Effects and Fates of Hazardous Chemicals Released to the Environment

Introduction

Description: Chemical fate and transport in the environment. Frequency and magnitude of accidents involving hazardous materials. Effects of these releases on the community.

Textbooks:

Hemond, H.F. and E.J. Fechner-Levy. *Chemical Fate and Transport in the Environment*. 2^{nd} edition. Academic Press. ISBN: 0123402751. 448 pages. October 1999.

Becker, S., R. Pitt, and S. Clark. *Environmental Health, Public Safety, and Social Impacts Associated with Transportation Accidents Involving Hazardous Substances*. University Transportation Center for Alabama Report 00214. Tuscaloosa, Alabama. 225 pages. July 2001. The full report is available at the UTCA website:

http://utca.eng.ua.edu/projects/final_reports/00214report.htm#_Toc522094490

appropriate sections for this class will be summarized and placed on the class website at:

http://civil.eng.ua.edu/~rpitt/Class/Classes.shtml

Instructor: Robert Pitt, P.E., Ph.D., Professor, room 347b. Office hours to be determined, or by email rpitt@eng.ua.edu or phone 348-2684. Drs. Shirley Clark (Dept. of Civil and Environmental Engineering, UAB) and Steven Becker (Department of Environmental Health Sciences, UAB) will be quest lectures for Module 9.

Course Goals: Integrate chemical property information to better understand the transport and fate of hazardous chemicals released to the environment. Examine case studies to understand the long-term social and environmental effects of these releases.

Prerequisite by Topic:

1. basic chemistry (Chemistry 131 and 132)

2. fundamental math (Math 126)

3. basic environmental engineering (CE 420)

4. water resources (CE 478)

5. air resources (CE 425)

or permission of instructor

Course Topics and Approximate Schedule:

Module	Topic	Hemond and Fechner-Levy	

		Chapters	
0.	Course overview and introduction		
1.	Basic concepts of chemical fate and transport	Chapter 1	1 week
2.	Surface water fate and transport processes	Chapter 2	3 week
3.	Subsurface water fate and transport processes	Chapter 3	1 week
4.	Fate and transport processes in the atmosphere	Chapter 4	2 weeks
5.	Accidental releases		1 week
6.	Basic prediction procedures		2 week
7.	Detailed case studies for hydrocarbon spills		1 week
8.	Detailed case studies for accidents involving ammonia		1 week
9.	Case studies of long-term community impacts associated with releases of hazardous materials		2 week

Modules 1 through 4 correspond to the first four chapters of Hemond, H.F. and E.J. Fechner-Levy's book: *Chemical Fate and Transport in the Environment*. We will review much of these chapters, but since our time is limited, and we will not be able to cover all of the material in this excellent book.

Modules 5 through 9 were mostly extracted from the following UTCA (University Transportation Center for Alabama) research report:

Becker, S., R. Pitt, and S. Clark. *Environmental Health, Public Safety, and Social Impacts Associated with Transportation Accidents Involving Hazardous Substances*. University Transportation Center of Alabama and US Dept. of Transportation. UTCA Project No. 00214. Tuscaloosa, AL. July 2001.

Periodic material will also be examined from additional references, especially recent EPA guidance reports on evaluating hazardous material releases.

Course Summary:

Accidents involving chemicals or radioactive materials represent a significant threat to the environment, public health and safety, and community well-being. In an increasingly complex and interconnected world, no community is immune from the threat posed by environmental accidents and contamination. Even communities far removed from industrial production or storage facilities can still be at risk from accidents associated with the transport of hazardous materials. While a variety of studies have been conducted on aspects of major transportation accidents, few have attempted to examine both environmental and community aspects of the problem. In contrast, this course takes an integrated approach to hazardous transportation accidents by considering environmental, safety, economic, and psychosocial issues.

The course will cover basic environmental chemistry topics and will conclude with practical applications covering an analysis of transportation-related accidents involving hazardous materials and likely important social, psychological and related community impacts that can occur after transportation-related hazardous materials accidents.

Several case studies will be examined of actual accidents, ranging from small to very large releases of hazardous materials and will illustrate the varied long-term problems that have resulted. In addition, quantitative procedures will be studied covering problems associated with spills of petroleum hydrocarbons (the most common material involved in transportation accidents) and losses of ammonia (a toxic gas).

Alabama hazardous material transportation-related accident information has been collected and analyzed using data from the National Response Center. The purpose was to identify the most common hazardous materials lost in the state of Alabama, where the accidents occurred, and which media (water, land, air) are affected. This information was used to present procedures that can be used to predict the movement and dispersion of the lost material. More than 1,700 transportation-related accidents involving hazardous materials occurred in Alabama during the past ten years, involving a large variety of different materials. The petroleum hydrocarbons were the most common hazardous material lost. Of the 226 reported accidents in 1998, there were 20 deaths and 27 injuries. In addition, four accidents caused property damage, two accidents resulted in evacuations, and nine accidents resulted in road closures. During the 1990s, the locations with the most frequent spills were the historical *USS Alabama* Battleship museum site and the hazardous waste landfill at Emelle, probably due to diligent reporting by the site operators. Additional locations of frequent spills include several sites where chemicals are transferred from marine craft to land vehicles, such as trains and trucks.

The material for this course includes several procedures to predict the fate and transport of spilled hazardous materials. Modules 1 through 4 present information on the fate and transport processes of contaminants in surface and groundwaters, and in the atmosphere. A general discussion in Module 6 is a general procedure that stresses downwind toxic and explosive hazards, summarized from a recent EPA manual, and is applicable for a wide range of hazardous materials. Two examples are also presented describing problems associated with spills of petroleum hydrocarbons (the most common material involved in Alabama transportation accidents) and losses of ammonia (a toxic gas) in Modules 7 and 8, reflecting specific characteristics of these materials.

Major transportation accidents involving hazardous materials have been shown to produce profound economic, social, and psychological impacts in affected communities, as described in Module 9. These impacts can be both widespread and long lasting. The Bellingham pipeline explosion is used to illustrate some of these effects. The case study is then followed by a more general discussion of the economic, social, and psychological effects of hazardous transportation accidents. Current scientific research is reviewed, examples are provided, and implications are considered.

Recommendations and conclusions are presented later in this module to illustrate the types of community impacts that can occur and steps that can be taken to enhance preparedness and response capabilities. The class modules also contain extensive appendices that present detailed information of Alabama accidents for the past ten years, and properties of hazardous materials that are needed for the calculation of expected exposure conditions.

"Workers transfer drums of hazardous material from the overturned truck into a van" (July 24, 1998). (Copyright Photo by *The Birmingham News*, 2000. All rights reserved. *Shown with permission*).

Project Rationale

Accidents involving chemicals or radioactive materials represent a significant threat to the environment, public health and safety, and community well-being. In an increasingly complex and interconnected world, no community is immune from the threat posed by environmental accidents and contamination. Even communities far removed from industrial production or storage facilities can still be at risk from accidents associated with the transport of hazardous materials. In the U.S., a staggering 4 billion tons of hazardous materials are moved each year via highways, railroads and other transportation routes (Lillibridge 1997; Quarantelli 1993).

Fortunately, the majority of transportation accidents involving hazardous materials are small and relatively easily managed. However, when major transportation accidents involving hazardous materials do occur, serious environmental health, safety and social problems can result. Indeed, depending on the nature and circumstances of an accident, some impacts can be both widespread and long-lasting.

While a variety of studies have been conducted on aspects of major transportation accidents, few have attempted to examine both environmental and community aspects of the problem. In contrast, this course takes an integrated approach to hazardous transportation accidents by considering environmental, safety, economic, and psychosocial issues. The approach combines the insights and experience of several disciplines, including civil and environmental engineering, public health, and social and behavioral science.

Rather than addressing the already well-explored topic of immediate emergency response and cleanup activities, this course material deals with issues specifically related to contingency planning and post-emergency response. Therefore, this course focuses on the medium and longer-term impacts of transportation-related accidents involving hazardous materials. More specifically, the purpose of the project is to (1) quantify transportation-related accidents involving hazardous materials in Alabama, and (2) identify key longer-term environmental health, public safety, and social impacts that are often overlooked after major transportation-related hazardous materials accidents.

Methodology

The methodology to obtain the necessary information used in the later modules was comprised of four main tasks: consultation with key stakeholders; summary and analysis of representative transportation-related accidents involving hazardous materials that have occurred in Alabama since 1990; presentation of simplified chemical transport and fate models; and presentation of information to identify and mitigate potential long-term adverse community impacts.

Stakeholder Meetings: Formal stakeholder meetings were held with staff from a variety of agencies and organizations that have a role to play planning for, or responding to, accidental hazardous releases. This included the Alabama Department of Transportation, the Alabama Department of Environmental Management, the Alabama Department of Public Safety, and others. In addition, informal discussions were held with personnel from the Alabama Department of Public Health, the Red Cross, and local emergency responders. Information from the stakeholder meetings was used to identify issues needing coverage in the report.

Diversity, Frequency, and Magnitude of Transportation Accidents Involving Hazardous Materials: For this task, the reported transportation-related accidents involving hazardous materials in Alabama were quantified and described. The primary source of information was the National Response Center's (NRC) nation-wide database on oil and hazardous materials spills. From this database, all transportation accident information for Alabama since 1990 was summarized. Data analyses were conducted to measure frequency of accidents by severity (volume of chemical spilled and number of accidents involving a particular chemical) and by location. Public records of several newspapers in the state were also reviewed (especially the *Birmingham News* and *Post Herald*, the *Huntsville Times*, the *Anniston Star*, the *Mobile Register*, the *Montgomery Advertiser*, plus the Gadsden and Dothan newspapers) to compile case histories of several representative transportation-related accidents. However, because many of these accidents were only reported in one issue of the paper, a complete case study for Alabama was only prepared for one transportation-related accident, the acrylonitrile spill on Interstate 65 in 1994. Additional case studies were also prepared for several notable national and international transportation accidents (a gasoline pipeline explosion in Bellingham, Washington; and a train derailment in Dunsmuir, California). These accidents were examined to provide additional information about local response scenarios and potential long-term social impacts of major transportation-related accidents that involved hazardous materials.

Simplified Chemical Transport and Fate Models: Hazardous materials that may be involved in transportation-related accidents are highly varied in their characteristics and potential amounts that may be lost during an accident. In addition, site conditions where an accident occurs can have significant effects on the behavior of the released materials. The results of the database analysis were used to determine the categories of potentially problem-causing chemicals frequently spilled in the state (such as petroleum hydrocarbons, ammonia, and chlorine). Transport and fate estimation procedures for several classes of chemical compounds, using methods given by EPA (1999), Hemond and Fechner-Levy (1999), Thomann and Mueller (1987), and Turner (1993) were used to produce generic (and some specific) exposure procedures for Module 6. This approach has frequently been used during the preparation of contingency plans (as required for the Coast Guard National Response Center and Federal Regional Contingency Plan regulations) for complex chemical facilities where numerous chemicals may be involved. Several examples taken from oil spill and ammonia contingency plans and environmental impact reports, are included as case studies in Modules 7 and 8. These general procedures, in addition to the specific procedures for petroleum hydrocarbons and ammonia, should cover the majority of accident conditions that would be predicted in the state (based on past accident reports).

The steps involved in predicting potential exposures to hazardous materials involved in transportation-related accidents are generally as follows:

1. Identify materials lost, location (land or water), amount lost, and loss rate (and volume).
2. Predict likely combinations of materials that may be involved in individual accidents that may increase the seriousness of the incident.
3. Predict the fate of the spilled material (air or water media)
4. Estimate downwind atmospheric and downstream water concentrations.

Identification of Potential Longer-Term Community Impacts of Major Transportation Accidents: Firefighters, police officers and other first responders have accumulated considerable experience in identifying and managing the *immediate* effects of transportation-related hazardous material incidents. Established protocols are in use, and training is conducted on a regular basis. However, because there is far less experience dealing with *longer-term impacts,* these effects can easily be overlooked. The fourth task, therefore, was to provide information to help anticipate important social, psychological and related community impacts that can occur after major transportation-related hazardous materials accidents, as presented in Module 9. To do so, we drew upon information from the three above-noted tasks, plus recent social science and public health studies. The two-fold aim was to enhance university-based training related to transportation accidents in the state and contribute to the state's planning, preparedness and response process.

Conclusions and Recommendations

Overview and Conclusions

Our purpose for the research that is the basis for this course was to (1) quantify transportation-related accidents involving hazardous materials in the state and (2) identify key longer-term environmental health, public safety, and social impacts that are often overlooked after major transportation-related hazardous materials accidents. In an increasingly complex and interconnected world, no community is immune from the threat posed by environmental accidents and contamination. Even communities far removed from industrial production or storage facilities can still be at risk from accidents associated with the transport of hazardous materials. While a variety of studies have been conducted on aspects of major transportation accidents, few have attempted to examine both environmental and community aspects of the problem. In contrast, material presented here takes an integrated approach to hazardous transportation accidents by considering environmental, safety, economic, and psychosocial issues.

Module 9 includes case studies illustrating the long-term social impacts associated with transportation accidents involving hazardous materials to highlight the problems encountered in transportation accidents. One case study, which took place near Dunsmuir, CA in 1991, involved a train derailment that spilled a large quantity of the pesticide metam sodium. The Dunsmuir case showed the massive ecological-scale effects that can result from a major transportation accident involving hazardous materials. In the Upper Sacramento River, fish, algae, plankton and insects were killed immediately and, in effect, the stream was sterilized. The airborne plume killed much of the streambank vegetation.

In another case study, a truck accident involving acrylonitrile on Interstate-65, near Warrior, Alabama, was far smaller and far less serious than the Dunsmuir case. It is noteworthy, however, because it illustrates how an accident involving even a very small quantity of hazardous material can produce significant problems. In addition, the fact that a barge with 100 times more acrylonitrile ran aground a year after the I-65 accident indicates that there is the potential for large-scale transportation accidents to occur in Alabama.

If the Dunsmuir and I-65 accidents both illustrated the need for improvements in training and preparedness, the point was further emphasized in the stakeholder discussions conducted in connection with producing the material in these modules. Several of the larger fire departments (Birmingham, Tuscaloosa, Montgomery, Mobile, and Huntsville) have hazardous materials responders who have had the required emergency response training. Fort Rucker also has its own hazmat unit. However, much of the state is served by volunteer/semi-volunteer fire departments. Interviews with stakeholders highlighted several concerns. First, the State has no mechanism for recovering its expenses relating to a hazardous materials incident response. Not only is there no money in the state budget for expenses relating to this type of emergency, but there are no requirements for the responsible party to reimburse the state for the money spent on a response. Second, stakeholders are concerned that there is no uniform standard for communications equipment between the Department of Public Safety (DPS) and local police, fire and emergency responder departments. Even inside the DPS, said stakeholders, there are three communications systems, which can cause coordination problems. Third, there is a concern about responders, especially local departments, not having the knowledge to respond to incidents involving 'unusual' chemicals, i.e., those chemicals that are not encountered frequently during a traffic accident. A fourth concern that was raised was the lack of alternate routes for detours and evacuations. The closure of I-65 resulted in large volumes of traffic passing through the town of Warrior on a roadway that was ill-equipped to deal with the volume of cars and trucks. Finally, concern was expressed that responders and residents are not always informed in a timely manner about potential hazards resulting from spills.

Module 5 reviews information about Alabama's transportation system and about the hazardous-materials transportation accidents that have occurred in the state in the 1990s. Major features of Alabama's transportation network include the following:

· Five major interstate highways and an extensive network of surface highways;

· The second longest inland waterway system in the nation and a deep-water port in Mobile (the nation's 12th busiest);

· Five Class I railroads;

· Eight commercial airports and 91 general aviation facilities;

· Almost 95,000 miles of roadways with motorists travelling approximately 50 billion miles on them per year;

· The Port of Mobile which serves 1,100 vessels annually (generating 66,000 truck movements and 119,000 train movements to and from the facility); and

· Over 5,200 miles of railroad track miles, with Birmingham being a major Southeastern hub.

Information on hazardous material transportation accidents in Alabama was collected and analyzed using data from the National Response Center. More than 1,700 transportation-related hazardous materials accidents involving a large number of materials occurred in the State over the past ten years. Petroleum hydrocarbons were the most common hazardous material lost. A review of the data showed that of the 226 reported accidents in 1998, there were 20 deaths and 27 injuries. In addition, four accidents caused property damage, two accidents resulted in evacuations, and nine accidents resulted in road closures. The locations with the most frequent reported spills were the historical *USS Alabama* Battleship museum and the hazardous waste landfill at Emelle, probably due in part to diligent reporting by the site operators. Additional locations of frequent spills include several sites where chemicals are transferred from marine craft to land vehicles such as trains and trucks.

A review of the data in the tables in Module 5 shows that transportation accidents involving hazardous materials can vary considerably in magnitude. Fortunately, most of the accidents were small. Many of these releases occurred during transfer operations (i.e., between trains or trucks and ships or other loading facilities). The mode of transport with the fewest accidents was air, but air accidents tended to involve the loss of large quantities of pesticides (accidents involving crop-dusting planes). Another frequent type of accident involves ships. These losses may be due to a ship running aground, and accidents often involve the release of the ship's fuel.

Stakeholders raised several issues related to potential future transportation accidents in Alabama. Concern was raised about the routing of hazardous materials in the state, particularly in relation to the tunnel in Mobile. Also at issue was the transport of transuranic waste from Oak Ridge and Savannah River. This waste has been scheduled to pass through downtown Birmingham on I-59/I-20. Public safety personnel were concerned that they would not be informed of the schedule for the waste transport.

Module 6 presents several procedures to predict the fate and transport of spilled hazardous materials. The initial discussion is a general procedure that stresses downwind toxic and explosive hazards, summarized from a recent EPA manual, and is applicable for a wide range of hazardous materials. An overview of potential reactions of mixtures of hazardous materials is also presented in this module. Two detailed examples are also presented describing problems associated with spills of petroleum hydrocarbons (the most common material lost in Alabama transportation accidents), and releases of ammonia (a toxic gas) in Modules 7 and 8. A review of the literature on several major historical oil spills produced the following general conclusions:

1. The principal damage from oil spills is to birds.
2. The effects in the intertidal zones, beaches, marshes, and rocky shores are sometimes of significant severity.
3. Little documentation is available that shows any significant damage to marine bottom communities in either deep or shallow water.
4. Damage to fisheries appears to be confined to those cases where animals live in intertidal zones.
5. Recovery from oil-spill damage is usually rapid and complete so far as marine communities are concerned.
6. No significant damage to plankton has been observed in the referenced incidents.

The interviews with stakeholders showed that there are fears about the types of chemicals that may be encountered during a transportation accident. The chemical groups that responders generally were not prepared and equipped to deal with were water-reactive chemicals, corrosives, elevated temperature materials, regulated medical waste, and precursor chemicals for clandestine laboratories. The typical response of a local fire department would be to put water on the chemical and wash it off the roadway. However, in the case of water-reactive chemicals, this may make a small problem much worse. When dealing with elevated temperature materials, the departments often do not have the appropriate gear. (Rubber suits are clearly unsuitable near a 250^{o}C fire.) One example of a commonly transported elevated temperature material was liquid asphalt. Regulated medical waste is another concern because of the variety of vehicles in which it can be transported and because of the lack of information that may be available about the exact nature of the waste. The last chemical group is the precursor chemicals for clandestine laboratories. These shipments are not placarded and there is no paperwork on what the truck contains. In many cases, these are rental trucks. Therefore, personnel responding to an accident likely do not know that they are entering a chemical hazard area, and they are not appropriately protected. The procedures presented in these modules can be used to address many of these concerns. It is possible to locate sensitive receptors (schools and hospitals, for example) at safe distances from potential accident locations, by hazardous waste responders to better understand the magnitude of possible accident problems, and by transportation planners to better select routes of especially hazardous materials.

As Module 9 demonstrates, major transportation accidents involving hazardous materials can produce profound economic, social and psychological impacts in affected communities. People in Bellingham, Washington, for example, viewed the pipeline explosion as "the most devastating thing that we've ever had happen to this community. This has shaken the community's sense of security to the core." Furthermore, as both the scientific literature and the case studies presented illustrate, the impacts of hazardous materials incidents can be traumatic, widespread and long lasting. "It comes as a shock to me how much suffering remains in this community because of this," a Bellingham doctor noted. And as a Dunsmuir resident made clear, the lingering effects of a contamination accident make getting "back to normal" difficult. "We all want to forget the spill, but we, as people who have been forced to live in the midst of the disaster, have changed. The spill affects our lives daily and will for a very long time."

Some of the most immediate effects of toxic transportation emergencies can result when an accident forces people to evacuate. Evacuations are highly disruptive, affecting businesses, schools and every aspect of community life. The economic effects of toxic emergencies can also be considerable. Response and clean-up operations are expensive, and contamination, or even the *perception* of contamination, can lower property values and seriously damage industries such as farming, fishing and tourism.

Less apparent than immediate disruption and economic effects – but potentially more problematic and complex to address – are the psychological effects of accidents involving hazardous materials. Concerned about their health and the health of loved ones, victims of chemical or radiological accidents live in what Erikson (1995) characterizes as a "permanent state of alarm and anxiety." Studies suggest that people who have suffered through transportation accidents involving hazardous materials are at increased risk of a range of psychological problems. "All evidence indicates that adapting to an invisible exposure is a toxic process. It is a process that can severely traumatize the exposed persons and change their lives for the worse" (Vyner 1988). Furthermore, just as hazardous materials accidents can have substantial and long-lasting mental health effects, so too can they leave profound social impacts in their wake. Loss of trust, social conflict and division are common, as are social stigma and a sense of a reduced quality of life in affected communities.

During the stakeholder discussions, concern was expressed over the limited resources available both to responder agencies and local emergency planning committees (LEPCs) in Alabama. Mandated under the Emergency Planning and Community Right to Know Act of 1986, LEPCs are a key component in preparedness and response for contamination incidents. Concern was expressed that current responder agency and LEPC resources are not adequate.

Recommendations

Many local fire departments are not adequately prepared to assist in a hazardous materials incident. In order to address this situation, several volunteer fire departments have begun cooperating with each other to create a hazmat unit for a county/region. This cooperative effort would require each department in the area to contribute equipment and/or personnel for the endeavor, but it would mean that each department would not have to have its own functioning hazmat unit. Greater support for such efforts is needed so that small fire departments can obtain needed training and equipment.

As has been clearly demonstrated, social, psychological and other community impacts are among the most significant consequences of major transportation-related hazardous materials accidents. At the present time, however, states and localities across the U.S. are only beginning to recognize such issues and fully integrate them into preparedness and response mechanisms. To enhance our ability to prevent and mitigate community impacts, it will be crucial to better incorporate social and psychological considerations into preparedness and response mechanisms for dealing with hazardous materials transportation accidents. Given what is now known about such accidents, it would be useful for such mechanisms to include not only immediate response issues but longer-term effects. In addition, it would be valuable for training exercises to include more attention to psychosocial issues and more realistic social-behavioral assumptions. It would also be beneficial, for strategies to prevent and mitigate stigma to be developed and integrated into large-scale contamination incident plans. Likewise, strategies to mitigate other social impacts (e.g., social division) would be very useful. The development of appropriate materials, as well as tailored interventions for high-risk populations, needs to be a priority, too.

Finally, there is the issue of information. In considering ways to reduce the community impacts of major hazardous materials transport accidents, information stands out as a crucial factor. It is vital in reducing community impacts *after* a chemical or radiological accident, and it is also crucial *beforehand*. Long before an accident occurs, members of the public need to be aware of the particular hazards in their community and of how to respond in an emergency situation. Furthermore, prior familiarity with, and understanding of, hazards may also help to reduce psychological morbidity should a major accident actually occur.

While mechanisms for *post-accident* communication are relatively well established, the situation with respect to *pre-accident* communication remains mixed. Unfortunately, at the present time, only a small number of local emergency planning committees in Alabama have the resources they need to communicate with the public on a regular basis. For example, only a few LEPCs in the state have websites. While a number of Alabama LEPCs are making valiant efforts, LEPC communication activities are clearly hampered by the fact that, in contrast to many other states, the State of Alabama provides no funding for LEPCs. As part of overall efforts to improve preparedness for major transportation accidents involving hazardous materials, it would be advantageous for funds to be allocated to Alabama's local emergency planning committees.

References

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