

A course in . . .

HAZARDOUS CHEMICAL SPILLS

Use of the CAMEO Air Dispersion Model to Predict Evacuation Distances

ASHOK KUMAR, GARY F. BENNETT,
VENKATA V. GUDIVAKA
The University of Toledo
Toledo, OH 43606

THE UNIVERSITY OF Toledo offers several air pollution courses taught by the senior authors to engineering undergraduate and graduate students. In the undergraduate courses, "Introduction to Air Pollution Engineering" and "Air Pollution Control," the students are exposed to the concept of air dispersion modeling. The training in dispersion modeling continues in two senior/graduate courses: 1) "Dispersion Modeling" and 2) "Hazardous Chemical Spills."

This paper provides an overview of the CAMEO model [1] and its uses in the classroom as a training tool in the "Hazardous Chemical Spills" course. The model can be obtained from the National Oceanic and Atmospheric Administration, Hazardous Materials Response Branch, 7600 Sand Point Way NE, BIN C15700, Seattle, Washington 98115.

Chemical accidents are an unfortunate reality of industrial society. With billions of pounds of toxic chemicals being produced, stored, shipped, and used daily, it is axiomatic that leaks, spills, and accidents will occur. The consequences of these chemical spills can range from a simple nuisance to virtual destruction of a body of water or to thousands of deaths and injuries.

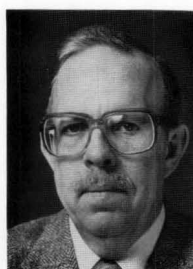
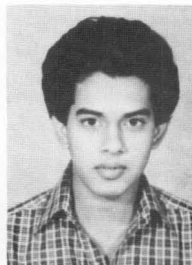
In the early days of spill technology and response (the 1970s), the major concern in dealing with chemical spills was for pollution of the aquatic environment. Indeed, spill response and cleanup efforts were ini-

tially directed only at oil spills, but soon chemical spills and the destruction they caused in the aquatic environment surpassed concern for the impact of oil on the ecology. Two early examples of chemical spills are the destruction of Shawnee Lake in Ohio [2] by a gallon of strychnine-treated corn mixed with endrin, and the intentional discharge of hexachlorocyclopentadiene into the sewers of Louisville, Kentucky. These spills severely impacted major bodies of water [3]. Subsequently, Louisville suffered a more serious incident when hexane that was discharged into the sewer system, vaporized and exploded, causing thousands of dollars of damage.

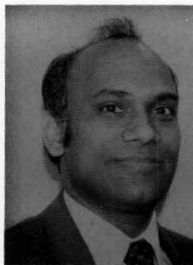
As serious as the environmental impact of chemicals on water resources is, it is those spills (or incidents) that result in emissions of toxic (volatile) chemicals into the air that pose the greatest danger to both first responders and nearby residents. Clearly the most dramatic and devastating chemical incident that has ever occurred was the release of 30 to 35 tons of methyl isocyanate at Bhopal, India, on December 3, 1984. This toxic chemical release killed an estimated 2,500 people and injured over 200,000 more [4].

Fortunately, extremely toxic chemicals such as methyl isocyanate are produced in limited amounts at

Venkata Gudivaka is a graduate assistant at The University of Toledo. He joined the Department of Civil Engineering program in the fall of 1987. He graduated with a Bachelor of Engineering degree from the University of Bombay, India, in 1987, and as part of this program he worked with Union Carbide Corporation in Bombay during the summer of 1986. He is presently working in the field of dense gas modeling and model evaluation for his MS thesis.



Gary F. Bennett received his BSc from Queen's University and his MS and PhD degrees from Michigan, all in chemical engineering. He has taught at The University of Toledo since 1963 and started a course there in hazardous chemical spills ten years ago. He is consultant to the Toledo fire division on chemical spills, has written several spill prevention and control plans for industry, and is author of the *Hazardous Spills Handbook*, published by McGraw Hill.



Ashok Kumar is a professor of civil engineering at The University of Toledo where he teaches courses on air pollution and conducts research in the area of air pollution modeling and monitoring. He received his BS from Aligarh University in India, his MS from the University of Ottawa, and his Doctoral Degree from the University of Waterloo. A registered professional engineer, he is a consultant to industrial organizations.

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very few locations in the world. But other toxic gases such as ammonia, chlorine, and hydrochloric acid are widely used and have been released all too frequently. Moreover, billions of pounds of these chemicals are produced every year, and their storage and use are ubiquitous. Notable spills involving these compounds include:

Ammonia • Houston, Texas: Tanker accident; 1.9 tons of ammonia released with a 30 m high cloud formed with danger persisting for two and one-half hours [5].

Chlorine • Mississauga, Toronto, Canada: Railroad derailment; 27 tons of chlorine released in a fire; 300,000 people evacuated over an area of 129 km² [6].

Silicone Tetrachloride • A storage tank released 1100 m³ (284,000 gal) of SiCl₄ over five days; HCl vapor was formed when the SiCl₄ contacted moisture in the air; 160 people were hospitalized, 16,000 were evacuated, and the toxic cloud extended 8 to 16 km from the tank [7].

Nitric Acid • A puncture in a rail tank car released 55 m³ (14,000 gal) of 99% solution of nitric acid; the resulting vapor cloud of toxic nitrogen dioxide forced the evacuation of 5,000 people [9].

Pesticides • Fires at facilities storing pesticides and/or hazardous waste have sent toxic gases wafting across the landscape to threaten anyone in their way. Fumes from a 1974 pesticide fire in Alliance, Ohio, caused fire personnel and residents to exhibit symptoms that included nausea, burning eyes and throats, and dizziness [8].

Transportation Accidents • Transportation accidents such as the ones involving chlorine in Canada [6] and white phosphorus at Miamisburg, Ohio [10], in 1987 with a resulting fire have threatened nearby residents. In Miamisburg, a railroad car of white phosphorus burned and released a toxic cloud of combustion products that caused a mass evacuation of nearby residents.

In all cases of releases of volatile toxic chemicals, whether or not a fire is involved, air dispersion modeling is of great assistance to the first responder. Indeed, dispersion modeling is essential in predicting areas that should be evacuated. Without such modeling, the evacuation area could not be calculated at all; it could only be "guess-timated." Consequently, without the calculation tools given by air dispersion modeling, the On-Scene Commander either under- or over-estimates the evacuation zone. Under-estimating the evacuation zone leaves people in danger; over-estimating needlessly moves people and constitutes a hazard of a different kind, especially to the sick and elderly who are negatively impacted by the move and concomitant disruption.

STUDENT MODELING PROGRAM

Environmental engineering students at the University of Toledo solve air dispersion problems by using computer models based on known theoretical concepts. The computer models are chosen from programs available in the public domain and include modeling programs used by regulatory bodies in both the United States and Canada.

One model chosen for this course is the CAMEO model which has been developed by the National Oceanic and Atmospheric Administration. The model performs a variety of calculations for a chemical spill, and in the classroom the CAMEO Air Model can be used for several purposes: 1) to develop an intuitive feeling for the importance of different variables related to the toxic releases and to test "what-if" type questions, 2) to compute the maximum ground level chemical concentration resulting from a spill, 3) to map hazard zones for evacuation purposes, and 4) to perform sensitivity analysis using varying chemical and toxicological inputs, source data, and meteorological information.

Additionally, all the features included in the model are useful in various contingency planning and response activities where it is necessary to compute the downwind concentrations as a function of distance resulting from a hypothesized release of a toxic volatile material.

THE CAMEO SYSTEM

An explanation of the CAMEO system, one of the commercially available air dispersion model programs, is given to the students. The level of discussion conducted in the classroom, however, depends on the course. The students are told that CAMEO has the following features for calculating downwind chemical concentration from release:

1. A basic Gaussian algorithm is used with either a continuous or instantaneous release configuration.
2. The atmospheric data can be inputted directly by the user or obtained from a remote meteorological station.
3. A chemical library is available; this library contains the toxicological, chemical, and thermodynamic parameters necessary to derive various source strength estimates and relate the pollutant distribution patterns to human health effects.

4. The source strength estimates can be entered directly in English or metric units; however, the program can calculate the effective source strength from an exposed pool of spilled chemical, given the chemical identity and the surface area of the pool.
5. The system has the ability to store a map using digitization.
6. A variety of graphic or tabular options can be displayed on the screen or sent to the printer; the system also has the ability to clip screen images to a file that can be overlaid on maps that are available in other parts of the system.

Since the CAMEO system uses the well-known Gaussian dispersion model, a brief discussion points out the limitations of the model as follows: 1) typical errors can be as high as a factor of two, and 2) greater errors can result from spills during low wind speed and very stable atmospheric conditions than at high wind speed.

It should be noted that the CAMEO model does not take into account terrain effects and the impact of building wakes. Also, heavy gas effects are not included. Moreover, the model results apply only to the selected chemicals; fire by-products or other chemical transformations can be entered into the system by the user as separate chemicals.

HOW TO USE THE CAMEO MODEL

The students are instructed to use the CAMEO program installed on an Apple Macintosh computer. They are told about the menu options in the CAMEO program and are informed that the best way to run the program is to use the following order for menu options: 1) select a chemical from the chemical option, 2) set the atmospheric options (either by the meteorological station or user input), 3) set the source

strength of the spill, and 4) run the model by selecting the continuous or puff option from the option menu.

EXAMPLES OF CLASSROOM EXERCISES

Six problems have been selected to illustrate classroom use of CAMEO. These six problems, when used in a course, enable a student to become familiar with some of the many uses of the CAMEO Air Model. The problems selected utilize most of the facilities offered by the demonstration program model.

The student is advised to try to solve the problems using the CAMEO program and to compare his results with those given by the instructors. The student is advised to try solving different problems given in air pollution textbooks with this model in order to gain familiarity with its applications.

The problems are based on "real-world" spill situations found in the literature. Problems 1 and 2 are modified from reference 11; problem 3 is from reference 12; problem 4 is from reference 13; problem 5 is from reference 14; and problem 6 is from reference 15.

Problem 1

Ammonia was released at a rate of 6050 g/sec for 30 min. The ambient wind speed at the time of release was 2 mi/hr (3.2 km/hr), and the wind was blowing from 350°. The atmospheric stability was "unstable" (A), and the ambient temperature was 28°C. Assume an inversion height of 1500 ft (457 m). Use the CAMEO Air Model for a continuous source and determine the downwind IDLH* and TLV-TWA* distances and travel times to reach those distances.

Locate the source at the chemical facility near South Chicago Street on Map E13 or F13 and plot the IDLH and TLV-TWA hazard zones (see Figures 1 and 2).

*IDLH defines the concentration of a chemical "Immediately Dangerous to the Life and Health" if someone is exposed. TLV is the "Threshold Limit Value" concentration which is the accepted safe concentration for 8-hr/day exposure of workers over their working life. TWA is the "Time Weighted Average" of the concentration

TABLE 1
Input Data for Six Chemical Spills

	Problem #1	Problem #2	Problem #3	Problem #4	Problem #5	Problem #6
1. Name of Chemical Selected	Ammonia Solution (> 44% Ammonia)	Hydrogen Sulphide	Nitric Acid Fuming	Chlorine	Methyl Isocyanate	Toluene
2. Atmospheric Stability Class	A	D	E	D	F	D
3. Inversion Height (ft)	1500	600	500	600	650	600
4. Wind Speed (mi/hr)	2	5	4.7	10	9	3
5. Wind Direction	350	350	315	90	310	280
6. Ambient Air Temperature(°C)	28	28	20	20	17.5	10
7. Average Ground Roughness	City Center	Very Smooth	Thick Grass (4 in. high)	Lawn	City Center	Homogeneous Forest
8. Source Strength	6050 g/s	72,000 g	66,000 g/s	11,340 g/s	7,400 g/s	-
9. Puddle Area (ft ²)	-	-	-	-	-	1,000
10. Exit Velocity (ft/sec)	-	-	-	-	-	1

Problem 2

A pipeline of a gas processing facility ruptured and released 72,000 g of H₂S. The ambient wind speed was 5 mi/hr (8 km/hr), and the wind was from 350°. The atmospheric stability was neutral (D), and the ambient air temperature was 28°C. Assume an inversion height of 600 ft (183 m).

Assume an instantaneous release and determine the downwind IDLH and TLV-TWA distances and travel times. Locate the source at the chemical facility of South Chicago Street on Map E13 or F13, and plot the IDLH and TLV-TWA vapor hazard zones (see Figures 1 and 2).

Problem 3

During the night, at about 2 a.m., 20 tons (20 x 10⁶ g) of fuming nitric acid were spilled on flat ground. At 2:05 a.m. the temperature was 20°C, and the wind was from the northwest (315°) at 4.7 mi/hr (7.5 km/hr). Assume an atmospheric stability of (E) and an inversion height of 500 ft (152 m). Assume a continuous source (66,000 g/sec).

Compute the downwind IDLH and TLV distances and travel times. Plot these contours on the map and make recommendations about the extent of the evacuation zone.

Problem 4

A continuous release of chlorine at a rate of 11,340 g/sec occurs at a chemical plant. The atmospheric conditions at the time are neutral (D). The ambient wind speed is 10 mi/hr (16 km/hr) and the wind is blowing from the west. The ambient air temperature is 20°C. Assume a mixing height of 600 ft (183 m). Assuming a continuous release, determine the TLV and IDLH travel times and distances; plot the TLV and IDLH hazard zones.

Problem 5

In a disaster at a pesticide plant in India, 40 tons (40 x 10⁶ g) of methyl isocyanate were released in 90 minutes (7400 g/sec) at 12:30 a.m. when the ambient temperature was 17.5°C.

The ambient wind speed was 9 mi/hr (14 km/hr) and the wind was from 310°. The mixing height at that time was about 650 ft (198 m). The conditions were said to be very stable, and a stability class of (F) may be assumed. Compute the TLV and IDLH travel times and distances, and determine the area for evacuation if the plant had been located at the chemical facility of South Chicago Street on map F13 (Figure 2). *HINT:* MIC does not exist in the chemical library. It has to be added to the library first. Enter "create library" and add MIC and the data for it as given below:

Molecular Formula	C ₂ H ₃ NO
Molecular Weight	57.06
Boiling Point	39°C
IDLH Value	20 ppm
TLV-TWA Value	0.02 ppm

Problem 6

100,000 gal of toluene were spilled as a result of a pipeline rupture in Ohio. The time was 10 p.m. and the ambient temperature was 10°C. The wind speed was 3 mi/hr (4.8 km/hr) and the

TABLE 2

Solutions for Six Chemical Spills Using CAMEO Model

	Prob. #1	Prob. #2	Prob. #3	Prob. #4	Prob. #5	Prob. #6
TLV-TWA Distance (km)	1.2	2.3	140.4	23.5	509.9	1.1
TLV-TWA Travel Time (min)	22.0	17.4	1046.0	87.5	2110.8	13.6
IDLH Distance (km)	0.2	0.7	8.9	3.0	3.6	0.2
IDLH Travel Time (min)	3.7	5.3	66.4	11.2	14.9	2.1

The students are asked to change the values of variables in order to understand the importance of the role played by the input data. The graphical display of results is of immeasurable value in accidents situations. Three possible plots are included in this paper.

conditions were neutral (D Stability). The mixing height was 600 ft (183 m). Use the puddle model to determine the TLV and IDLH distances and travel times. Assume a puddle area of 1000 ft² (93 m²) and an exit velocity of 1 ft/sec (0.3 m/sec).

RESULTS

Table 1 shows the input required for each problem. The input for each variable is obtained from the statement of the problem given above. The name of the chemical, atmospheric stability, inversion height, wind speed, wind direction, ambient air temperature, and source strength are required for the first five problems. In the sixth problem, values for puddle area and exit velocity are also needed for the computation of the source strength term. If the puddle area is known, it can be used in place of the mass of the chemical spilled, but this assumption might give different results. Since, in an accidental spill, it is relatively easier to estimate puddle area than mass spilled, the area covered by the spilled chemical has been used in this problem. Moreover, the average ground roughness around the spill site must be specified for each problem; the model gives five options.

Table 2 shows the solutions obtained for each of the six illustrative problems. IDLH distances and TLV distances are given in this table along with the arrival times of plume at those distances. The distances give the student an understanding of the potential area of the evacuation zone, and the arrival time helps him/her to appreciate the importance of time available for control measures and evacuation schedules. The TLV distances are higher than IDLH distances because TLV concentration is smaller than IDLH concentration. For Problem 5, the TLV distance is more than 140 times the IDLH distance. In such cases, it may be appropriate to use one-tenth of the IDLH concentration to compute the hazard zone.

The students are asked to change the values of variables in order to understand the importance of the role played by the input data. The graphical display of results is of immeasurable value in accident situations. Three possible plots are included in this paper. Figure 1 is the TLV plot that is obtained from Problem 1, while Figure 2 is the IDLH plot obtained from Problem 2. A plot of IDLH distances for varying in-

puts of wind speed for Problem 1 is shown in Figure 3.

CONCLUSION

The CAMEO system is a useful tool for teaching basic concepts related to dispersion modeling of chemical spills. The students are able to conduct computer experiments to enhance their understanding of the effects of accidents involving hazardous chemicals. With



FIGURE 1. TWA contour for ammonia solution (>44% ammonia) on Map E13.



FIGURE 2. IDLH contour for hydrogen sulphide (instantaneous release).

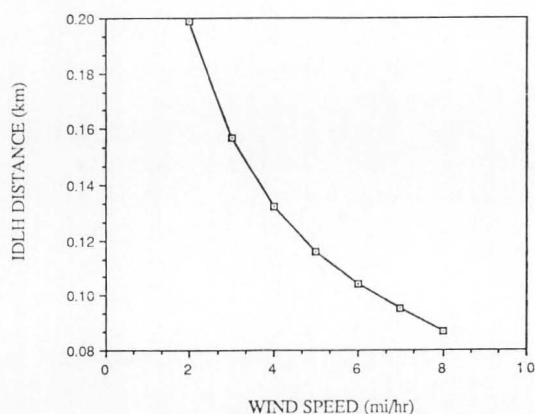


FIGURE 3. Variation of IDLH distances with wind speed.

increasing public concern of chemical releases and the recent passage by Congress of spill planning regulations (Title III of SARA), inclusion of chemical spill modeling in the chemical engineering curriculum becomes very important. Modeling of spills at fixed base facilities (in advance of a spill) to produce predictions of danger zones is becoming common, and chemical engineering students should be familiar with the modeling methods and public concern of possible dangers of chemical spills.

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