vide satisfactory results. We intend no specific endorsement of Hewlett-Packard equipment by either the government or ourselves.

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Toxic Corridor Projection Models for Emergency Response

MARK D. RYCKMAN AND JEFFREY L. PETERS

Rapid definition and communication of ground level toxic corridors during an environmental crisis are paramount concerns to protect public health and safety during an accident involving hazardous materials. Changing meteorological conditions, definition of dynamic stability conditions, and rapid identification of source strength have profound effects on the definition of horizontal and vertical transport of toxic materials released during a transportation or industrial accident. The pragmatic application of toxic corridor projection models during an agricultural chemical warehouse fire, a derailment involving the release of chloroform, and a tractor-trailer accident resulting in the release of ethyl chloroformate is reviewed.

The purpose of this paper is to provide information to assist those charged with the responsibility of rapidly assessing ground-level toxic corridors resulting from hazardous material accidents in industry and transportation. Three case histories are presented to demonstrate the application of toxic corridor projections for (a) a tractor-trailer accident resulting in the release of ethyl chloroformate, (b) a railroad derailment resulting in the discharge of chloroform, and (c) an agricultural chemical warehouse fire resulting in the release of toxic air pollutants.

The authors and engineers and scientists with REACT's National Hazardous Material Response System were directly involved with each of the incidents discussed here. Toxic corridor projections and emergency directives were issued from REACT's St. Louis-based Corporate Response Center. Toxic corridor projections were determined based on hands-on experience with more than 700 hazardous material incidents. Physicochemical and toxicological material properties and projection maps were obtained from REACT's Computer Assist Program containing information on more than 250 000 hazardous materials and more than 40 000 U.S. Geological Survey (USGS) 7.5- and 15-min topographic maps. (1).

TOXIC CORRIDOR PROJECTION CRITERIA

Two principal criteria should be met when developing toxic corridor projections: (a) protect public health, property, and the environment; and (b) provide rapid information for determining the appropriate emergency resources required, safe approach corridors, sensitive populations, potential evacuation routes, and identification of assembly areas.

Projections must be made quickly to activate the appropriate emergency services required, including fire, ambulatory, and hospital. Safe approach routes for emergency services personnel and hazardous material experts should be defined to protect their health during an emergency. Consideration should be given to sensitive populations in defining toxic corridors, including elderly people in nursing homes, hospital patients, and areas of high population density. The movement or evacuation of sensitive populations may result in undesirable negative health impacts and/or panic. Consequently, displacement impacts should be considered with potential toxic effects such that the resulting corridor will yield the minimum public health, property, and environmental impacts.

Evacuation routes should be defined such that an orderly and rapid evacuation can be conducted. Routes should be defined such that they do not interfere with emergency personnel and equipment access. Consideration needs to be given to identification of safe assembly areas for displaced personnel. Typical assembly areas include schools, auditoriums, and other areas defined by the Civil Defense or local emergency authorities.

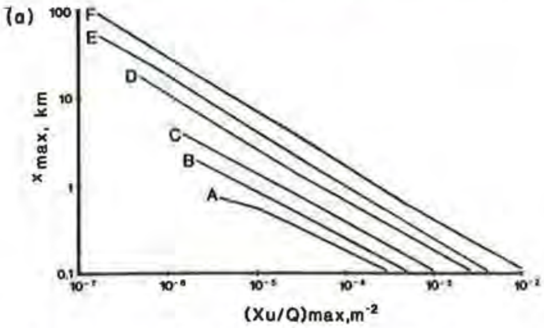
MODELS

Toxic corridor projection models provide rapid information for emergency action decisions. It is emphasized that models serve only as a tool and should be used and interpreted by experienced personnel. The authors have developed computer programs for Texas Instrument's Programmable Fifty Nine Calculator for the Turner and Ocean-Breeze Dry-Gulch models as shown in Figures 1 and 2, respectively.

By using the same source strength and meteorological inputs, the Ocean-Breeze model projects a more conservative (longer) toxic corridor length than the

Figure 1. (a) Distance of maximum concentrations and maximum Xu/Q as a function of stability and (b) stability categories.

(a)



(b) KEY TO STABILITY CATEGORIES

Surface Wind Speed(at 10 m) m sec^{-1}	Day			Night	
	Incoming Solar Radiation			Thinly Overcast or ≥4/8 Low Cloud	≤3/8 Cloud
	Slight	Moderate	Strong		
< 2	A	A–B	B		
2–3	A–B	B	C	E	F
3–5	B	B–C	C	D	E
5–6	C	C–D	D	D	D
> 6	C	D	D	D	D

The neutral class, D, should be assumed for overcast conditions during day or night(Turner, 1970)

Turner model for distances less that 10 000 ft. For distances greater than 15 000 ft, both models converge and yield approximately the same corridor lengths as given below:

	Corridor Length (ft)		
	Turner	Ocean-Breeze	Deductive Experience
Ethyl chloroformate	2 300	4 000	2 500
Chloroform	3 300	6 600	5 280
Phosgene	18 150	19 750	10 560

Consequently, the authors recommend use of the Ocean-Breeze Dry-Gulch equation for initial time zero toxic corridor estimates.

However, both models must be put in perspective with actual experience gained from other accidents. Threshold odor levels, skin irritation, dizziness, or other symptoms observed around an accident may be used to adjust toxic corridors to site-specific characteristics and conditions. Injuries or fatalities seldom occur from fragments or toxic exposures at distances greater than 2500 ft from the source as reported by the authors and the National Transportation Safety Board accident reports. Victims treated and released from toxic exposures are seldom located in excess of 1 mile from the source (2-6).

A combination of deductive experience and the use of the Ocean-Breeze Dry-Gulch model provides for rapid estimates of toxic corridors to protect public health and safety during a hazardous material emergency.

MODEL INPUTS

The following information is required to estimate a toxic corridor: material identification and properties, location, source strength, meteorological conditions, and topical conditions. A material's lethal, serious, and noxious concentrations are defined as the concentration at which more than 50 percent of the exposed population may be expected to expire; the concentration at which irreversible health impacts may be expected; and the concentration at which reversible but irritating health effects may be experienced, respectively. This information is available from REACT's Computer Assist Program for more than 250 000 materials. Information on several thousand materials can be obtained from the U.S. Environmental Protection Agency (EPA) OHM/TADS System (7), Patty (8), and Sax (9).

The accident source and toxic corridors should be immediately located on a 7-min or a 15-min USGS topographical map. This will facilitate identification of egress corridors, sensitive populations, and potential toxic vapor sinks.

Source strength is probably the most difficult model input to obtain. Consequently, it is recommended that for volatile liquid releases the source strength be determined by assuming the complete release of the entire container's contents over a 10-min period. For fires involving volatile liquids, it is recommended that the source strength be estimated by selecting the most toxic combustion product as emitted over a 60-min period. However, it should be noted that both these assumptions are subject to revision for material and site-specific circumstances as interpreted by an experienced environmental health engineer.

Figure 2. (a) Estimation of temperature differential, ΔT, and (b) downwind travel distance, X, estimated from Ocean-Breeze model.

(a) OCEAN-BREEZE ΔT ESTIMATE

SURFACE WIND SPEED(kt)	Day				Night					
	Incoming Solar Radiation (solar elevation angle)				Clear		1/8–3/8		4/8–8/8	
	Clear Sky or Scattered Clouds				SNOW	NO SNOW	SNOW	NO SNOW	SNOW	NO SNOW
	STRONG (≥60°)	MODERATE (35-60°)	WEAK (15-35°)	RISE/SET (≤15°)						
≤3	-2	-1	-1	0	6	5	5	4	4	3
4-10	-3	-2	-2	0	6	5	5	4	4	3
>10	-2	-1	-1	0	5	4	4	3	2	1

SURFACE WIND SPEED(kt)	Broken Clouds (>7000 ft. - A(>), ≤7000 ft. - B(≤))							
	A	B	A	B	A	B	A	B
≤3	-1	-1	-1	-1	-1	0	0	0
4-10	-2	-2	-2	-2	-2	0	0	0
>10	-1	-1	-1	-1	-1	0	0	0
	Overcast Clouds							
≤3	-1	0	-1	0	-1	0	0	0
4-10	-2	0	-2	0	-2	0	0	0
>10	-1	0	-1	0	-1	0	0	0

(b)

$$X = 1.63\left[3.28\left(\frac{29.75}{GMW}\right)^{.513}\left(\frac{C}{Q}\right)^{-.513}(\Delta T+10)^{2.53}\right]$$

where:

GMW=gram weight of material

C=peak concentration 5 ft. above ground(ppm)

Q=source strength(lbs./min.)

ΔT=temperature at 54 ft.-6 ft. (°F)

ESTIMATION OF TOXIC CORRIDORS

Meteorological conditions, topical conditions, and material properties have profound effects on ground level toxic corridor lengths and widths. Information on the wind speed, incoming solar radiation angle, time of day or night, ground cover conditions, percentage of cloud cover, and cloud elevations will determine selection of a stability category for Turner's model or the Delta T estimate for the Ocean-Breeze Dry-Gulch equation.

Toxic corridors are projected with Turner's model by calculating Xu/Q (where X is the limiting concentration in grams per cubic meter, u the wind speed in meters per second, and Q the source strength in grams per second) for the noxious and lethal conditions. For a given stability class, the corridor length can be calculated from Figure 1 [an abbreviated version of Table 1 from Kaehn (10)] for the noxious and lethal conditions.

The corridor length is determined for the Ocean-Breeze Dry-Gulch equation, shown in Figure 2, for a given source strength, Delta T, and peak ground concentrations for the noxious and lethal conditions.

The ground level toxic corridor widths for both models may be defined as the sum of two areas:

1. Area 1--A circle with a radius for the lethal concentration corridor length drawn from the centroid of the accident source; and
2. Area 2--The downwind arc distance as calculated for the noxious concentration drawn from centroid of the accident source. (For wind speeds greater than 10 knots, the arc length is 45° centered on the prevailing downwind vector. For wind speeds from 4 to 10 knots, the arc length is 90° centered on the prevailing downwind vector. The side boundaries are located by drawing lines from both ends of the arc, tangent to Area 1 as defined above. For wind speeds of less than 4 knots, Area 2 is a circle with a radius for the noxious concentration corridor length drawn from the centroid of the source.)

Toxic corridors are redefined with changing meteorological conditions and source strengths. It is important to have technical feedback from the field in redefining toxic corridors as meteorological, sorption characteristics, and other site-specific changing conditions may have significant effects on the definition of toxic corridors.

CASE HISTORIES

Ethyl Chloroformate Spill

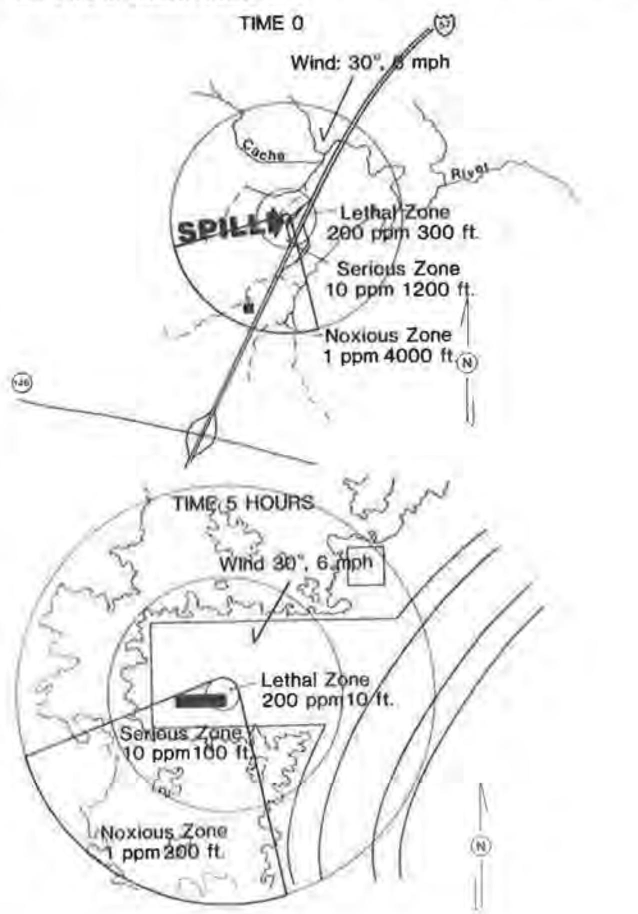
At 9:00 a.m. on August 15, 1980, a tractor-trailer carrying 80 55-gal drums of ethyl chloroformate, traveling southbound on Illinois Interstate-57, experienced a load shift and one drum was punctured. The driver's eyes immediately began to lacrimate and he experienced difficulty in breathing. The driver pulled off the road to a rest stop and staged his unit in an isolated area, as shown in Figure 3. He then placed a call for emergency assistance.

By using the Ocean-Breeze Dry-Gulch equation, the toxic corridor was projected at time zero for the lethal, serious, and noxious zones, as shown in Figure 3. Delta T for the Ocean-Breeze Dry-Gulch equation at time zero was estimated to be -2 (see Figure 2). The Turner Stability Class was estimated for the prevailing meteorological conditions at time zero. The rest stop area was closed, and a decision was made not to close southbound I-57 as the travel time through the noxious zone was estimated to be less than 1 min.

At time 5 h after the incident, REACT engineers collapsed the toxic corridor to 200 ft downwind from the prevailing wind direction. The toxic corridor was redefined by using threshold odor observations and Bendix tube air testing equipment. REACT emergency response personnel donned full protective gear and proceeded to remove the skid-mounted pump that had punctured one of the drums of ethyl chloroformate. Contaminated crating material and the damaged drum were overpacked using recovery drums.

U.S. Department of Transportation regulations stipulate that shipments of ethyl chloroformate

Figure 3. Toxic corridor projects for ethyl chloroformate spill at time 0 and time 5 h after product release.



transported in 55-gal drums be shipped in dedicated loads. This incident would not have occurred if the pump and crated materials had not been loaded on the rear of the trailer.

Chloroform Spill

On January 26, 1981, a train derailment occurred near Albion, Illinois, as noted in Figure 4. A coupler from an adjacent corn syrup tank car punctured the chloroform tank car, resulting in the release of an estimated 20 000 gal of chloroform. By using the Ocean-Breeze Dry-Gulch equation, an estimated source strength of 25 000 lb/min and a Delta T of zero projected a time zero toxic corridor length of 6600 ft for the noxious zone and 2000 ft for the lethal zone.

All residents were evacuated from the projected corridor, including residents in a farmhouse. REACT engineers and scientists covered the punctured tank car with a polyvinyl canopy to reduce the vapor emissions from an estimated 2000 gal of product remaining in the tank car.

An unknown quantity of corn syrup was released from two adjacent tank cars. Interceptor containment barriers were constructed and the water/corn syrup solution formed a vapor barrier over the spilled chloroform that reduced the control zone to 200 ft at time 4 h after the incident. To prevent soil and water transport of the dense chloroform plume, which is only slightly soluble in water, from entering shallow wells in the vicinity, a containment and decontamination plan was developed.

Figure 4. Toxic corridor projects for chloroform spill at time 0 and time 4 h after product release.

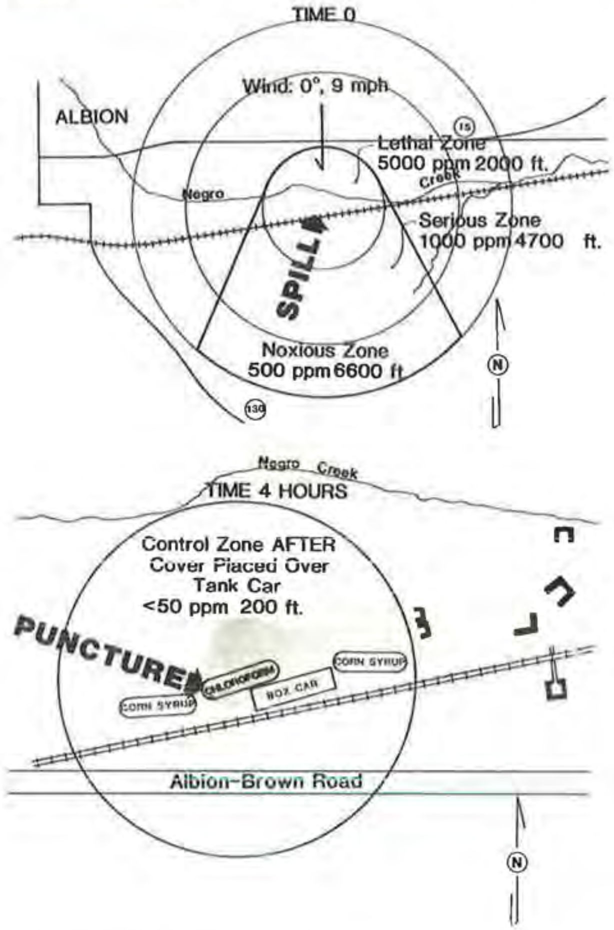


Figure 5. Phosgene toxic corridor projections for agricultural chemical fire at time 0 and time 6 h.

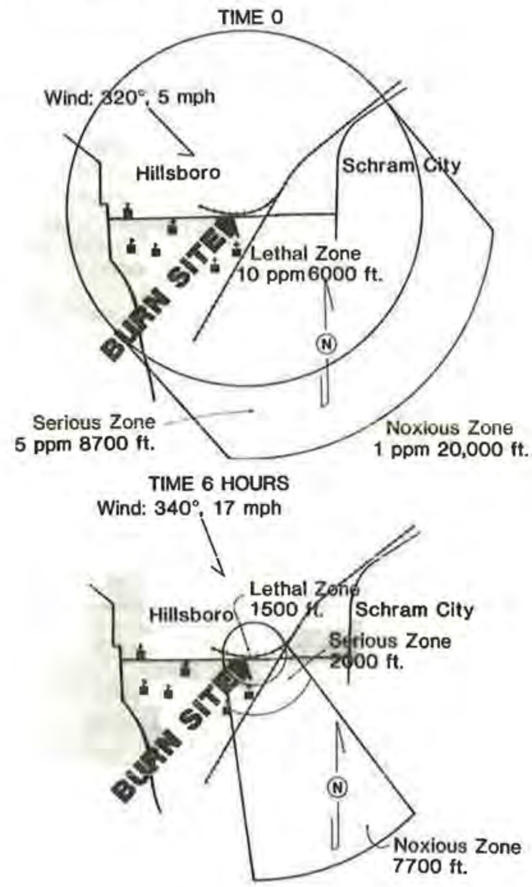


Figure 6. Phosgene toxic corridor projection for agricultural chemical fire at time 12 h.

Agricultural Chemical Fire

On April 24, 1981, an agricultural chemical warehouse was set on fire by arsonists at approximately 5:00 a.m. The warehouse was located near Hillsboro, Illinois (see Figure 5). The warehouse contained an estimated 40 000 lb of 21 different agricultural chemicals.

The time zero toxic corridor was projected by using the Ocean-Breeze Dry-Gulch equation, assuming that 50 percent of the total inventory would be converted to phosgene, as a combustion by-product over a 60-min burn time. A Delta T of zero yielded a toxic corridor length of 20 000 ft for the noxious zone and 6000 ft for the lethal zone, as depicted in Figure 5. More than 400 families were evacuated from Hillsboro and Schram City from within the lethal zone. Also, the schools located within the lethal zone were evacuated.

A hospital and a nursing home were located in the lethal zone, approximately 2000 ft downwind from the burn site. It was determined that movement of these sensitive populations would pose a greater health risk than potential toxic exposure from the burning agricultural chemicals. All intake systems, windows, and air vents at both of these facilities were closed during the fire to minimize the influx of toxic gases. Firefighters applied water to the fire to attempt to knock down toxic fumes and reduce the source strength of toxic air pollutants generated from the fire.

REACT engineers and scientists at the accident scene reduced the source strength by 10 percent at time 6 h. The corridor was redefined, as depicted in Figure 5, with a new Delta T of -1. Fortunately, there were no roads or significant population in the southeast quadrant. Consequently, evacuation limits were confined to the serious zone.

At time 12 h, REACT engineers redefined the toxic corridor as shown in Figure 6. The source strength at time 12 h was reduced an additional 10 percent and the new Delta T of zero was used. Due to variable wind conditions experienced during the day, evacuation limits were extended for the corridor vector from zero to 360° for the noxious zone, or 1700 ft from the burn site.

Figure 7. Evacuation limits for agricultural chemical fire at time 18 h.

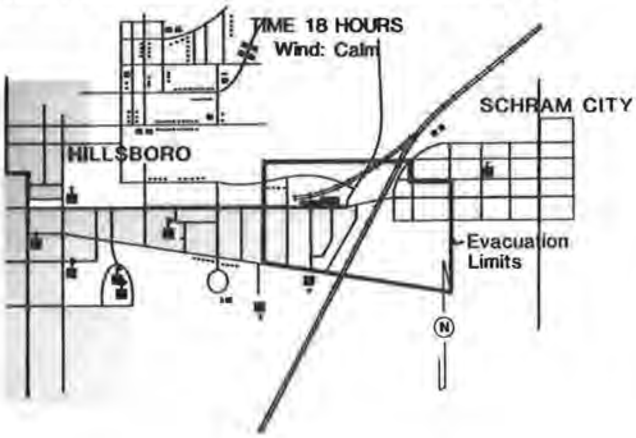
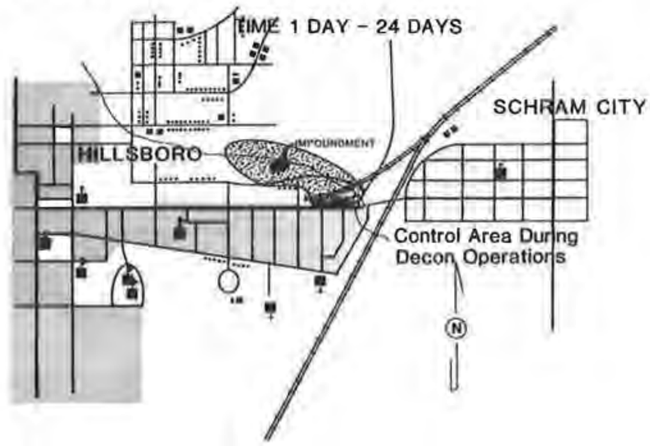


Figure 8. Control area during decon operations for agricultural chemical burn residues.



At time 18 h, all burning and smoldering residues had been extinguished. Consequently, phosgene was no longer considered to be the critical toxic air emission. Since the toxic characteristics of the remaining burn residues were unknown, threshold odor analysis and sensitivity analysis were conducted by experienced engineers and scientists to redefine evacuation limits, as shown in Figure 7. These evacuation limits were maintained during the period time 18 h through time 24 h.

Several engineering control measures were used to collapse the toxic corridor area to the control area, as depicted in Figure 8, for the period time 1 day through 24 days. These procedures included (a) reduction of evaporative surface areas through the construction of a network of interceptor trenches and pits; (b) containerization of concentrated contaminant runoff at the burn site; (c) application of powdered activated carbon and soda ash, which controlled odors and accelerated pesticide destruction via alkaline hydrolysis; (d) construction of an impoundment dam in the run-off area where more than 200 000 gal of contaminated fire-fighting waters were pumped into a treatment lagoon; and (e) treatment of the lagoon contents with powdered activated carbon at a self-flocculating dosage of 1000 parts/million where pesticide residues were adsorbed and clarified out of the water matrix and released to the adjacent stream.

SUMMARY

Toxic corridor projection models such as the Ocean-Breeze Dry-Gulch and Turner models are useful tools in providing information for emergency action decisions. However, these models only generate estimates and the Turner model may underestimate corridor lengths for distances of less than 10 000 ft by factors of 2 or 3. Consequently, it is recommended that the Ocean-Breeze Dry-Gulch model be used for initial estimates.

Experienced personnel who are familiar with the many factors that affect toxic corridor projections should be consulted. A combination of deductive experience and the use of the Ocean-Breeze Dry-Gulch model provides for rapid estimates of toxic corridors to protect public health and safety during a hazardous material emergency.

Development of control plans will greatly reduce response times and potential environmental health impacts. Knowledgeable environmental health personnel should be made an integral part of control plans and should be available 24 h/day, 365 days/year, to assist emergency response personnel with projection of toxic corridors. Mock drills should be conducted to test communication systems and to develop time zero toxic corridor projections in less than 1 min.

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