parts in 100 parts water
Solubility in Other Chemicals: Miscible in alcohol and ether, soluble in acetone and benzene
Specific Gravity (Liquid): 0.8074 at 68°F (20°C)
Boiling Point range: 171 to 172°F (77.5 to 77.9°C) at 1 atm.
Melting Point: -118.3°F (-83.5°C)
Freezing Point: -118.3°F (-83.5°C)
Molecular Weight: 53.06
Heat of Combustion: -7930 cal/g
Vapor Pressure: 67 mmHg at 59°F (15°C)
Flash Point: Liquid 32°F (0°C) Open & Closed Cup
Autoignition Temperature: 898°F (481°C)
Burning Rate: Unknown
Stability: Stable, when inhibited; may violently polymerize when uninhibited or chemical inhibitor has been exhausted through exposure to heat
Corrosiveness: Corrosive to metals containing alloys of copper, brass or aluminum
Reactivity with Water: Soluble in water with no reaction
Reactivity with Other Chemicals: Reacts violently with strong acids like sulfuric acid, potassium hydroxide, and sodium hydroxide. Attacks copper and copper alloys. In high concentrations acrylonitrile will attack aluminum.

IDENTIFICATION

Shipping Names: Acrylonitrile
Synonyms and Tradenames: Propenenitrile, vinyl cyanide, Acritet, Acrylon, acrylonitrile monomer, Carbacryl, cyanoethylene, Fumigrain, Millers Fumigrain, Ventox, cyano-ethylene
Chemical Formula: CH_2CHCN
Constituent Components (% each): 98-100% pure
49 STCC: 49 064 20
UN Designation: UN 1093
IMO Designation: 3.1
Physical State As Shipped: Liquid
Physical State As Released: Liquid
Color of the Shipped Material: Colorless liquid
Odor Characteristics: Mild, pungent, onion, garlic, or horseradish.
Common Uses: Raw material for synthetic fibers, synthetic resins, synthetic rubbers, antioxidants, pharmaceuticals, dyes, surfactants, and chemical synthesis.

FIGURE 2 Cover page of EAG.



ACRYLONITRILE

Flammable Liquid

POTENTIAL HAZARDS

GENERAL HAZARDS

Threshold Odor Concentration: 0 0031-50 4 ppm

Unusual Hazards: EXTREMELY DANGEROUS, may emit hydrogen cyanide gas when heated or burned Highly flammable and may explosively polymerize when heated NIOSH considers acrylonitrile to be an occupational carcinogen

Short Term Exposure Limits: 4 ppm for 30 min (NIOSH)

Time Weighted Average (TWA): 2 ppm for each 8 hours of a 40 hour workweek (OSHA)

Conditions to Avoid: Exposure to visible light or contact with acids, amines, strong alkalies, copper, copper alloys, ammonia or oxidizing agents may cause polymerization Avoid exposure to heat or flame Direct exposure to large concentrations may result in cyanide poisoning Cyanide effects may be delayed for up to 72 hours

HEALTH HAZARDS

Public Health Hazards: Vapors and liquids are poisonous If on fire or involved in fire, acrylonitrile may explosively polymerize Acrylonitrile may threaten public or industrial water supplies if spilled into water sources

Hazards to Skin or Eye Contact: Liquid may be absorbed through skin Contact with liquid may cause chemical burns Prolonged contact may cause weakness, headaches, abdominal pain, and vomiting Severe exposures may result in cyanide poisoning Contact with eyes may cause severe irritation or burns

Hazards of Inhalation: Breathing vapors may irritate nose and throat Prolonged breathing of low concentrations may cause weakness, headache sneezing, abdominal pain and vomiting Breathing concentrated vapors may cause collapse and convulsions and may possibly result in cyanide poisoning Symptoms may be delayed several hours after exposure

Hazards of Ingestion: Swallowing acrylonitrile may cause lightheadedness, nausea, vomiting and abdominal pain Victim may collapse and go into convulsions Symptoms may be delayed for several hours after exposure

FIRE HAZARDS

Lower Flammable Limit: 3 05%

Upper Flammable Limit: 17 0%

Behavior in Fire: Vapors are heavier than air and may travel a considerable distance to a source of ignition and flash back If acrylonitrile is on fire or involved in fire, it may polymerize and explode

Hazardous Combustion Products: Unknown, fumes may contain hydrogen cyanide gas and oxides of nitrogen

EXPLOSION HAZARDS

Lower Explosive Limit: 3.05%

Upper Explosive Limit: 17.0%

Explosiveness: Very reactive Explosive polymerization may occur in presence of concentrated alkaline materials, fire or strong acids Acrylonitrile that has lost its inhibitor may violently polymerize spontaneously, especially on exposure to light or heat

PROTECTIVE CLOTHING AND EQUIPMENT

Protective Clothing Required: Equipment should provide protection from direct contact with acrylonitrile This may include rubber boots, gloves, face and eye protection, and resistant clothing Compatible materials include neoprene, buna-N, polyvinyl alcohol, polyethylene, Ryton, or latex rubber

Respiratory Protection: In concentrated or unknown concentrations of acrylonitrile use only self-contained breathing apparatus or supplied air respirator with full facepiece

FIRST AID

Nonspecific Symptoms: The ACUTE EFFECTS OF EXPOSURE TO ACRYLONITRILE MAY BE DELAYED FOR SEVERAL HOURS AFTER EXPOSURE Symptoms may include headache, dizziness, eye irritation or painful sensitivity to light, flushed face, increased salivation, shallow breathing Skin contact may cause reddening and eventual dermatitis Severe exposures may result in cyanide poisoning Any person suspected of being exposed should be kept under medical surveillance

First Aid for Inhalation: Remove victim to fresh air Get medical attention immediately For CYANIDE POISONING ONLY, break amyl nitrite pearle under victim's nose Administer amyl nitrite for 15 seconds each minute If breathing becomes difficult or breathing has stopped, administer artificial respiration Get medical attention immediately (Caution: administration of mouth-to-mouth resuscitation may expose the first aid personnel to the chemical contained within the victims lungs or vomitus)

First Aid for Skin and Eye Contact: Flush eyes immediately with water for at least 15 minutes Remove all contaminated clothing Wash contaminated areas with soap and water Get medical attention immediately

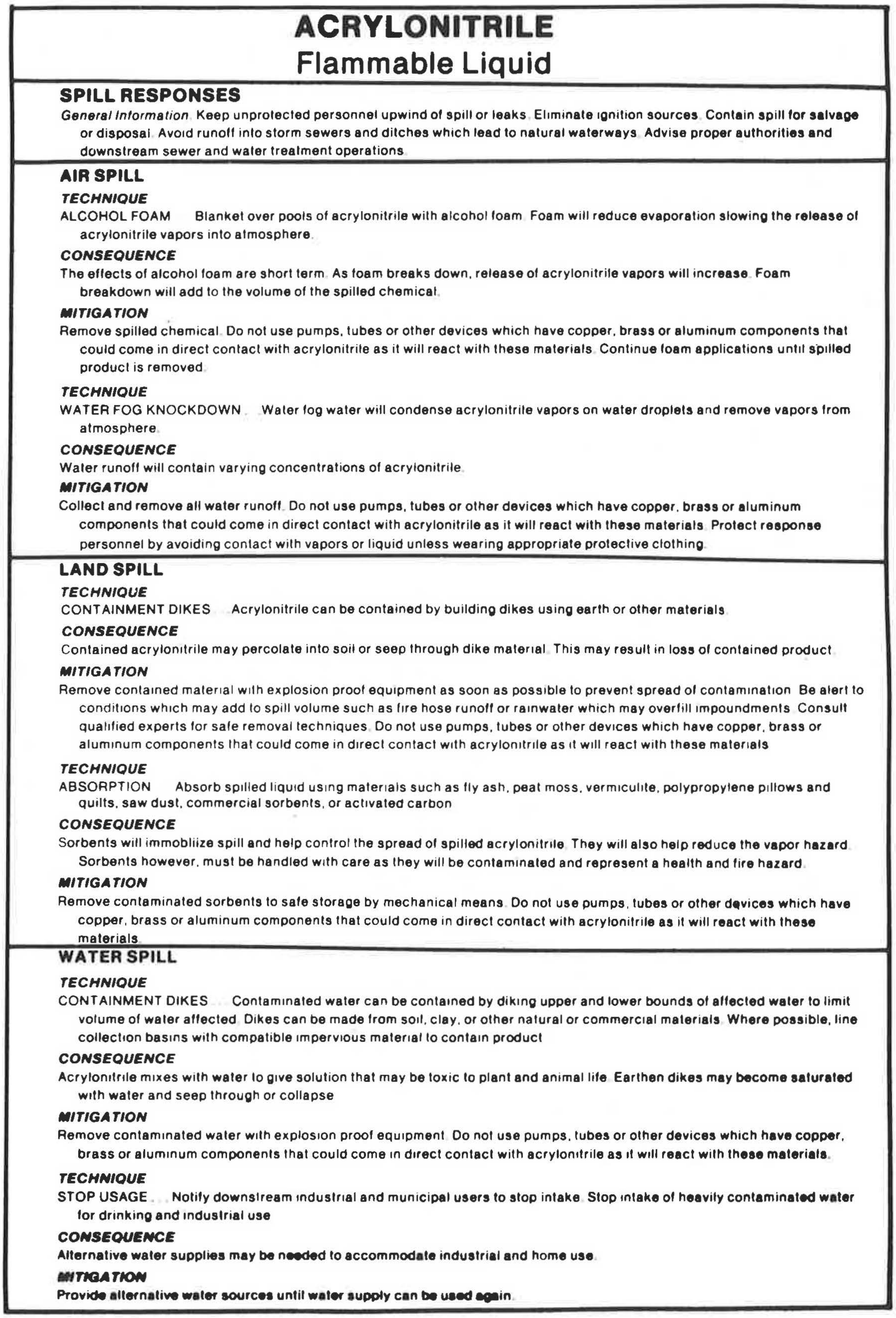
First Aid for Ingestion: If conscious, induce vomiting by administering strong solution of salt water If unconscious, DO NOT induce vomiting get medical attention immediately For CYANIDE POISONING ONLY, break amyl nitrite pearle under victims nose Administer amyl nitrite for 15 seconds each minute If breathing becomes difficult or breathing has stopped, administer artificial respiration Get medical attention immediately

FIRE RESPONSE

Extinguishing Materials: Fight fire with carbon dioxide, dry chemical, or alcohol foam

Extinguishing Techniques: EXPLOSION HAZARD, fight fire from a safe distance only Use alcohol foam, dry chemical or carbon dioxide Water may be ineffective as an extinguisher, but useful to cool containers exposed to fire, apply as spray or fog

FIGURE 3 Inside page 1 of EAG.



ACRYLONITRILE
Flammable Liquid

SPILL RESPONSES

General Information Keep unprotected personnel upwind of spill or leaks. Eliminate ignition sources. Contain spill for salvage or disposal. Avoid runoff into storm sewers and ditches which lead to natural waterways. Advise proper authorities and downstream sewer and water treatment operations.

AIR SPILL

TECHNIQUE

ALCOHOL FOAM Blanket over pools of acrylonitrile with alcohol foam. Foam will reduce evaporation slowing the release of acrylonitrile vapors into atmosphere.

CONSEQUENCE

The effects of alcohol foam are short term. As foam breaks down, release of acrylonitrile vapors will increase. Foam breakdown will add to the volume of the spilled chemical.

MITIGATION

Remove spilled chemical. Do not use pumps, tubes or other devices which have copper, brass or aluminum components that could come in direct contact with acrylonitrile as it will react with these materials. Continue foam applications until spilled product is removed.

TECHNIQUE

WATER FOG KNOCKDOWN Water fog water will condense acrylonitrile vapors on water droplets and remove vapors from atmosphere.

CONSEQUENCE

Water runoff will contain varying concentrations of acrylonitrile.

MITIGATION

Collect and remove all water runoff. Do not use pumps, tubes or other devices which have copper, brass or aluminum components that could come in direct contact with acrylonitrile as it will react with these materials. Protect response personnel by avoiding contact with vapors or liquid unless wearing appropriate protective clothing.

LAND SPILL

TECHNIQUE

CONTAINMENT DIKES Acrylonitrile can be contained by building dikes using earth or other materials.

CONSEQUENCE

Contained acrylonitrile may percolate into soil or seep through dike material. This may result in loss of contained product.

MITIGATION

Remove contained material with explosion proof equipment as soon as possible to prevent spread of contamination. Be alert to conditions which may add to spill volume such as fire hose runoff or rainwater which may overfill impoundments. Consult qualified experts for safe removal techniques. Do not use pumps, tubes or other devices which have copper, brass or aluminum components that could come in direct contact with acrylonitrile as it will react with these materials.

TECHNIQUE

ABSORPTION Absorb spilled liquid using materials such as fly ash, peat moss, vermiculite, polypropylene pillows and quilts, saw dust, commercial sorbents, or activated carbon.

CONSEQUENCE

Sorbents will immobilize spill and help control the spread of spilled acrylonitrile. They will also help reduce the vapor hazard. Sorbents however, must be handled with care as they will be contaminated and represent a health and fire hazard.

MITIGATION

Remove contaminated sorbents to safe storage by mechanical means. Do not use pumps, tubes or other devices which have copper, brass or aluminum components that could come in direct contact with acrylonitrile as it will react with these materials.

WATER SPILL

TECHNIQUE

CONTAINMENT DIKES Contaminated water can be contained by diking upper and lower bounds of affected water to limit volume of water affected. Dikes can be made from soil, clay, or other natural or commercial materials. Where possible, line collection basins with compatible impervious material to contain product.

CONSEQUENCE

Acrylonitrile mixes with water to give solution that may be toxic to plant and animal life. Earthen dikes may become saturated with water and seep through or collapse.

MITIGATION

Remove contaminated water with explosion proof equipment. Do not use pumps, tubes or other devices which have copper, brass or aluminum components that could come in direct contact with acrylonitrile as it will react with these materials.

TECHNIQUE

STOP USAGE Notify downstream industrial and municipal users to stop intake. Stop intake of heavily contaminated water for drinking and industrial use.

CONSEQUENCE

Alternative water supplies may be needed to accommodate industrial and home use.

MITIGATION

Provide alternative water sources until water supply can be used again.

FIGURE 4 Inside page 2 of EAG.

various times in the accident versus the information needed to effect a more favorable response within the first-response time frame.

Once information needs had been established, data were organized according to the following scheme:

1. Identification,
2. Health effects,
3. Protective equipment,
4. First aid,
5. Acute hazard response, and
6. Environmental response.

Resource Evaluation

Data requirements having been identified and organized, existing information sources were evaluated for content and clarity of presentation.

The following major deficiencies were observed in this review:

1. Identification was generally limited to one or sometimes two systems,
2. Health information was vague and inadequately characterized,
3. Protective equipment sections were often generic in nature,
4. Spill response sections were generally limited to one or two responses applied to all situations with no discussion of the possible consequences of a response, and
5. Overall descriptions of a substance generally provided little insight into how it might be expected to behave beyond what would be immediately observed.

The foregoing analysis was taken into consideration when compiling the EAG. The priorities in organization were identification and health effects, and the presentation of data was designed to overcome the deficiencies observed in other response guides.

Each EAG consists of three pages. The cover page (Figure 2) provides a general discussion of the chemical's properties and its anticipated behavior. Although the potential hazards intrinsic to a substance may be great, the substance's actual behavior is highly dependent on the spill situation. This introduction is provided to give the responder a perspective from which to evaluate the remaining information. In addition, chemical and physical properties and identification information are provided.

Health and hazard information is detailed on the next page (Figure 3). This includes health effects, fire and explosion data, protective clothing, and first aid material.

Inside page 2 of the EAG (Figure 4) provides the response information for air, land, and water spills. The most significant improvement over other guides is the adoption of the format in which the response consequences and mitigation are detailed. This section of the guide is designed to convey the idea that adverse consequences may result from the application of a particular response technique. If the responder is aware of this problem, plans can be made to eliminate or control for this possibility.

The categories air, land, and water each contain several response options. A single response is not always applicable to every situation. With a list of multiple responses, the user is encouraged to evaluate the uniqueness of a particular spill and apply the most effective response, not the one most frequently cited.

The layout of the EAG is predicated on the assumption that a user would scan the document from front to back, top to bottom, and left to right. This organization follows the priority scheme commodity identification, hazard identification, protection, and action.

SUMMARY

Safety in transportation is a primary concern of the U.S. rail industry. The research conducted in tank car design, head shields, shelf couplers, and thermal protection has contributed enormously to the reduction in the type of accidents observed 15 years ago. Although it is recognized that some accident factors are uncontrollable, handling an accident properly is of paramount importance. The EAGs, as well as other programs such as the development of a chemical and medical reference and the identification of chemical combustion products, are targeted at increasing the understanding of spill behavior. Through this understanding, better and faster cleanup technologies and management will undoubtedly result.

Quality of information is the first step. By identifying the two basic user levels, the information needs of each can be more completely satisfied. Through ICARIS, state-of-the-art assessment of a spill can occur. Improvements to ICARIS will come as the science of chemicals in the environment becomes more advanced.

The development of the EAGs was based on the observed need for a more complete understanding of chemical spill management on the part of the first responder. The considerations used in the EAG development were selected to enhance that understanding.

REFERENCES

1. Hazardous Materials; Emergency Response Guidebook. Materials Transportation Bureau, U.S. Department of Transportation, 1980.
2. Emergency Handling of Hazardous Materials in Surface Transportation. Bureau of Explosives, Association of American Railroads, Washington, D.C., 1981.

A Survey of Foreign Hazardous Materials Transportation Safety Research Since 1978

M. E. WRIGHT and T. S. GLICKMAN

ABSTRACT

Recent hazardous materials transportation research outside the United States and Canada is surveyed. The survey is limited to truck, rail, and air transportation and is based on publications within the past 5 years. Specific areas of research include vehicle and container technology, emergency response technology, traffic flow and accident information, risk assessment, and policy analysis regarding operations, emergency planning, and regulations. The results of computer searches and surveys of journals and periodicals are summarized, and references are included.

Safety in hazardous materials transportation is a subject of serious concern both to the industries involved and to the general public. Large-scale incidents such as the Spanish campsite disaster in 1978 when more than 200 people were killed by the explosion of a liquified petroleum gas tanker (1) have focused international attention on the gravity and importance of safety in the transport of hazardous materials. Although the subject has been extensively researched within the United States and Canada, quite a bit of work has also been done by other nations. If there is to be success in preventing or controlling incidents that not only endanger the public but also cost millions of dollars for cleanup and lost revenue, collective resources must be pooled. Thus it is the purpose of this study to survey the current developments outside the United States and Canada and to provide a bibliography of the literature that represents the thrust of the international community's approach to safety in hazardous materials transportation.

SCOPE

In the interests of being current, the survey is limited to truck, rail, and air transportation safety research conducted during the last 5 years. Topics such as pipelines, nuclear materials, hazardous waste, and marine transportation safety have such exclusive problems and extensive bibliographies that they were considered to be beyond the scope of the survey, to be addressed separately. Specific subtopics surveyed include vehicle and container technology, emergency response technology (including communications and containment), information (including traffic flow estimation and accident reporting), risk assessment, and policy analysis (including operations, emergency planning, and regulations). Release behavior and hazardous materials codes and classifications were generally excluded from the survey as topics too specific and technical for this broad overview of foreign developments.

APPROACH

A search of the Highway Research Information Service (HRIS) data base identified numerous monographs, conference proceedings, and technical reports that satisfied the criteria for inclusion in this survey. A Library of Congress search identified some additional documents. In addition, the appropriate issues of the following journals and periodicals were searched for pertinent articles: Accident Analysis and Prevention, Hazardous Cargo Bulletin, Hazardous Materials Intelligence Report, Hazardous Materials Management Journal, Hazardous Materials Newsletter, Journal of Hazardous Materials, Risk Analysis, and Transportation Research.

As expected, most of the published research originated in Great Britain, the Netherlands, and Sweden. However, Australia, Belgium, France, Italy, Spain, South Africa, and West Germany also published research that was included in the survey. Austria, East Germany, Finland, New Zealand, and the USSR experienced new developments in hazardous materials transportation safety that were reported in the literature. These articles were also included in the survey.

SUMMARY

A brief outline of the nature of the surveyed articles and papers and a complete bibliography follow.

Vehicle and Container Technology

The papers in which vehicle and tanker technology was discussed unanimously stress the need for improved construction to prevent puncture, allow pressure relief, and the like. The literature also stresses the importance of legislation in encouraging industry to exploit the latest advances in technology. The costs associated with replacing or improving older vehicles (tankers) may prove prohibitive in the face of competition. Careful legislation could provide the needed incentive.

H.G. Stinton of the Hampshire Fire Brigade Headquarters, Eastleigh, Great Britain, discusses the need for improved container design and legislative control in a report on the Spanish campsite disaster (1). He stresses that such an incident could have occurred in England. The circumstances surrounding the Spanish disaster were not particularly unique: A typical tanker carrying liquified petroleum gas (LPG) was traveling over main roads on a hot summer day. British tankers of similar construction would carry the same materials over comparable roads. British and Spanish regulations governing LPG transportation were also similar.

Stinton explores the lessons that should be learned from this disaster to avert future similar tragedies. He describes the various causes of the disaster: "The road vehicle was without a pressure relief valve, ...the road vehicle was over-loaded, ...corrosion had taken place in the high tensile steel tank due to carrying ammonia [and] ...the high ambient temperature, ...the road vehicle was without a current pressure test certificate." Stinton also points out that the tanker's lack of external impact protection contributed to the rupture. Although the safety record for LPG transport in the United Kingdom is fairly good, Stinton stresses that to be confident of avoiding such disasters, it is crucial to ensure that tankers carrying LPG products "are more adequately protected against impact than they are at present."

C. Swinbank discusses the use of intermediate bulk containers (IBCs) for the transport of hazardous materials (2). Because of the economy of their intermediate size, their application to the carriage of dangerous goods has recently attracted attention. Swinbank reports on initial studies regarding IBC use, which focus on establishing a definition of an IBC. He points out that IBCs carrying hazardous materials cannot properly be categorized as packages (per United Nations guidelines), portable tanks [per Intergovernmental Maritime Consultative Organization (IMCO) and the British Blue Book], or tank containers [per Reglement International Concernant le Transport des Marchandises Dangereuses (RID) and Accord Dangereuse Routier (ADR)]. "The United Nations Committee of Experts will need to determine whether IBCs can be recognized as a separate class of receptacle, and the constructional and/or test requirements which are necessary to ensure safety in transport and use." Swinbank emphasizes the considerable economic and technical significance of this UN work to manufacturers and users of IBCs worldwide.

The proceedings of three major conferences include papers that address the issues associated with vehicle and container technology. D.A. Beattie, at an October 1978 conference organized by Oyez International Business Communications (3), presented a paper describing tanker design as a compromise between several conflicting parameters. In a review of the conference published in the Hazardous Cargo Bulletin (4), the reviewer stresses that these compromises demonstrate that technology is not 100 percent foolproof in hazardous materials transportation. He emphasizes that the community must accept this fact and offers examples of the inherent uncertainty by quoting Beattie: "Transverse baffles will also ameliorate to some extent the side-to-side surges that can occur, [and] rubber (tank) linings may be adversely affected by switching products." The reviewer concludes these remarks on a rather pessimistic note: "Should it prove possible to replace these doubts with assurances, other problems will probably take their place."

The design of road vehicles and tankers was also addressed during the Symposium on the Transport of Hazardous Materials held in London in December 1977 (5,6). The papers delve into the complexities of recovery of damaged tankers as well as the need for improved analysis of incident reports as they relate to tanker design performance. The relatively low incidence of tank ruptures compared with the number of tanker journeys could have as much to do with safe driving practices as with impact-resistant tanker designs. Better analysis of incident reports would clarify the causes and help lead to truly improved tanker designs.

Finally, the Spring Conference on the Transport and Handling of Dangerous Goods held in Sweden in April 1978 included a number of papers in which vehicle technology was discussed (7). M. Lidstroem presented a discussion of the maneuverability and dynamics of heavy vehicles, and Y. Dagel, C. Lager, H.G. Linder, and L. Lindberg et al. offered views on the packing of dangerous goods.

Emergency Response Technology and Information

A number of different articles discuss what appears to be the key element to effective emergency response: an easily accessible and comprehensive identification and hazard information system. The implementation of such a system was hailed as a great advance at the Symposium on the Transport of Hazardous Materials (5,6). However, the development of a comprehensive international system incorporating both action and properties codes is identified as an ultimate goal. An information system approaching this goal is the BTK system developed in Belgium and described in the Hazardous Cargo Bulletin (8). The most outstanding feature of the BTK is that the code is structured to allow requests for information to be dispatched in Dutch, French, English, or German. Italian and Spanish will be added shortly, and additional capacity is provided to handle two more languages for a total of eight. The information is accessed by UN number, product name, or by internal BIG-number, and the computer returns with the corresponding Hazchem code. The operator can then select from 10 different program modules: type of hazard, emergency action, personal protection, properties, first aid, general precautions, remarks, experts, literature, and synonyms. Belgium thus has a multilingual computer-aided data system to help cope with hazardous materials incidents.

In "Son of Hazfile" (9) a microcomputer-based successor to the U.K. chemical emergency response computer data bank Hazfile is described. Called CHEMDATA, it is designed for use by U.K. fire brigades. The role of CHEMDATA is to supplement immediate emergency response guidance with comprehensive information on hazards, protection, and procedures. The system has been made more user friendly than Hazfile by building in easier commands and guidance messages and by reorienting data around the products rather than the manufacturer. In addition, after the initial hardware investment (microcomputer, disk drives, and printer) the operating costs will be minimal, making CHEMDATA more cost effective than Hazfile. The evolution of the various information systems available to the British fire services was also discussed at the Transchem 82 in Middlesborough, England, held June 2-3, 1982 (10).

Some practical procedural aspects of emergency response are described by H.G. Stinton in the Hazardous Cargo Bulletin (11). He discusses the correct response to averting and coping with flammable liquids, boiling liquid expanding vapor explosions (BLEVEs), and unconfined vapor cloud explosions (UVCEs). Stinton provides a technical discussion about the conditions that cause BLEVEs and UVCEs, and the disastrous effects of these phenomena, citing the Spanish campsite disaster as an example. He lists recommendations for emergency service response to incidents that could culminate with a liquid gas explosion, with particular emphasis on procedures for highly populated areas. Stinton discusses evacuation, fire control, crowd control, and the need for clearly defined roles for the various authorities who become involved in emergency response. He stresses that swift and proper response are the keys to averting disasters like the Spanish campfire incident.

In "Backing up the Hardware" (12) the labeling and other regulations on hazardous materials transport enforced on New Zealand Railways (NZR) to protect railway workers and ensure quick response in the event of an emergency are described. Despite its relatively small population, New Zealand operates an extensive network of railways. NZR builds its own rolling stock, including tanks for such hazardous materials as LPG, CO_2, and chlorine gas. Placards with hazard warning labels and emergency procedure guides are placed on both sides of all tank cars. Destination cards are placed at the ends of these cars, and consignment documentation requirements are designed to ensure that all of those concerned with the physical handling of the cars and their contents are aware of the hazardous nature of the cargo. Cars containing hazardous cargo may not be conveyed as part of express trains and must be segregated from the locomotive, guard's van, and cars containing other classes of hazardous goods for safety.

B. Gandham and P.J. Hills examine the feasibility of monitoring the movement of vehicles carrying hazardous substances over British roads (13). They discuss various methods of monitoring the movement of vehicles carrying hazardous freight, including radiolocation techniques, proximity-to-fixed-objects methods, and the dead-reckoning technique. The emergency services, local authorities, and the chemical industry contributed to determining the benefits of a monitoring system in general, and the costs versus benefits of such methods are discussed. The primary benefit of such monitoring would be the virtually instantaneous notification of the emergency services in the event of an accident. The decrease in response time this would represent could be crucial to the ability of the fire brigades to avert disaster. However, the cost of such a system would probably not justify even this benefit; the conclusion is that the money would be better spent on improving existing prevention schemes.

Risk Assessment

An underlying concern in the literature on risk assessment in hazardous materials transportation is the emotional public response elicited by hazardous materials transportation issues. Despite the relative safety of hazardous materials transportation (versus overall traffic statistics), the potential for disaster arouses significant public concern and attention. In addition, social, economic, and technological development have led to both an increase in hazardous materials traffic and increased load sizes. Thus a technological approach to hazard control and risk assessment is necessary. This was the theme of the October 1978 Oyez International Business Communications conference on managing the risks caused by the carriage of hazardous goods over land (3,4). Papers included a discussion by L.S. Fryer regarding the risk to the public from the transport of dangerous goods and the effect of accidents on the community, a paper by D.H. Napier that dealt with BLEVEs and techniques for minimizing hazards and achieving a fuller assessment of risk, and a paper by D.H. Slater that attempted to quantify the risks involved with hazardous materials transportation and the costs when accidents occur.

M. Benwell addressed the public perception and acceptance of risk at Transchem 81, held in Middlesborough, England, May 27-28, 1981 (14). Benwell pointed out that despite the relevance of public opinion toward decisions made to enhance public safety, little research has been done to predict public response to such decisions. She also stressed that public response is often irrational: The public expects the benefits of hazardous materials but may be unwilling to accept the risks associated with their transportation. Although the public may object that they are kept in ignorance of the risks they face, Benwell observed that programs for public education often cause alarm rather than lessen it. She contended that significant benefits could be achieved both for those engaged in the movement of hazardous materials and for the public if some concerted effort were made to help the public understand the actual risks associated with hazardous materials transportation.

At Transchem 82 (10) Somerhoff of the Hamburg Fire Department suggested that difficulties encountered by emergency services could be remedied if a systematic investigation of transport risks were conducted before the transport of hazardous goods and if all those involved with the transport were made to understand the risks at the outset. This, he contended, would significantly facilitate proper emergency response in the event that it were needed.

T.B. Meslin (15) discusses the specific risks involved with chlorine transport in France within the framework of a general model for evaluating risks associated with the transport of dangerous materials.

> Stated simply, the problem is to evaluate the number of accidental releases that could occur during transport of a product under a number of conditions, as well as the range of possible consequences. Consequences are measured by using such deliberately simplified indicators as the number of victims (death, injuries, and illnesses), which permit a synthetic evaluation of risk. Each protection measure under study is assigned a risk level. The overall cost of the various protection policies is calculated, so that it is possible to compare them and select the most cost effective, that is the one that presents the most satisfactory compromise between risk reduction and the increased cost of protection.

Because so few data are available that describe the causes and dynamics of accidents, an analysis of probabilities cannot be based on direct observation. Thus indirect models are used to simulate accidents. Meslin describes the process by which an assessment of the risks involved with any specific means of transporting any particular hazardous material can be made. He contends that it is possible with current technology to make rational choices concerning dangerous activities and institute measures to reduce the risk to the public.

Additional discussions of risk assessment appearing in the literature include papers by P.N. Anderson (16), who discusses means for assessing the risks associated with the handling and transport of hazardous chemicals, and by De Malherbe et al. (17), who discuss hazard identification, hazard analysis, risk analysis, and safety measures designed to reduce hazards. De Malherbe et al. also provide an introduction to the system analysis methodology of risk analysis.

Policy Analysis

A great number of papers have been written about the general topics that fall under the heading of policy analysis. Several have been published in which the regulation of hazardous materials transportation within a particular country and attempts to explain those regulations and compare them with international standards have been discussed. The significance of these is the diversity of their origins. It is clear that the regulation of hazardous materials transportation is internationally recognized as deserving public and government attention.

A paper from Sweden (18) outlines the principles behind the various international directives for safer transport of dangerous goods. Directives from the different sources are compared with regard to their being combined into a single international set of standards in the future. In addition, the Swedish system for internal transport of hazardous materials is discussed. H. Frostling, from Sweden, also discusses and compares the national and international regulations governing hazardous materials transportation (19).

The developments in technical regulations regarding the transport of new hazardous materials are discussed by G. Dobias et al. (20), from France. The regulations are updated by the Interministerial Committee for Transport of Dangerous Materials, whose charter is explained. Regulations and developments covering such diverse aspects of hazardous materials transportation as vehicle design, road routing, and professional training are also recounted.

J.C. Hillman discusses the need for increased regulation governing hazardous materials transportation in South Africa (21). Hillman examines the factors that could increase the likelihood that an accident would occur and makes recommendations as to how the dangers can be minimized through emergency response preparedness. He also discusses the merits of forthcoming new regulations and examines both the advantages of good regulation and the disadvantages of restrictive legislation.

The implications of national Dutch legislation for local municipal authorities are the subject of a paper by A.G. Kaag-Vanrp (22), who includes discussions of loading and delivery of dangerous materials; road, water, and rail routing; and emergency response.

Specific national regulations for the transport of hazardous materials by road are described in a Spanish paper (23), and the Italian regulations regarding road transport of hazardous materials are recounted by V. Rocco (24).

Numerous conference proceedings have been published that address policy issues associated with hazardous materials transportation. The proceedings of the Symposium on Transport of Hazardous Materials (5,6) includes discussions of routing of hazardous loads and lessons to be learned from incidents involving hazardous materials. The benefits to be gained from rerouting hazardous goods through rural rather than populated urban areas are enumerated. However, the point is made that expert advice in the event of an incident can be far from rural sites, whereas it may be immediately available in more populated areas.

The proceedings of the Conference on Chemical Distribution into the 80's (25) includes papers on a variety of policy issues. J.H. Locke offered a paper discussing the regulations and codes, K.L. Holland presented a paper on the role of the fire service in transportation of chemicals by road, vehicle labeling was discussed by P.N. Anderson, the selection and training of drivers for the handling of hazardous substances was described by H.J. Morley, and P.T. Mabbitt discussed the status of national and international regulations concerning the transport of dangerous goods by rail.

A broad variety of policy issues, from general regulations on transport of dangerous goods by A. Lindstedt to A. Hoengstroem's discussion of insurance matters in connection with handling and transport of dangerous goods, were presented at the Swedish Spring Conference on the Transport and Handling of Dangerous Goods (7). Other papers include a discussion of Swedish and international directions on transport of dangerous goods by rail, road, sea, and air by M. Baang et al.; a presentation of the views on packing of dangerous goods by L. Lindberg et al.; and an overview of the experiences of the fire services, the Swedish Board of Occupational Safety and Health, and the police on transport of dangerous goods by G. Schnell et al.

Australian policy regarding hazardous materials transportation was the theme of the National Seminar on the Transport of Dangerous Goods in Canberra (26). J.F. Wilding and I.E. Kolm both presented papers on the transport of dangerous goods in Australia, regulation was discussed by P. Brazil and R.P. Sammon and by H. Blackmore, and G.C. Uniacke offered views of the road transport industry.

In a number of papers presented at Transchem 79, the Sixth Symposium on the Safe Transportation of Hazardous Substances (27), various policy issues associated with hazardous materials transport are discussed. Some papers of unusual interest were ones on first aid and medical aspects by A.P. Wright, recovery of damaged chemical tankers by W.E. Clayton, and the role of the highway authority by M.R. Hilton. Transchem 81 (May 27-28, 1981) (14) and Transchem 82 (June 2-3, 1982) (10) also included interesting discussions of hazardous materials transportation regulations and public policy.

H.G. Stinton (1) examines some specific aspects of policy that should be addressed in the light of the Spanish campsite incident. The safest routing of vehicles carrying hazardous materials, the danger associated with transport of hazardous materials over roads through areas with dense holiday populations, and other issues associated with the medical response to such disasters are specified. Stinton places particular emphasis on the need for improved regulation: "Any preventive steps which are taken will only be truly effective if backed by legislation rather than voluntary agreement. Obviously any such legislation should be valid across Europe and not simply an internal measure in the United Kingdom."

Several countries have legislated new regulations restricting hazardous materials transportation, as reported in the literature. Both France and Austria have imposed restrictions that prevent the transport of specified hazardous materials through certain tunnels, for example, the French Prefectoral Decree 3302 of December 20, 1980, which includes regulations limiting access to the Mont Blanc tunnel on the French-Swiss border, and Austrian regulations limiting access to specified portions of the Arlberg Expressway, the Tavern Motorway, and the Flebertavern Road, including several tunnels (28). The regulations include limiting access during specific hours of the day as well as bans on the transport of certain hazardous materials.

New requirements imposed by the German Democratic Republic for the movement of hazardous goods into or through East Germany are described in the Hazardous Cargo Bulletin (29). Registration of and the provision of escorts for 80 hazardous substances are required, and the specified information must be provided up to 4 working days in advance. The regulations specify requirements for transport of hazardous materials both by road and by rail.

Finally, a Finnish study conducted on the transit traffic of Russian railway tank cars carrying hazardous cargos into and through Finland is reported in the Hazardous Cargo Bulletin (30). The study was conducted in response to the rapidly expanding flow of Russian railway tank cars carrying chemical and petroleum products through Finland. The greatest threat this traffic posed to public safety was identified as the poorly maintained state of some of the tank cars and the occasional congestion of the system at certain stations for extended periods of time. As a result of the study, specific inspection regulations have been instituted. The number of tank cars allowed in the system at one time has been limited by additional new regulations.

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