Lecture 08

Risk Profiles
for
Complex Engineering Systems

Construction of Risk Profiles

Case Study 1

Keeney et al. LNG Terminal

Case Study 2

Raj and Glickman- Transportation of Haz Materials

Studies illustrate:

frequency*conditional probabilities,
evaluation of complex tree,
use of empirical data, and
models of technology and accidents

Related Learning Objectives

- Students should be able to build mathematical models of risk and reliability, and be able to make reasonable choices between different mathematical formulations to capture the characteristics of the phenomena described.

- Be able to construct fault trees, event trees, and *risk profiles for realistic problems* and compute the resulting probabilities.

- Students should recognize which probabilities can be obtained directly from historical data, which can be obtained by extrapolating from historical data, and which should be obtained by mechanistic/probabilistic arguments.

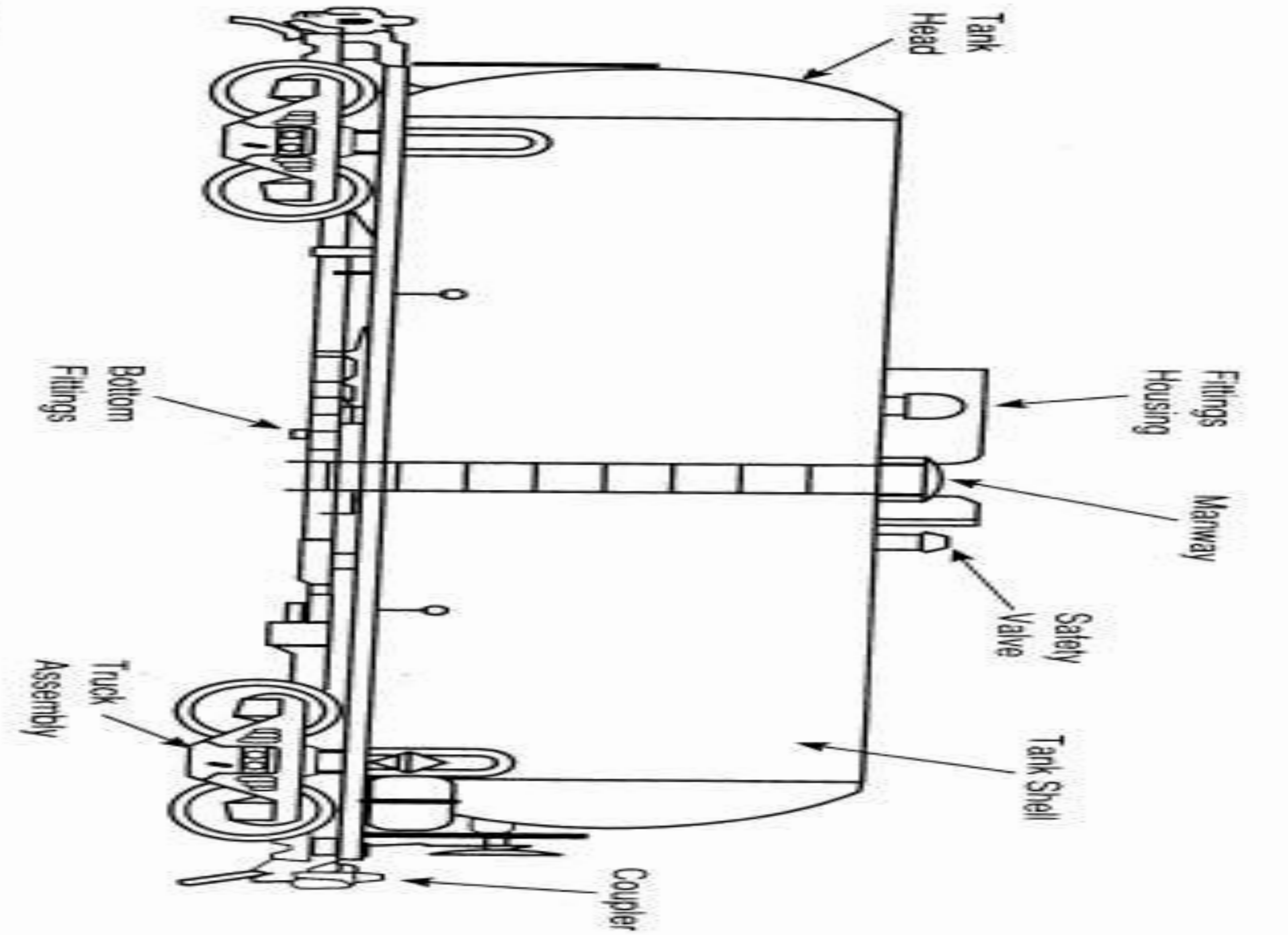
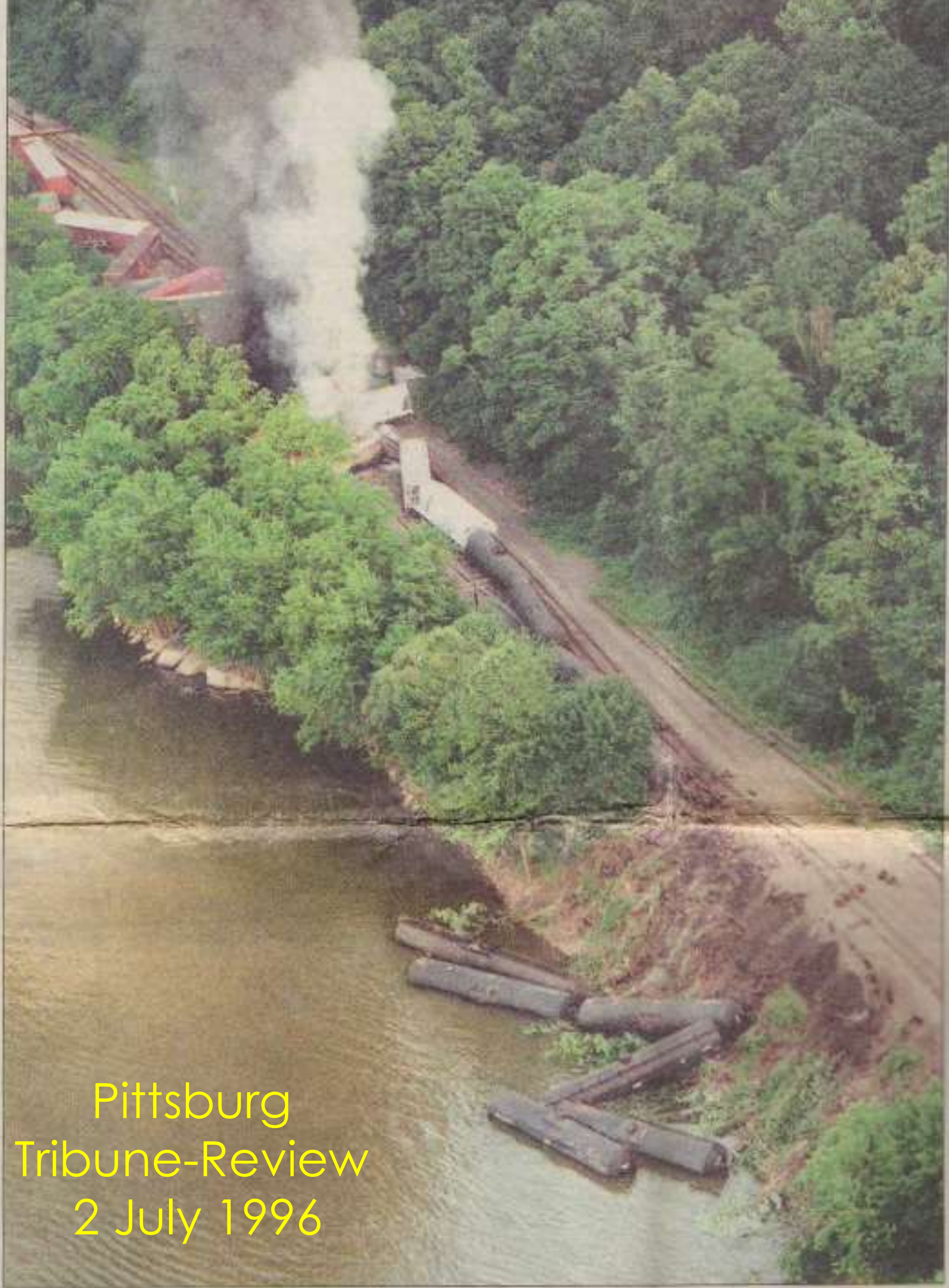
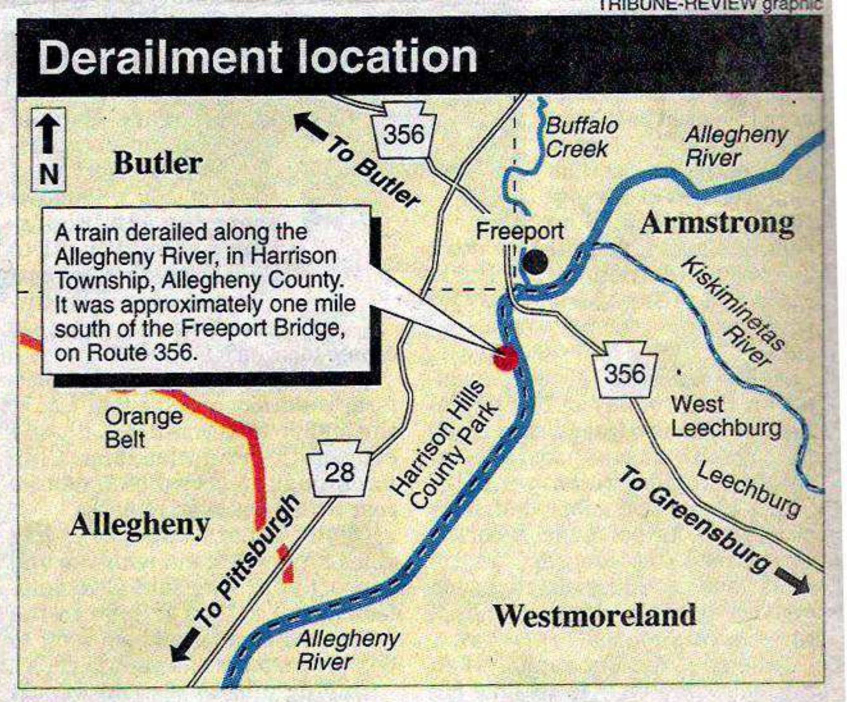


FIGURE 2-1 Principal design elements of nonpressure tank car (NTSB 1991).



Wreckage of derailed train burns while tanker cars lie in the Allegheny River in Harrison Township



27 cars jump the track; Toxic gas fears allayed

Water plants close intake valves as precaution

By Mary Anne Lewis and Kim Burger
TRIBUNE-REVIEW

Several cars of a freight train derailed Monday afternoon, triggering a fire that belched heavy black smoke into the sky and prompting water suppliers along the Allegheny River to close intake valves.

But fears a highly toxic gas was released in the fiery derailment were allayed late yesterday after hazardous material teams discovered the emissions were mostly

into the river. Four covered hopper cars that derailed caught fire and burned for several hours.

Initial reports indicated at least one of the burning cars contained vinyl chloride as a liquefied gas, which emits poisonous vapors when ignited. The chemical is used to make plastic piping.

By 6 p.m., emergency officials had determined that the fire was fueled by isophthalic acid, not considered a highly hazardous material.

"We have now found the smoke is minimally dangerous," said Allegheny County Commissioner

March
2001

Great
Neck,
England

Train wreck kills 13

The Associated Press

Police and rescuers at the scene of a train collision Wednesday at Great Heck near Selby, north Yorkshire, some 200 miles north of London, England. At least 13 people were killed when a high-speed passenger train collided with a car and then a freight train. More than 70 peo-

North Korea

24 April 2004

Train explosion

54 dead 1,250 injured

CBS News
www.cbsnews.com/stories/2004/04/23/world/main613525.shtml

N. Korea: Several Hundred Dead

DANDONG, China, April 23, 2004

North Korean officials tell an aid worker that an electical spark tocuhed off dynamite, causing the massive blast. **(AP)**

1 2 3

PREVIOUS IMAGE | NEXT IMAGE

QUOTE

"They got caught in the overhead electric wiring, the dynamite exploded, and that was the cause of the explosion."
Anne O'Mahony, aid worker, on what North Korean officials told her

(CBS/AP) North Korean officials say several hundred people were believed killed in an explosion at a train station in the town of Ryongchon near the Chinese border, the British ambassador to North Korea said Friday.

The officials also told Ambassador David Slinn and other European envoys stationed in Pyongyang that several thousand people were believed injured and many might still be trapped in collapsed buildings nearby, a British Foreign Office spokesman said in London.

Earlier, a U.N. agency in Geneva said the secretive communist government had acknowledged at least 50 people were killed and more than 1,000 injured in Thursday's blast. An aid worker says government officials told her that at least 150 people were killed.

World's worst train disasters

- June 2002: Dodoma region, Tanzania - at least 200 killed when passenger train collides with goods train
- Feb 2002: Egypt - 300 killed in fire on train travelling to Cairo
- June 1989: Ufa, Russia - More than 400 killed in gas explosion under two trains
- Aug 1995: Uttar Pradesh, India - 300 killed in train collision
- June 1981: Bihar, India - 800 killed when cyclone blows train into river

BBC - World Worst Train Accidents

http://news.bbc.co.uk/2/hi/middle_east/3498851.stm

Death Toll Rises to More Than 300 in Iran Train Explosion

Associated Press

Iranian railway company workers Wednesday in front of the wreckage of a train that derailed, then caught fire, igniting a cargo of chemicals and fuel. At least 195 people were killed in the explosion, in the northeast of the country, including local government officials and rescue workers.

By NAZILA FATHI

Published: February 19, 2004

http://www.nytimes.com/2004/02/19/international/middleeast/19CND-IRAN.htm

Iran train blast kills hundreds

Hundreds of people, including top local officials, have been killed in a massive freight train blast in Iran.

The explosion left an untold number of people injured

The train exploded in the north-east of the country, leaving up to 295 dead near the town of Neyshabur in Khorasan province on Wednesday morning.

Hundreds more were injured when wagons carrying sulphur, petrol and fertiliser derailed, caught fire and blew up.

Nearly 200 of the dead are thought to be rescue workers who were fighting the fires when the blast occurred.

According to Iranian TV, the train wagons - which included 17 wagons of sulphur, six wagons of petrol, seven wagons of fertilizers and 10 wagons of cotton wool - broke loose from a train station and rolled about 20km (12 miles).

Then they derailed and caught fire at 0400 local time (0030 GMT).

Fire-fighters had nearly put out the blaze when an explosion occurred at 0935.

February 2004

Iranian Train Explosion Kills 310

including governor, mayor, fire chief

http://news.bbc.co.uk/2/hi/middle_east/3498851.stm

Graniteville, S. Carolina, 2005

U.S.

Train crash kills 8, injures 200

Toxic fumes chase thousands from homes

Friday, January 7, 2005 Posted: 2:25 AM EST (0725 GMT)

GRANITEVILLE, South Carolina (AP) -- A freight train carrying chlorine gas struck a parked train early Thursday, killing eight people and injuring at least 200 others, nearly all of them sickened by a toxic cloud that persisted over this small textile town at nightfall.

Authorities ordered all 5,400 people within a mile of the crash to evacuate in the afternoon because chlorine was continuing to leak and the gas was settling near the ground as temperatures dropped. They were unsure when the gas leak might be sealed.

Chemicals leak from train cars after Thursday's crash.

YOUR E-MAIL ALERTS

Disasters and Accidents

U.S.

Some residents returning home after chlorine leak

Thursday, January 13, 2005 Posted: 8:28 AM EST (1328 GMT)

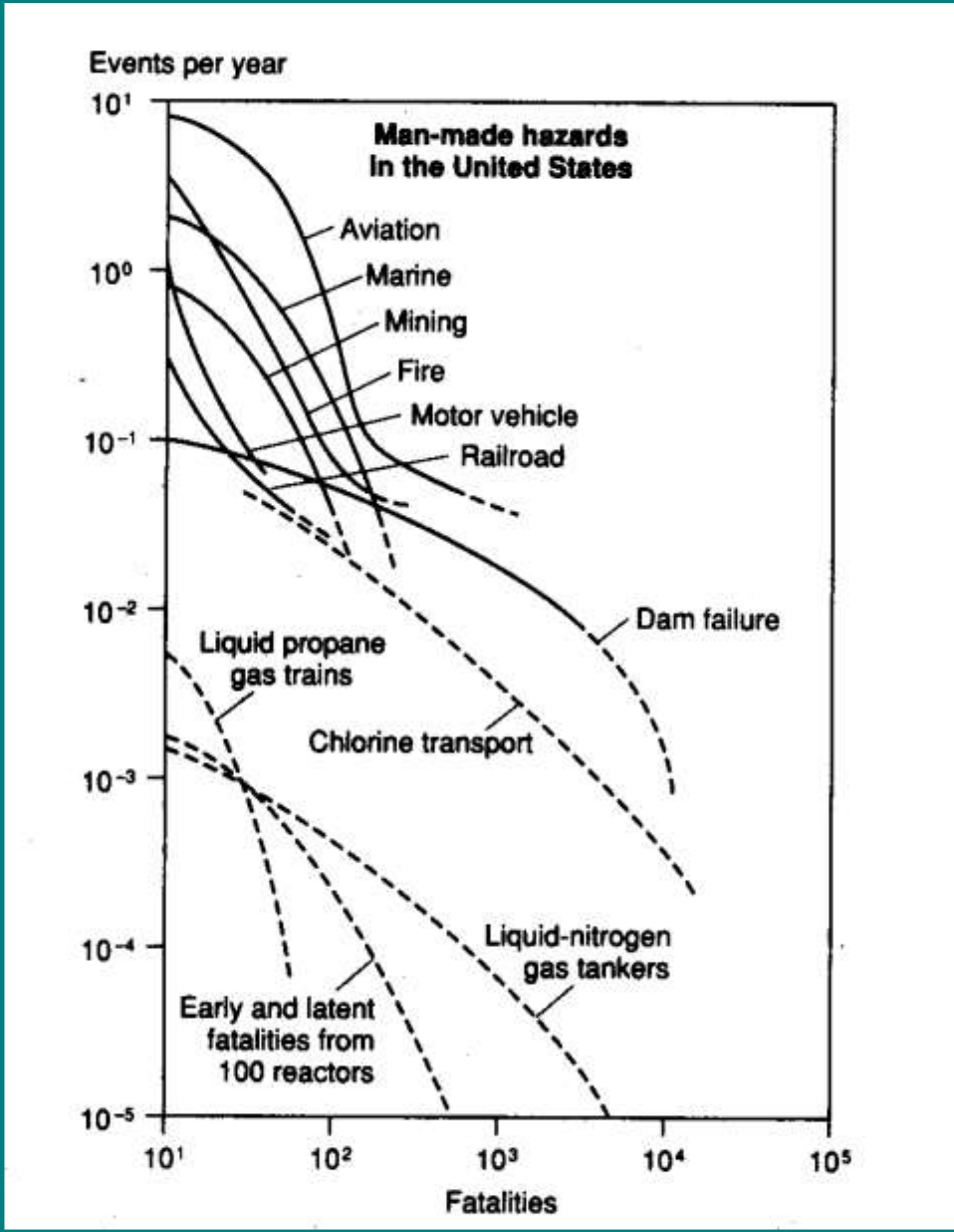
COLUMBIA, South Carolina (AP) -- A week after chlorine gas leaked from a train wreck and killed nine people in this mill town, officials will let about half the 5,400 residents displaced by the accident return home Thursday morning.

Air quality tests show chlorine has returned to normal levels on the edges of the evacuation area, which extended a mile from the crash site, according to the Aiken County Sheriff's Office.

Conditions remain too dangerous to allow people back into homes and businesses closer to the crash site, near the Georgia line and about 60 miles southwest of Columbia.

An aerial photo of the train collision in Graniteville, South Carolina.

Risk for man-made hazards In US



Assessing the Risk of an LNG Terminal

TECHNOLOGICAL RISK ASSESSMENT

Assessing the Risk of an LNG Terminal

RALPH L. KEENEY, RAM B. KULKARNI, and KESHAVAN NAIR
Woodward–Clyde Consultants, San Francisco, California

Focus of Analysis

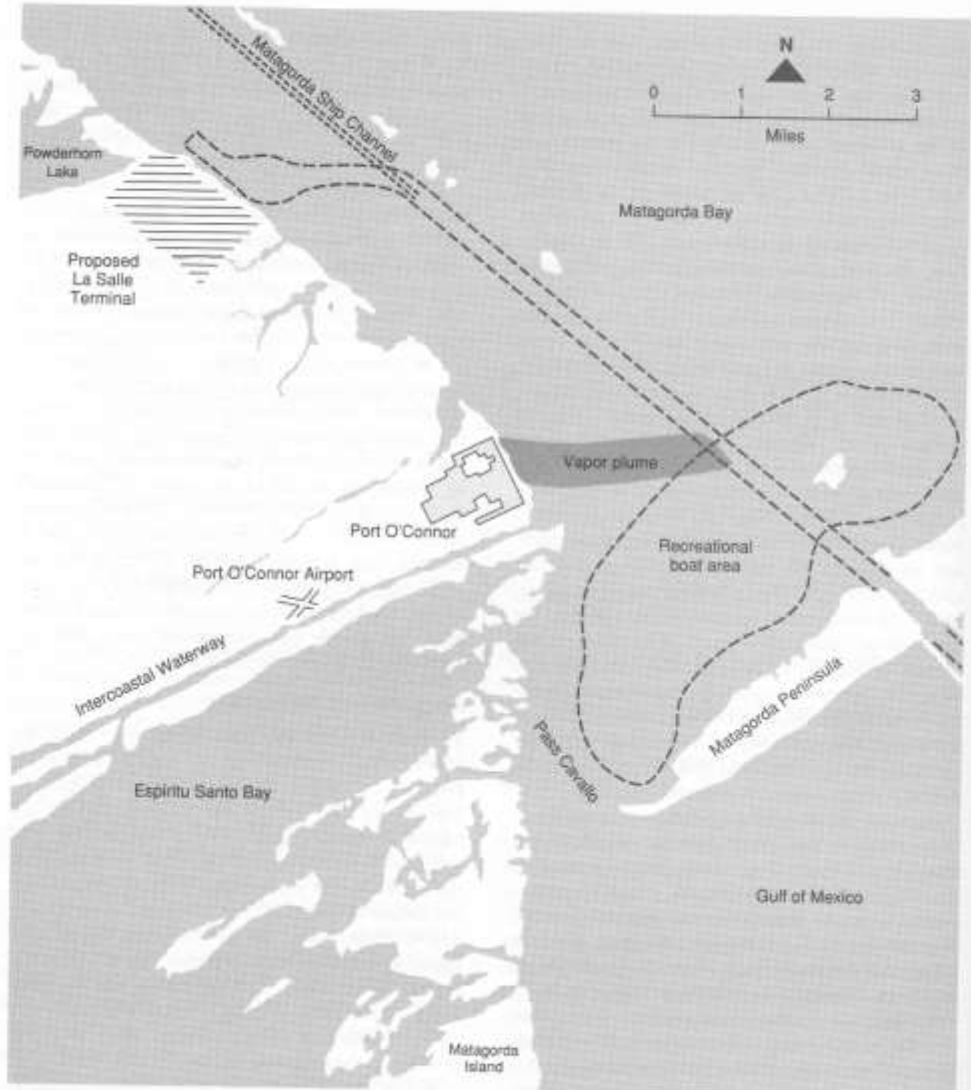
Need to evaluate risk of this new technology.

Risk at facilities low safety devices
with tanks plus dikes and buffer zones

Major concern is LNG spill on water at or near terminal

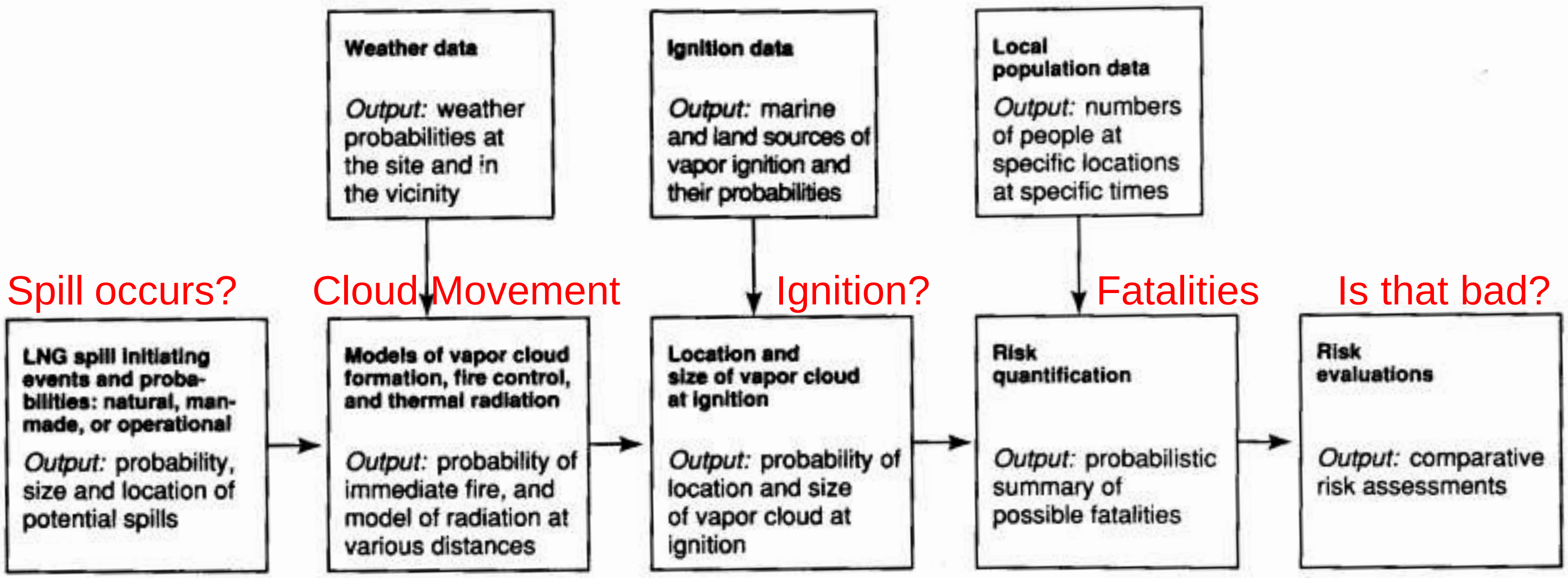
1000 daytime transient visitors at beach in summer.

Mapping a Hypothetical LNG Accident



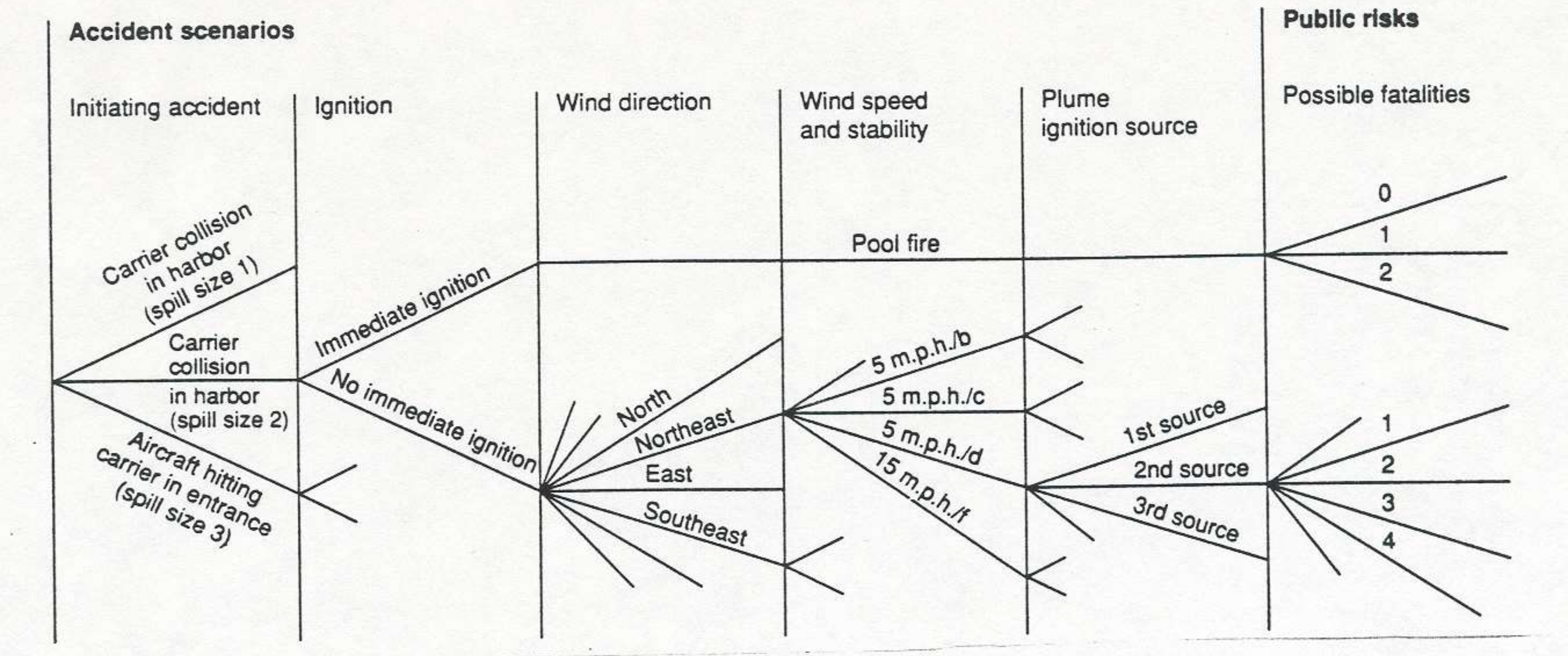
[Figure 3.] Mapping a hypothetical LNG accident. The La Salle Terminal for receiving and vaporizing liquefied natural gas from Algeria would be built by the El Paso LNG Co. and its subsidiaries northwest of Port O'Connor on Matagorda Bay, between Galveston and Corpus Christi, Texas. To reach it, LNG carriers would enter the Matagorda ship channel from the Gulf of Mexico. As part of the authors' risk analysis, they studied the probability of a collision scenario in which one tank of an LNG carrier was ruptured so as to instantaneously release 19,400 cubic meters of LNG. A 10 m.p.h. east wind would move the resulting vapor cloud toward the town of Port O'Connor, where fatalities from possible ignition of the vapor cloud might exceed 400. But the probability of this specific episode is shown to be 2.71×10^{-12}, and the expected fatalities per year among residents and visitors to Port O'Connor due to the proposed LNG facility is 1.7×10^{-6}.

LNG Accident Scenarios



[Figure 1.] Problem: to examine the public risks from possible releases of LNG from the proposed La Salle Terminal. Solution: a formal risk analysis according to the model shown here. The analysis is accomplished in three stages: develop accident scenarios and their associated probabilities (the three columns at the left); quantify public risks associated with each probability; and, finally, evaluate the risks by comparing them with those involved in other human activities.

Event Tree for LNG Accident Scenarios

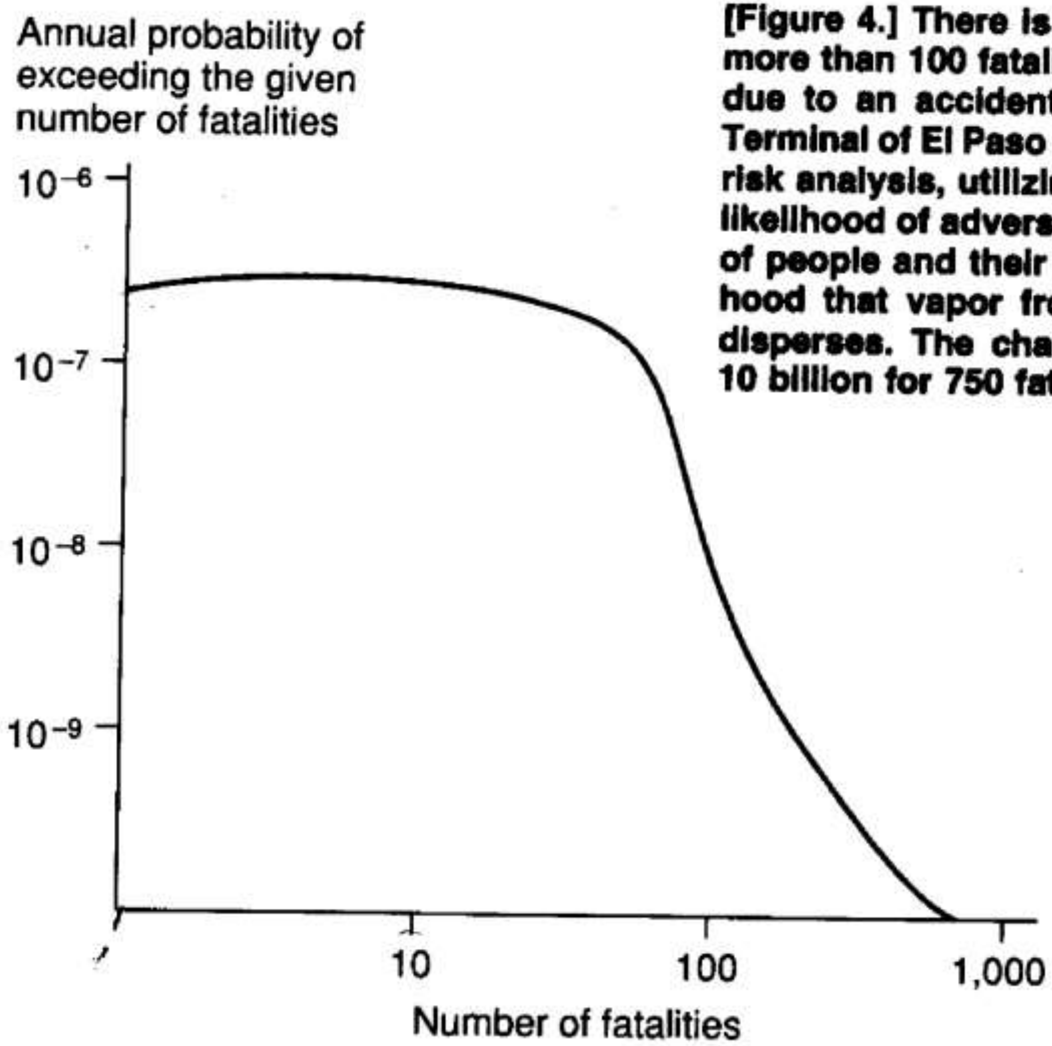


Probabilities of various winds & air turbulences

[Table 2.] Should there be an LNG accident in Matagorda Bay, Texas, how will the winds carry the flammable vapor clouds which may be formed? These probabilities of various winds and air turbulences (increasing turbulence is represented by higher "stability classes") were an essential input into the LNG risk analysis described in the accompanying article. To assure a conservative result, winds of 20 miles an hour and greater were included in the 15-m.p.h. category since this results in longer time periods until the vapor cloud is dispersed.

Wind speed (m.p.h.)	Stability class	Wind direction							
		North	Northeast	East	Southeast	South	Southwest	West	Northwest
5	C	0.0775	0.1042	0.0545	0.0230	0.0357	0.1986	0.1615	0.0916
5	D	0.0619	0.0763	0.0499	0.0273	0.0382	0.0906	0.0817	0.0833
5	F	0.0872	0.1341	0.2582	0.1374	0.2379	0.4742	0.4912	0.1277
10	C	0.0968	0.1200	0.1085	0.0814	0.0664	0.0614	0.0364	0.0763
10	D	0.1517	0.1809	0.1856	0.1460	0.1378	0.0673	0.0841	0.1527
10	F	0.0549	0.0600	0.0853	0.1050	0.1284	0.0635	0.0465	0.0392
15	C	0.0065	0.0197	0.0260	0.0448	0.0358	0.0034	0.0058	0.0093
15	D	0.4636	0.3048	0.2320	0.4351	0.3198	0.0411	0.0929	0.4198

Probability of fatality accidental LNG spills



[Figure 4.] There is one chance in 100,000,000 that there will be more than 100 fatalities in Port O'Connor, Texas in any one year due to an accidental spill of LNG near the proposed La Salle Terminal of El Paso LNG Co. This chart is the result of the authors' risk analysis, utilizing the likelihood of the original accident, the likelihood of adverse winds and air conditions, the likely number of people and their distribution in Port O'Connor, and the likelihood that vapor from the spilled LNG will be ignited before it disperses. The chances of a larger loss of life is less—one in 10 billion for 750 fatalities in any given year.

So does this risk profile make sense?

Measures Social Risk, Exposure & Individual Risk

Group	Expected fatalities per year	Number of people sharing the risk	Risk per person per year
Permanent population in Port O'Connor	2.0×10^{-8}	800	2.5×10^{-11}
Permanent population in Indianola	1.3×10^{-7}	80	1.7×10^{-9}
Transient daytime visitors	2.5×10^{-6}	2500	9.9×10^{-10}
Individuals in boats	1.35×10^{-5}	3000	4.5×10^{-9}
All individuals exposed to risk	1.7×10^{-5}	9000	1.9×10^{-9}

US Bureau of Reclamation - Dam Safety

Criteria for evaluating safety of large high-hazard dams:

probability of failure $\leq 10^{-4}$ per year

expected lives lost $\leq 10^{-3}$ per year

1st criterion ensures that dams are relatively safe and that failures are unlikely to happen.

2nd criterion recognizes that level of safety should primarily take into account number of individuals at risk.

Final Risk Comparison

Risk Evaluation: How LNG Compares

To put these figures in perspective, it's necessary to compare them with similar figures for other forms of energy production.

The La Salle Terminal is designed to receive and vaporize approximately one billion cubic feet of natural gas per day. This is equivalent to the power produced by eighteen 1,000-megawatt electric power plants operating at a 70 per cent capacity factor. Based on 1970 data for the State of Wisconsin used by W. A. Buehring, the expected number of deaths to the public due to transporting fuel or direct deaths due to plant accidents for a 1,000-megawatt coal facility was 0.695 per year. The implication of 18 such plants is 12.51 expected fatalities per year; this compares with La Salle's expected level of 0.000,017. Buehring's corresponding number for 18 1,000-megawatt nuclear plants is 0.36 expected fatalities per year.

Other individual risk levels due to government and private activities have been computed. The risk to an average individual in the U.S. due to fire is 16,000 times greater than the risk to an individual exposed to the operations of the proposed La Salle Terminal. The group with the highest annual risk from the proposed LNG facility is people in boats. The risk is 4.5×10^{-9} per person—one chance in approximately 220 million. From the La Salle Terminal, the annual risk per person in Port O'Connor is 2.5×10^{-11}. The expected public risk due to gas distribution systems in the U.S. is 5.15×10^{-7} per individual per year, which represents one chance in 1.9 million; this is 271 times as great as the possibility of death due to the operations of the proposed La Salle Terminal. Public fatalities due to electric shock in electrically wired residences are 1.11×10^{-6} per individual per year.

To help interpret these risks, consider the following. Approximately 65 meteorites weighing more than one pound hit the United States each year; if one owns a one-floor house with 3,050 square feet, the probability that one of these meteorites will hit that house within a year is 1.9×10^{-9}. This is identical to the average individual risk to operation of the La Salle Terminal.

National Research Council - 1994

Tank Car Safety

About 1 million shipments of hazardous materials are moved by railroad tank car every year. Shipments of these materials, which can be flammable, corrosive, poisonous, or pose other hazards, are regulated by the U.S. Department of Transportation (DOT). The agency determines which materials must be shipped in tank cars specially designed to withstand train crashes and to prevent accidental spills. A Transportation Research Board study, commissioned by Congress, examined DOT's procedures for making these determinations.

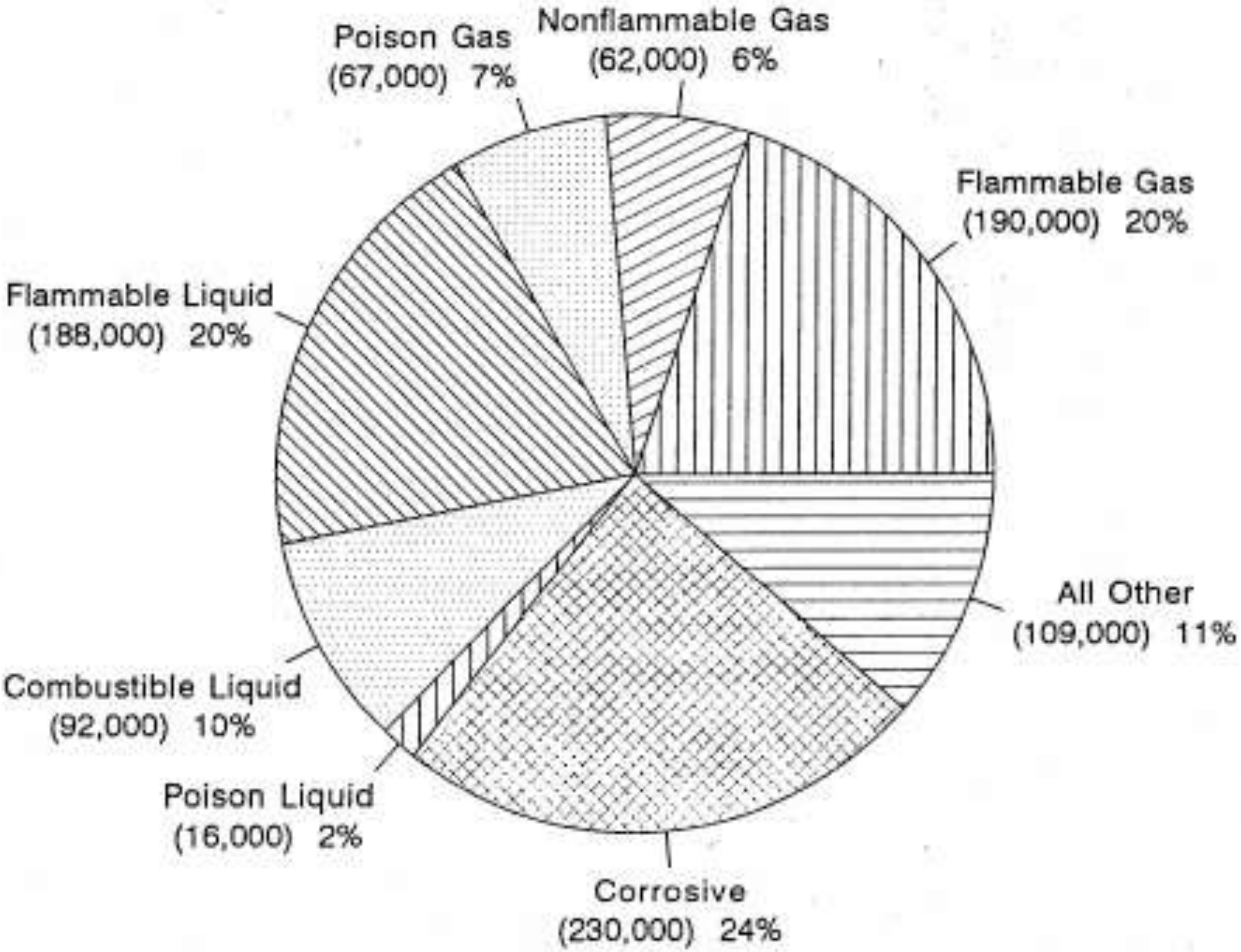
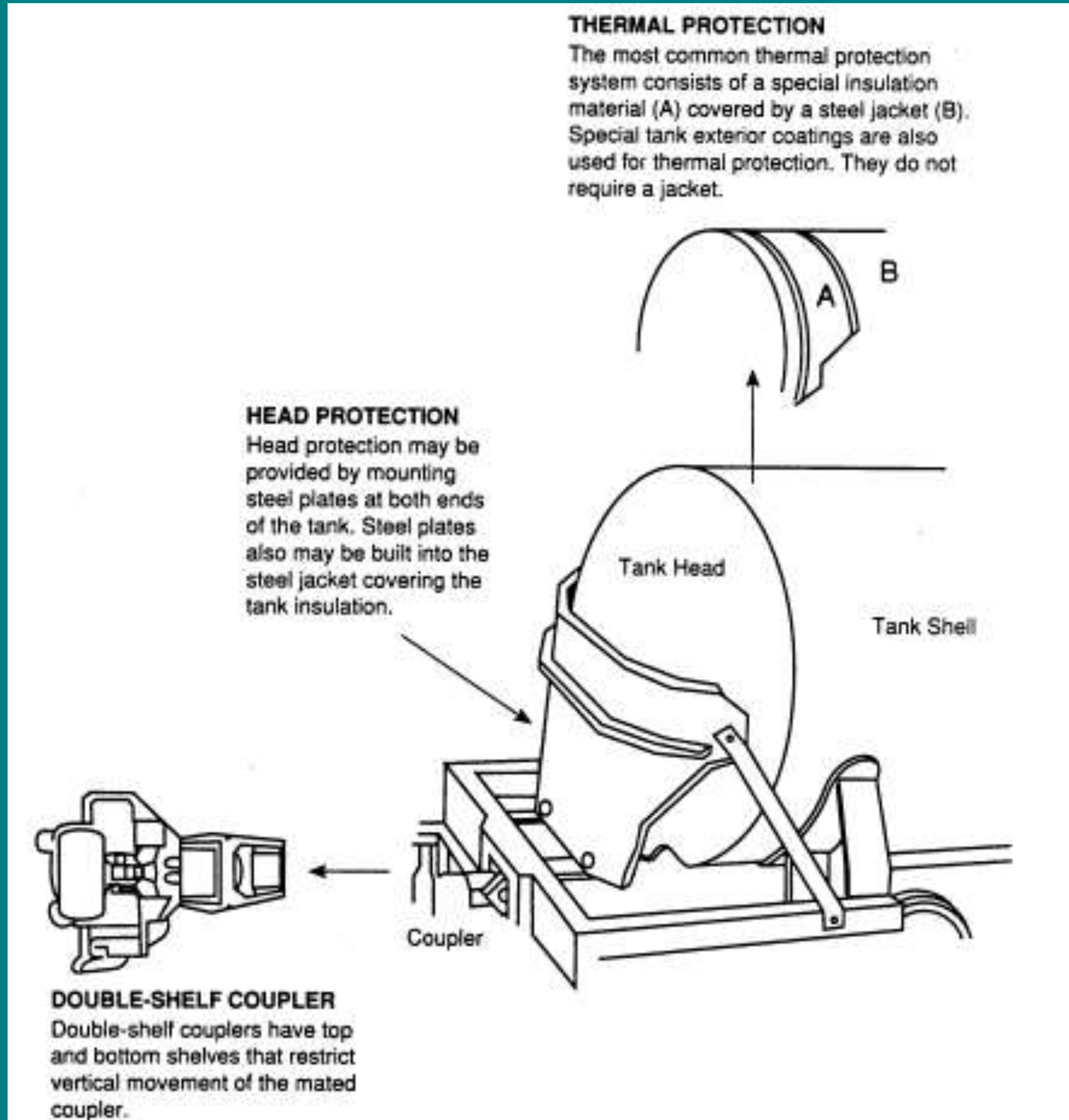


FIGURE 2-7 Tank car traffic (originating carloads) by DOT hazard class, 1992 (Bureau of Explosives 1993, 10).


THERMAL PROTECTION
The most common thermal protection system consists of a special insulation material (A) covered by a steel jacket (B). Special tank exterior coatings are also used for thermal protection. They do not require a jacket.
A
B
HEAD PROTECTION
Head protection may be provided by mounting steel plates at both ends of the tank. Steel plates also may be built into the steel jacket covering the tank insulation.
Tank Head
Tank Shell
Coupler
DOUBLE-SHELF COUPLER
Double-shelf couplers have top and bottom shelves that restrict vertical movement of the mated coupler.

Raj & Glickman

Risk Profiles on Railroad Routes

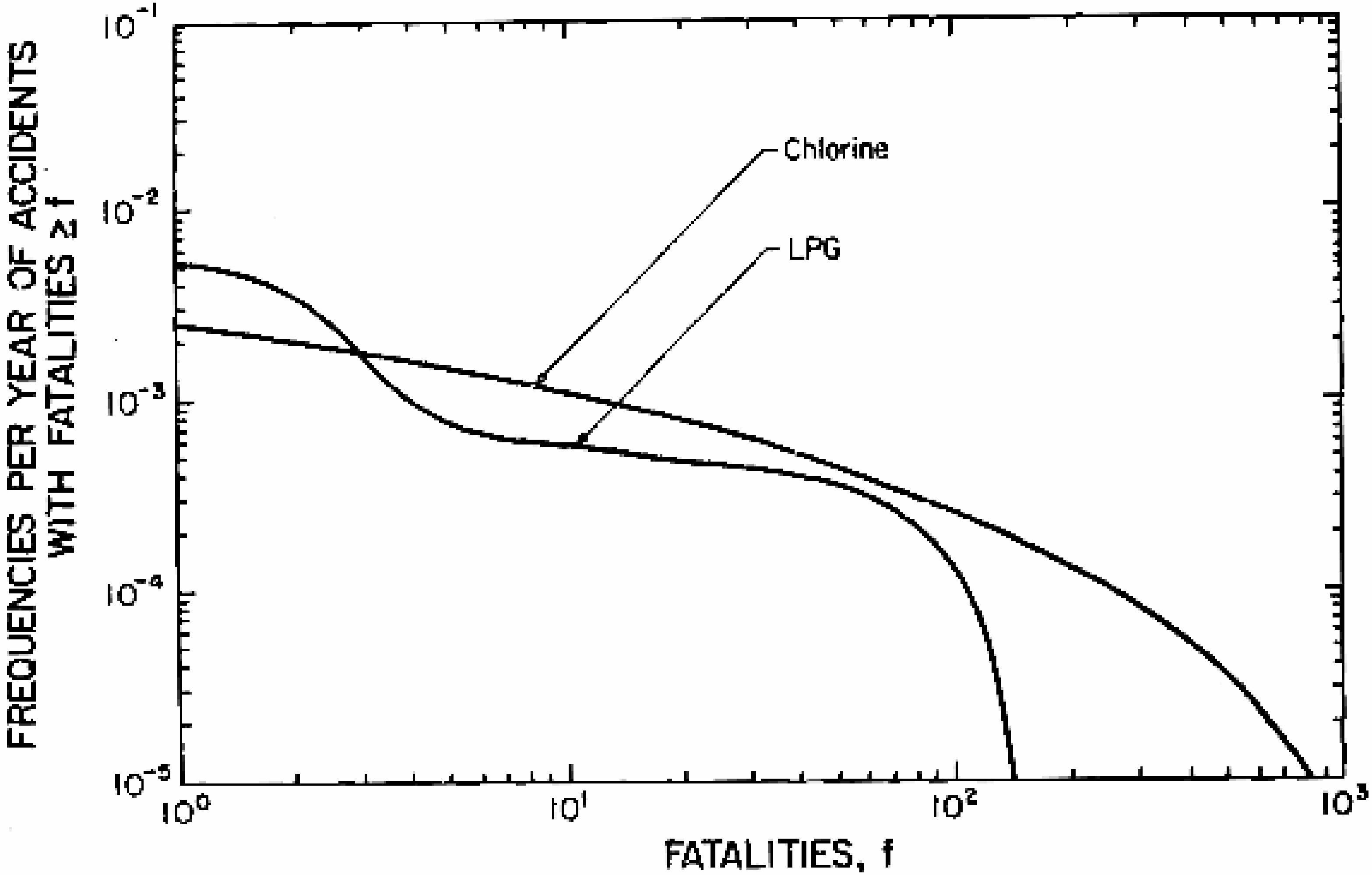


FIGURE 1 Risk profiles for chlorine and LPG on the illustration route.

Risk Profiles on Railroad Routes

Kinetic accidents: collisions and derailments

Less frequent but *more severe* than static accidents

Frequency of accidents with d fatalities

= sum of frequencies of all accidents
(different routes & modes) that cause d fatalities

Compute first for each route:

f_s = frequency of accidents on route segment s

$P(l_X \mid s)$ = prob. l_X cars release X in route s accident

Getting the Frequency of Accidents

Frequency of accidents with I_X cars releasing X on route s:

$$f_s(I_X \mid s) = P(I_X \mid s)\, f_s$$

Determine possible deaths resulting from I_X cars releasing contents.

I_X = key intermediate state variable summarizing many possible train accidents.

Typical main-line accident rate = 0.83 per billion gross ton-miles (BGTM)

For yard accidents, accident rate of 6.56 per million classifications; average speed 10 mph

(accidents/ton-mile) (ton-miles/yr)

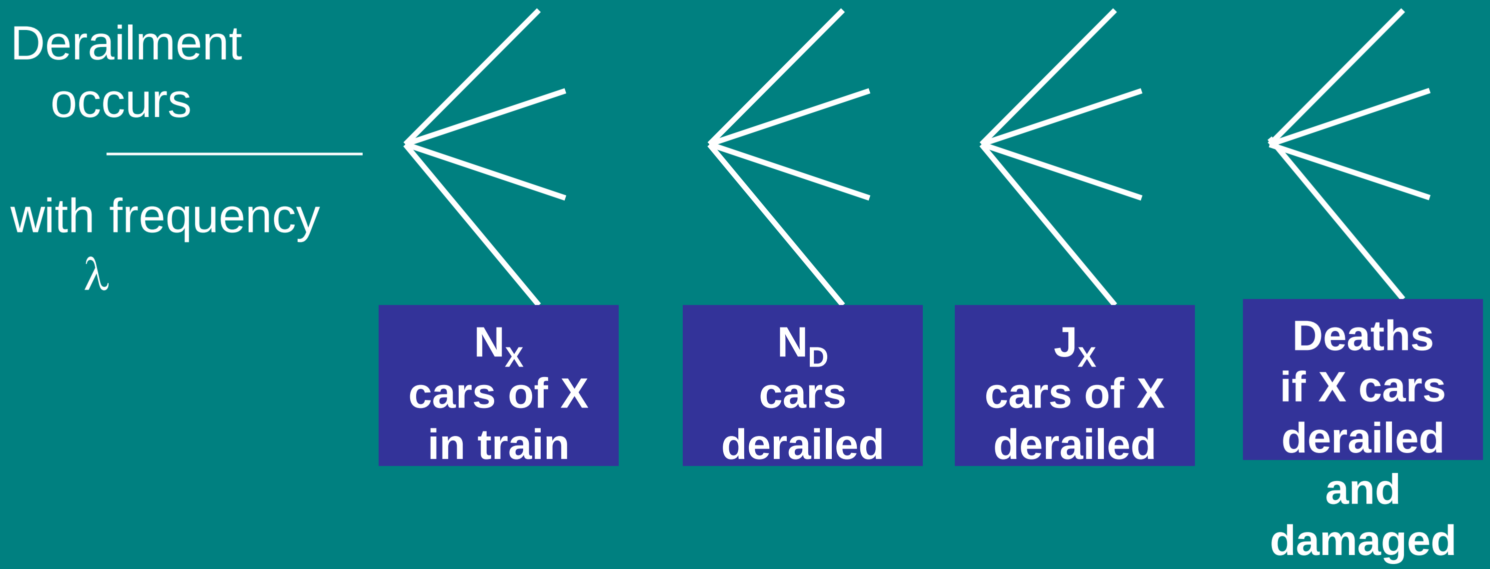
Compute accidents/year

using (traffic/year) times (accidents/traffic)

f_s = (accidents/year)

= (accidents/ton-mile) (ton-miles/yr)

Event Tree for Derivation of $P(I_X | s)$

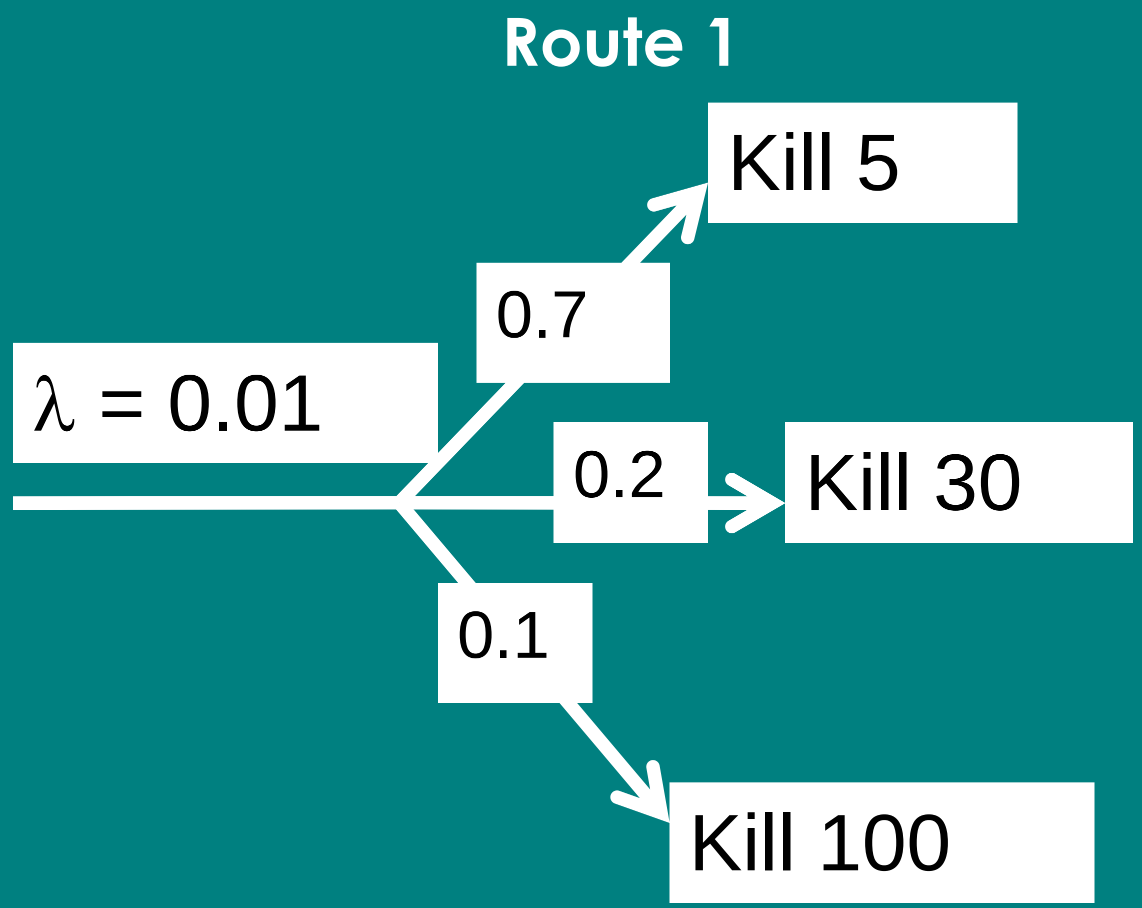


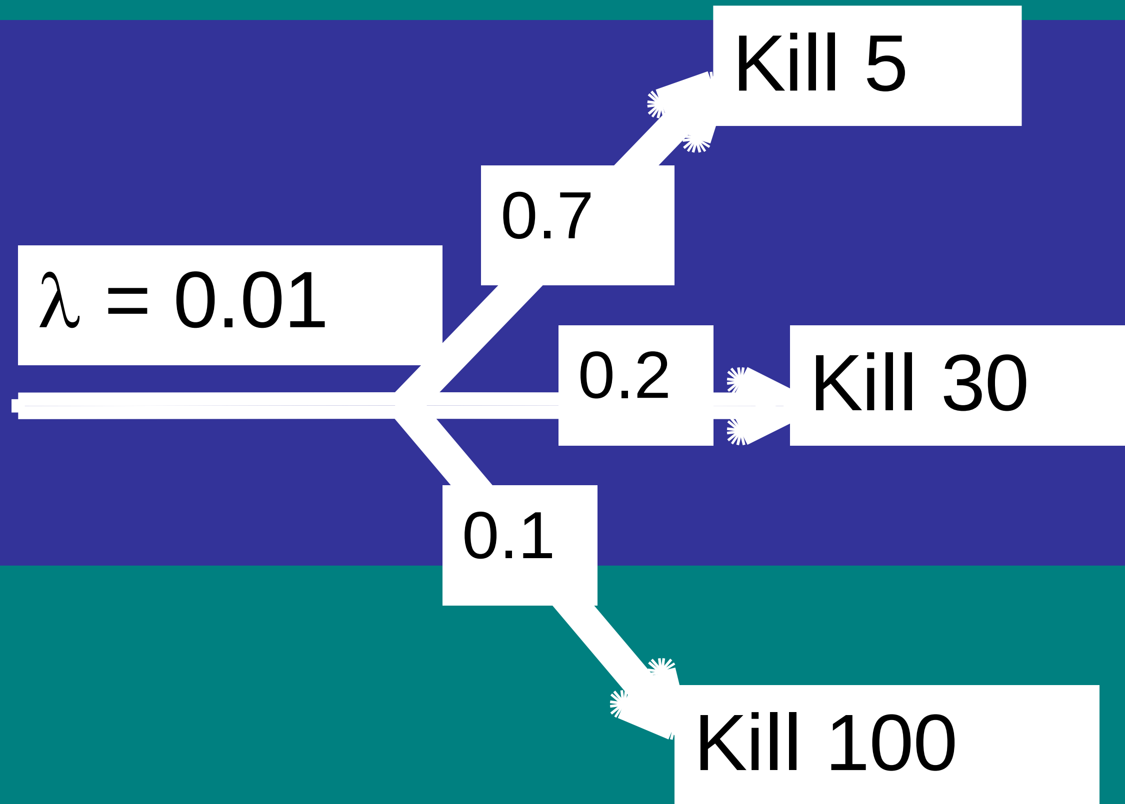
Different routes have different characteristics in terms of speed and traffic. Thus different route segments should be evaluated separately.

TABLE 1 Route Segment Data

Segment	Volume (10^6 ton/yr)	Length (mi)	Speed (mph)	Population Density (No./mi^2)
1	17.7	18.9	30	2,800
2	17.7	21.3	45	127
3	17.7	39.3	45	41
4	17.7	20.0	45	48
5	17.7	13.3	45	141
6	17.7	32.4	45	89
7	17.7	11.6	45	26
8	17.7	20.0	45	51
9	21.2	30.8	45	110
10	23.1	27.8	45	19
11	23.1	16.0	45	18
12	23.1	21.9	45	23
13	23.1	35.4	35	103
14	42.7	38.0	30	602
15	31.7	31.2	45	65
16	31.7	24.5	45	196
17	31.7	19.4	45	22
18	31.7	18.8	45	65
19	31.7	9.4	45	112
20	21.3	18.8	30	268
21	21.4	11.3	30	868
22	29.5	14.1	30	1,104
23	37.7	4.2	30	1,789
24	35.5	7.3	30	1,016
25	35.5	23.9	30	113
26	35.5	17.8	45	73
27	35.5	17.8	45	37
28	35.5	8.9	30	594

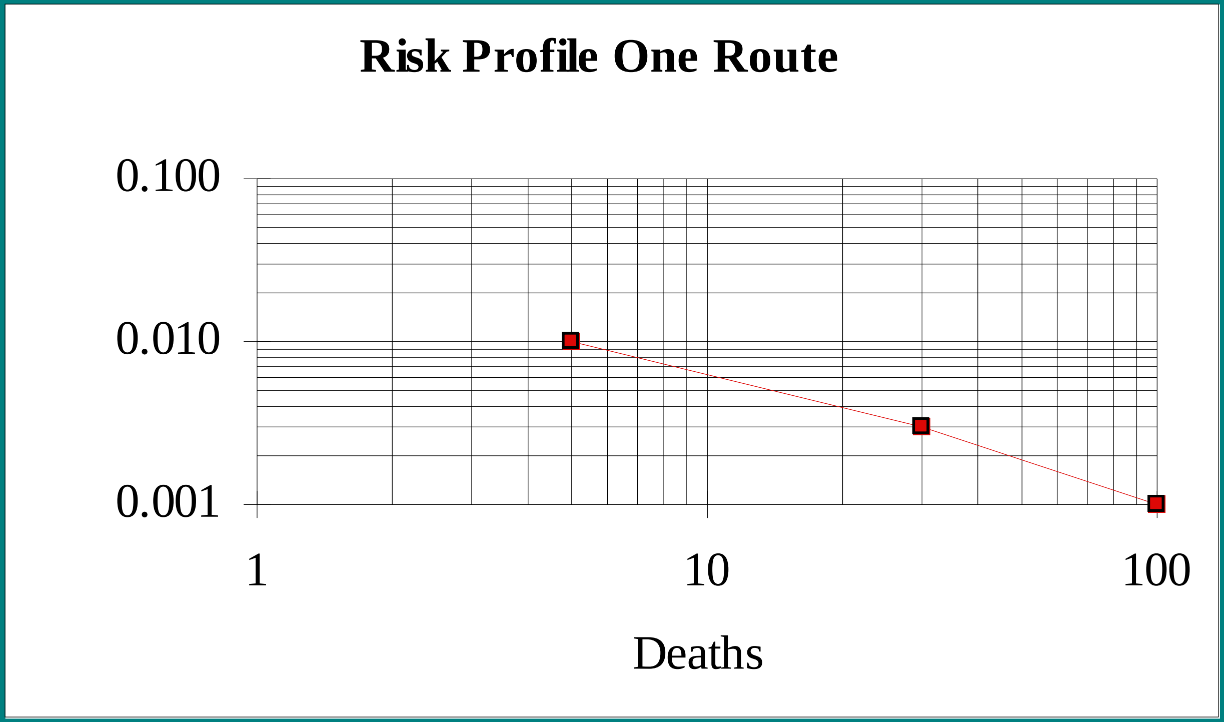
Construction of Risk Profile for One Route





Freq of Event *f*	Prob. of deaths Pr[N = n (i)]	Number Killed n(i)	Freq of n(i) ?* P[n(i)]
0.01	0.7 0.2 0.1	5 30 100	0.007 0.002 0.001

Freq of Event	Prob. of deaths	Number Killed	Freq of n(i)	Risk Profile
f	Pr[N = n (i)]	n(i)	?* P[n(i)]	Freq[N?n]
0.01	0.7	5	0.007	0.010
	0.2	30	0.002	0.003
	0.1	100	0.001	0.001



Risk Profile for 4 Train Routes

Frequency of d deaths

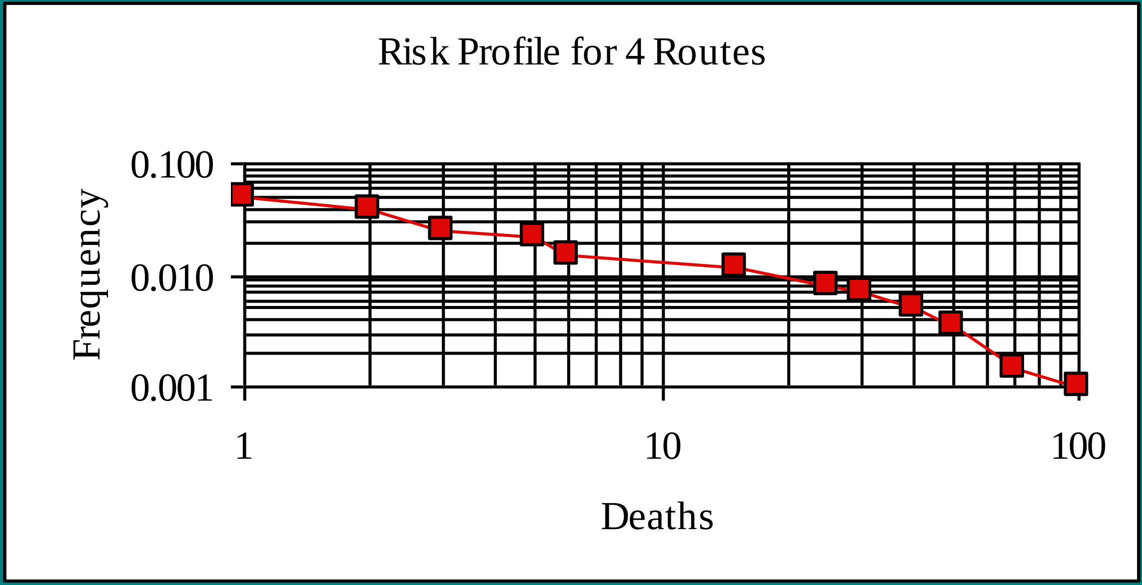
= λ * Pr (deaths | accident)

λ = accident rate

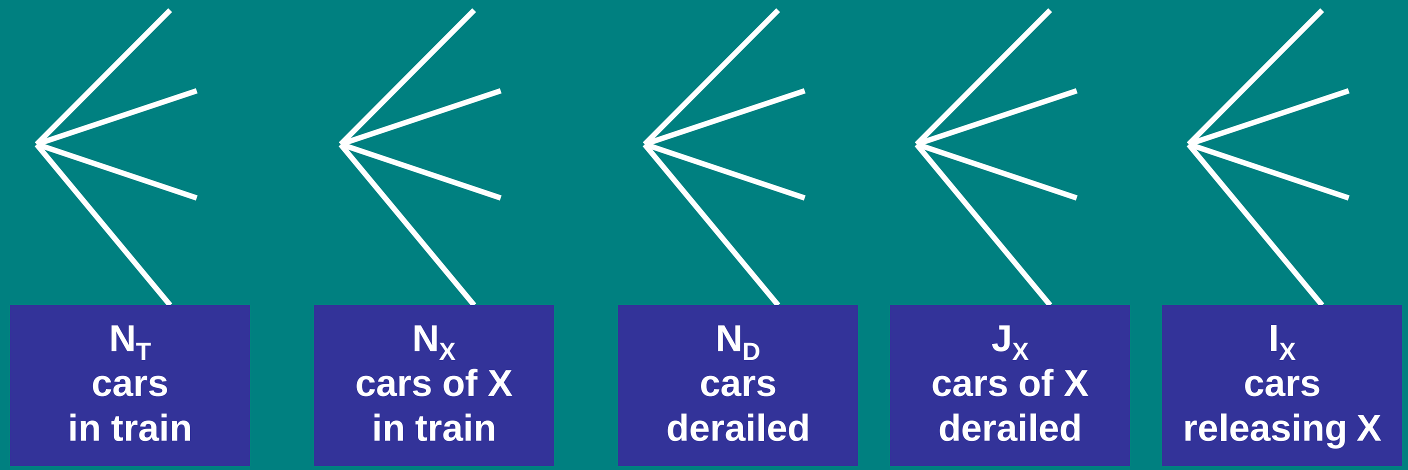
Freq of Event f	Prob. of deaths Pr[N =n(i)]	Number Killed Deaths n(i)	Freq of n(i) Freq f * P[n(i)]
Route 1			
	0.7	5	0.0070
0.01	0.2	30	0.0020
	0.1	100	0.0010
Route 2			
	0.7	2	0.0140
0.02	0.2	15	0.0040
	0.1	50	0.0020
Route 3			
	0.7	1	0.0105
0.015	0.2	6	0.0030
	0.1	40	0.0015
Route 4			
	0.7	3	0.0035
0.005	0.2	25	0.0010
	0.1	70	0.0005

Computation of Risk Profile for 4 Train Routes

n(i)	f(i)	Risk Profile
1	0.0105	0.0500
2	0.0140	0.0395
3	0.0035	0.0255
5	0.0070	0.0220
6	0.0030	0.0150
15	0.0040	0.0120
25	0.0010	0.0080
30	0.0020	0.0070
40	0.0015	0.0050
50	0.0020	0.0035
70	0.0005	0.0015
100	0.0010	0.0010



Expanded Event Tree for Derivation of $P(I_X \mid s)$



$P(N_T)$ = Normal with $\mu = 88$ and $\sigma = 4.4$

$P(N_X \mid N_T)$ = Poisson with $\upsilon = E[N_X]$ which depends on route s.

$P(N_D \mid N_X, N_T) = P(N_D)$ = Gamma$\{\mu = 1.7\upsilon^{0.5}; \sigma = 1.64\upsilon^{0.5}\}$

for $N_T > 25$ cars

Derivation of $P(J_X \mid N_D, N_X, N_T)$

$P(J_X \mid N_D, N_X, N_T)$	$= 0$	$J_X > \min [N_D, N_X]$
	$\approx 2/(N_T - N_X + 1)$	$1 \le J_X < \min [N_D, N_X]$
	$\approx \{\lvert N_D - N_X \rvert + 1\}/(N_T - N_D + 1)$	$J_X = \min [N_D, N_X]$
	$= ???$	$J_X = 0$

Ignored end effects: X cars might not be in middle and have smaller probability of being in N_D-car derailment near ends. But derailments more likely near front of train.

Model of $P(I_X \mid J)$

$P(I_X \mid J_X)$ = Binomial with $n = J_X$, $p = 0.013\upsilon^{0.5}$

υ = velocity of train

But are failures of each car independent,

or are they all affected by violence of accident,

or faiure of adjacent car?

Risk Profile from Chlorine Releases

For route s let

f_s = frequency of accidents on route segment s

From analysis of the derailment decision tree

$P(I_X \mid s)$ = prob. of I_X cars releasing their content on route s

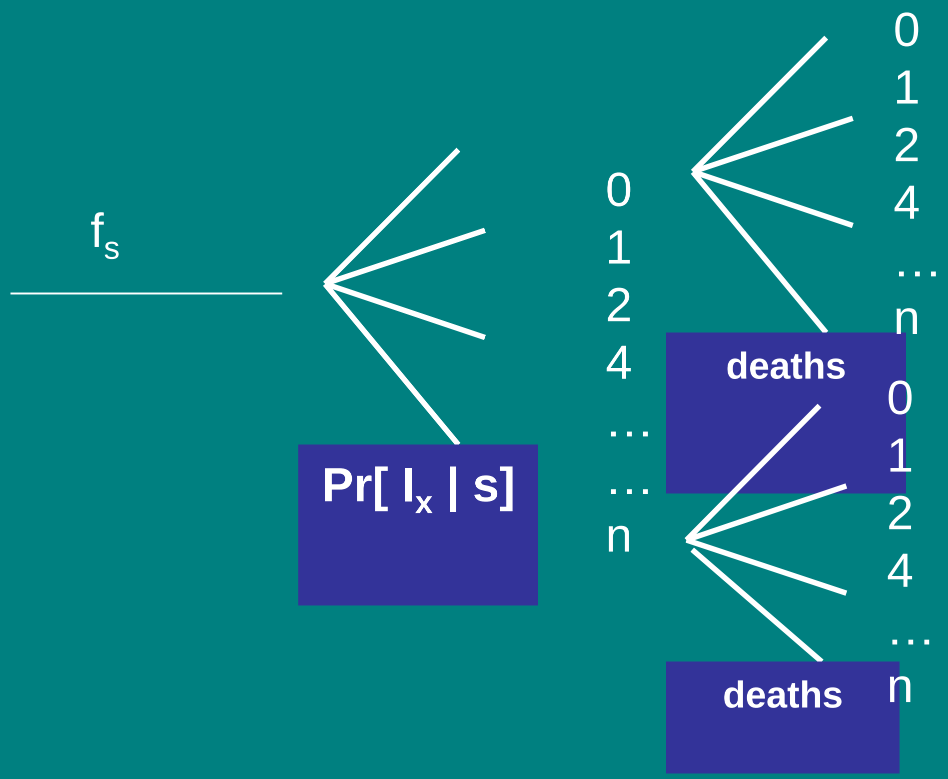
Frequency of jth fatalities d_{sij} (deaths) on route s

from I_X = i car release: $Freq[\, d_{sij} \,] = P[\, d_{sij} \mid s, I_X] \; P(I_X \mid s) \; f_s$

Risk Profile: $Freq[\, D \geq d \,] = \Sigma_{all\ d_{sij} \geq d} \; Freq[\, d_{sij} \,]$

Risk Profile from Chlorine Releases - Figure

Risk Profile: $\text{Freq}[\, D \geq d \,] = \Sigma_{\text{all } d_{sij} \geq d} \text{Freq}[\, d_{sij} \,]$



Given an accident, preceding analysis generates probability that different numbers of cars release their contents.

Next compute distribution of deaths resulting from each numbers of cars releasing their contents.

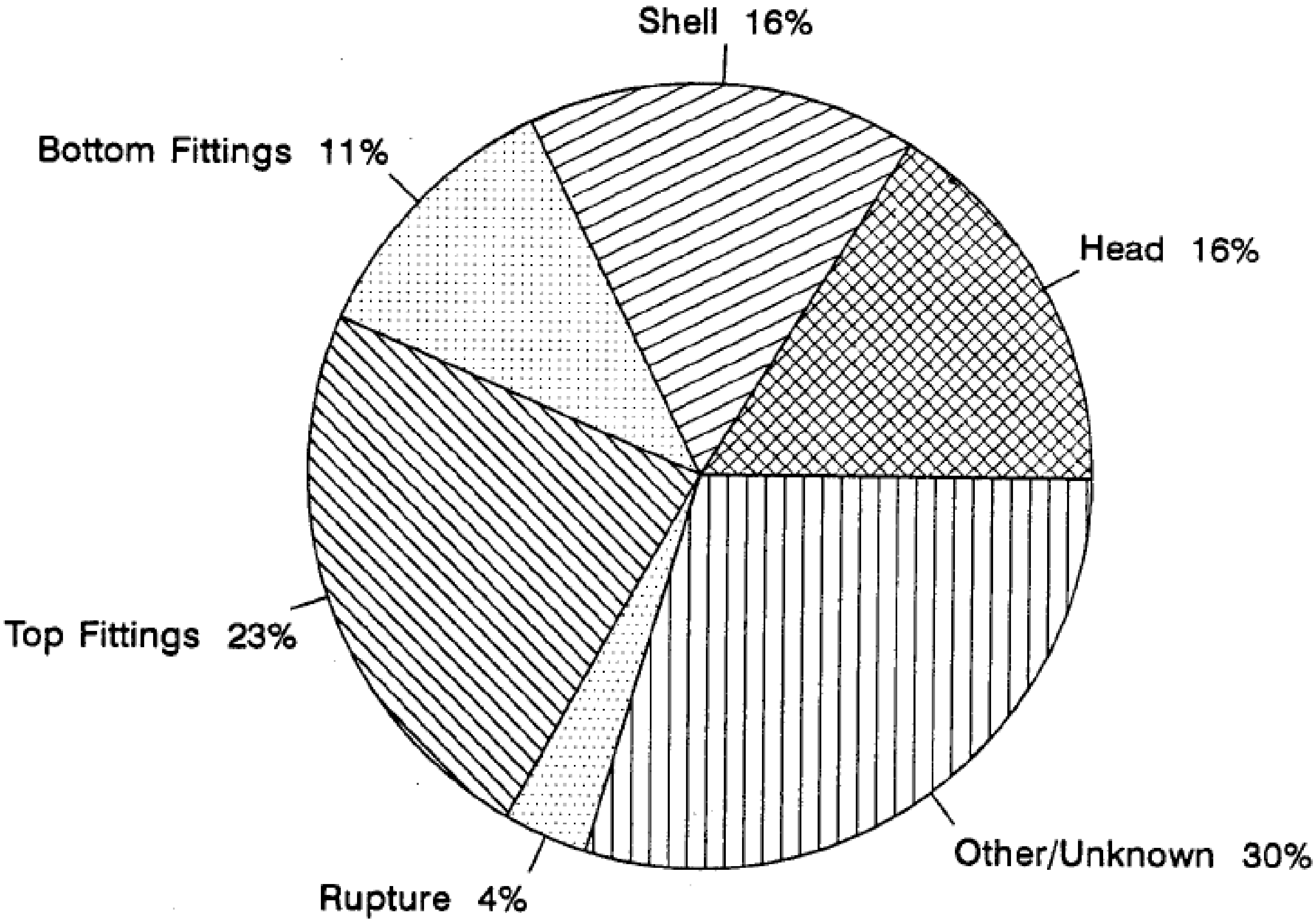
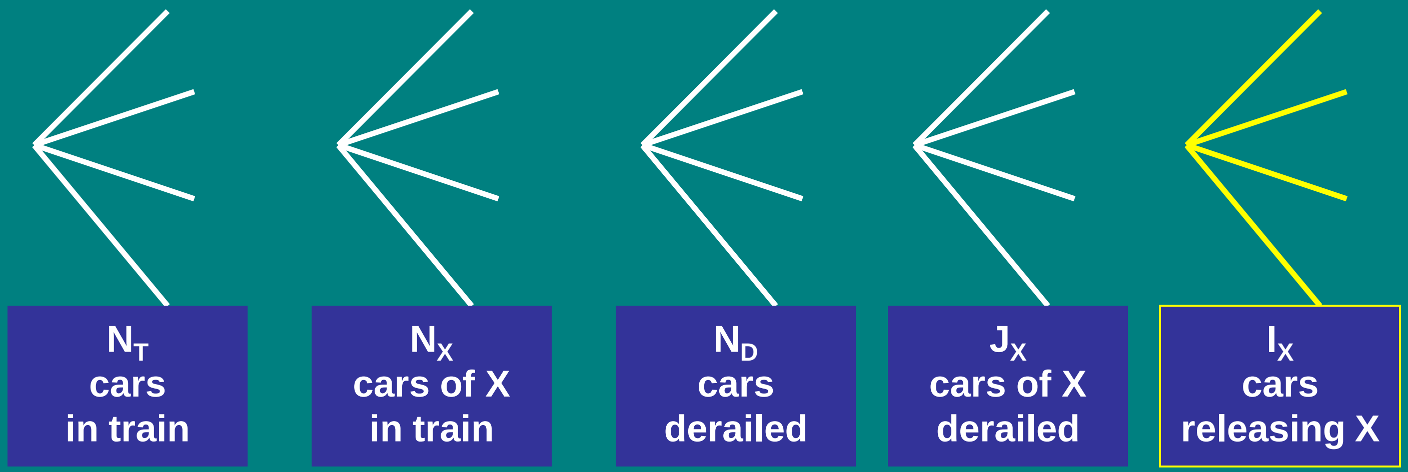


FIGURE 3-5 Sources of releases from tank cars damaged in accidents from 1965 to 1986 (RPI-AAR 1990). (During much of the period studied, few tank cars were equipped with double-shelf couplers or head and thermal protection systems.)

Risk Profile - Accident types

If one allows different accident types k, then the model would include the probability of different accident types in a derailment $P(k \mid s)$ or $P(k \mid N_D, N_X, N_T, s)$ as well as $P(I_X \mid k,s)$ and $P[\, d_{sij} \mid k, s, I_X \,]$.



Need to replace with accident type model

Leaks versus Explosions.

If one car bursts or explodes, do we care if other cars just leak?

Fire is the principal lethal hazard from LPG tank car releases. Several different types of fires can result: torch fires, pool fires, vapor fires, unconfined detonations in dispersed vapor, and fireballs. The other lethal hazard is mechanical in nature, arising from the fragmentation or rocketing of tank cars. The calculations of the hazard areas associated with the different types of fire hazard and mechanical hazard are described next.

Fireball

The exposure of an LPG tank to a fire results in the occurrence of two phenomena, collectively known as a BLEVE. First, the boiloff from the heat input is vented into the atmosphere through the relief valve. This gas outflow is ignited and forms a torch fire. Second, the tank wall not backed by liquid inside overheats and weakens. Failure of the tank wall is sudden, resulting in the rupture of the tank, instantaneous release of remaining contents, and then ignition of the contents released. This ignition results in the formation of a spectacular fireball.

Boiling Liquid Expanding Vapor Explosion (BLEVE)

http://www.epa.gov/superfund/programs/er/resource/images/d1_22.jpg

ESTIMATION OF CONSEQUENCES

When a substantial quantity of a lethal hazardous material is released in an accident the most important consequence of concern is the loss of human life. The expected magnitude of this consequence may be estimated by multiplying the expected density of population in that area by the expected size of the lethal area. To be precise, the population density factor should include any on-scene professionals (train crew, fire fighters, and related emergency personnel) and the time of day should be taken into account when estimating the number of exposed individuals in the general public. Furthermore, the degree to which persons in the lethal area are vulnerable (depending on their preparedness, mobility, protection, and so forth) should be reflected. For expediency, however, residential county census data are used to estimate the population density along each segment of the illustration route. Estimates of the other factors affecting consequence magnitudes (i.e., the expected lethal areas for chlorine and LPG releases) were calculated using the models described hereafter.

Number of deaths

Authors compute :

Number of deaths =

(expected lethal area) * (average population density)

This surely underestimates both mean and possible large number of deaths in a bad accident.

Where is the region population is located?

TABLE 2 Expected Hazard Area Calculation for Release of Chlorine from a Single Tank Car

Release Scenario	Source of Release	Conditional Probability of Source, Given a Release[a]	Hazard Area (km^2)	Probability-Weighted Hazard Area (km^2)[b]
1	Pressure relief safety valve and top fittings	0.442	5.5×10^{-3}	2.43×10^{-3}
2	Bottom fittings and stuck relief valve when car is upside down	0.138	15.1×10^{-3}	2.08×10^{-3}
3	Shell and head punctures	0.319	1.2	0.383
4	Fire exposure and catastrophic release	0.200	1.8	0.360

[a] Based on 1978-1983 railroad industry data.
[b] Total expected hazard area = 0.747 km^2.

Prob. weighted hazard area
= Prob. * Hazard Area

Lessons

Origin of probabilities and frequencies for a realistic risk profile

- Use historical accident data to compute f_s and many probabilities.
- Combine with current or projected travel rates (traffic per year).
- Use mechanistic arguments to get $P(I_X \mid N_D, N_X, N_T)$ because insufficient historical data.

Divide problem: Separate analysis of probabilities of different I_X from transport model to get deaths as function of route s and I_X cars that release contents.

Losses from Serious Transportation Incidents related to movement of hazardous materials

(damages reported in millions of dollars)

	Highway Deaths	Railroad Deaths	Highway Injuries	Railroad Injuries	Highway Damages	Railroad Damages
1991	10	0	107	29	26	6
1992	16	0	189	78	19	10
1993	15	0	242	11	13	2
1994	11	0	188	45	14	12
1995	7	0	88	20	17	7
1996	8	2	85	892	24	17
1997	12	0	68	6	19	7
1998	13	0	54	9	22	16
1999	8	0	109	3	24	29
2000	12	1	39	57	38	24
Total	**112**	**3**	**1,169**	**1,150**	**216**	**131**

Now a little about

Accident Response & Risk Management

An important component of a risk management strategy is

1. to design emergency response strategies and
2. improve the ability of emergency responders to take control of an accident, without making things worse.

Remember the Disaster Management Cycle.

Consider laboratories with and transport of hazardous materials.

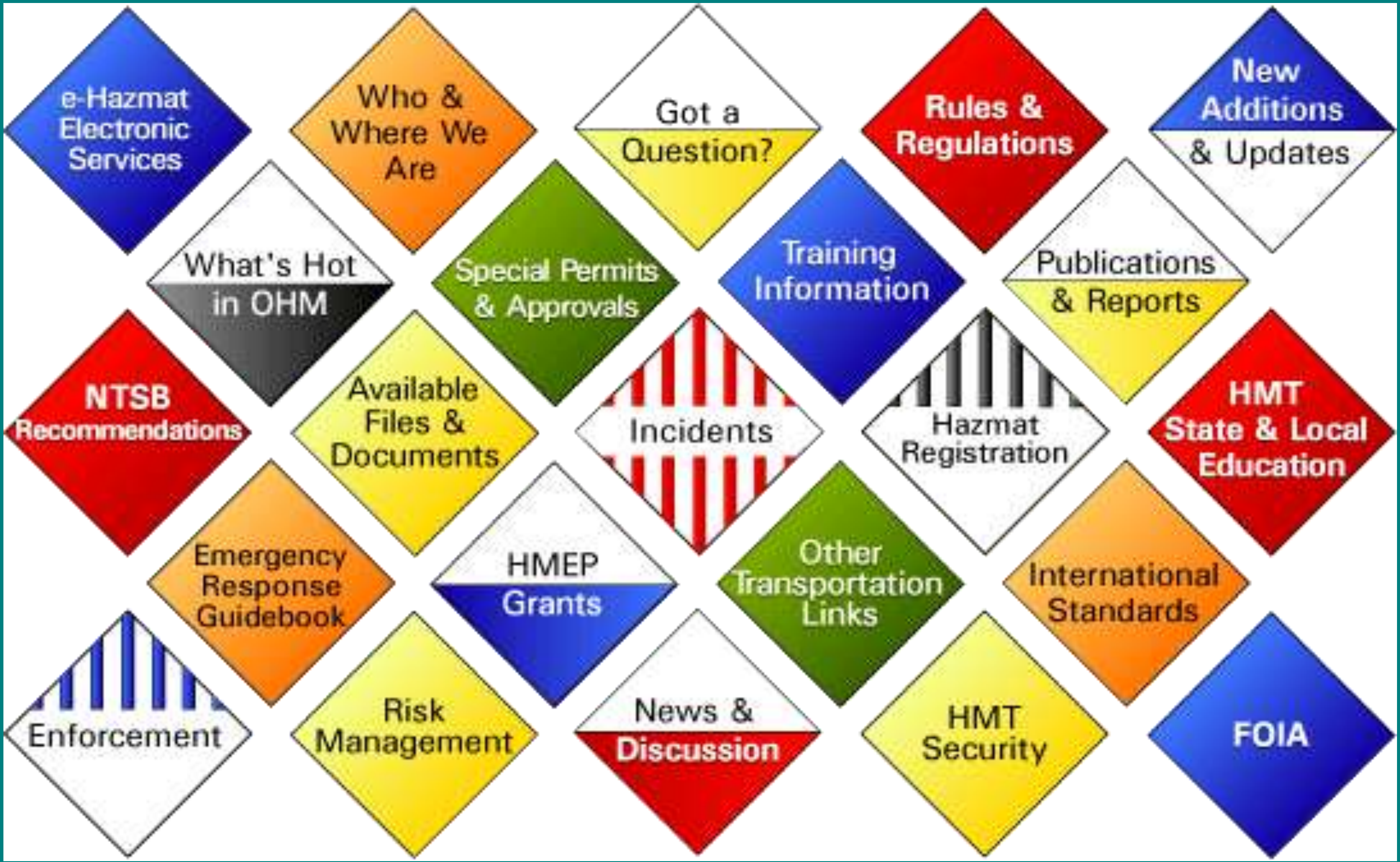
Accidents Do Happen!

Department of Transportation

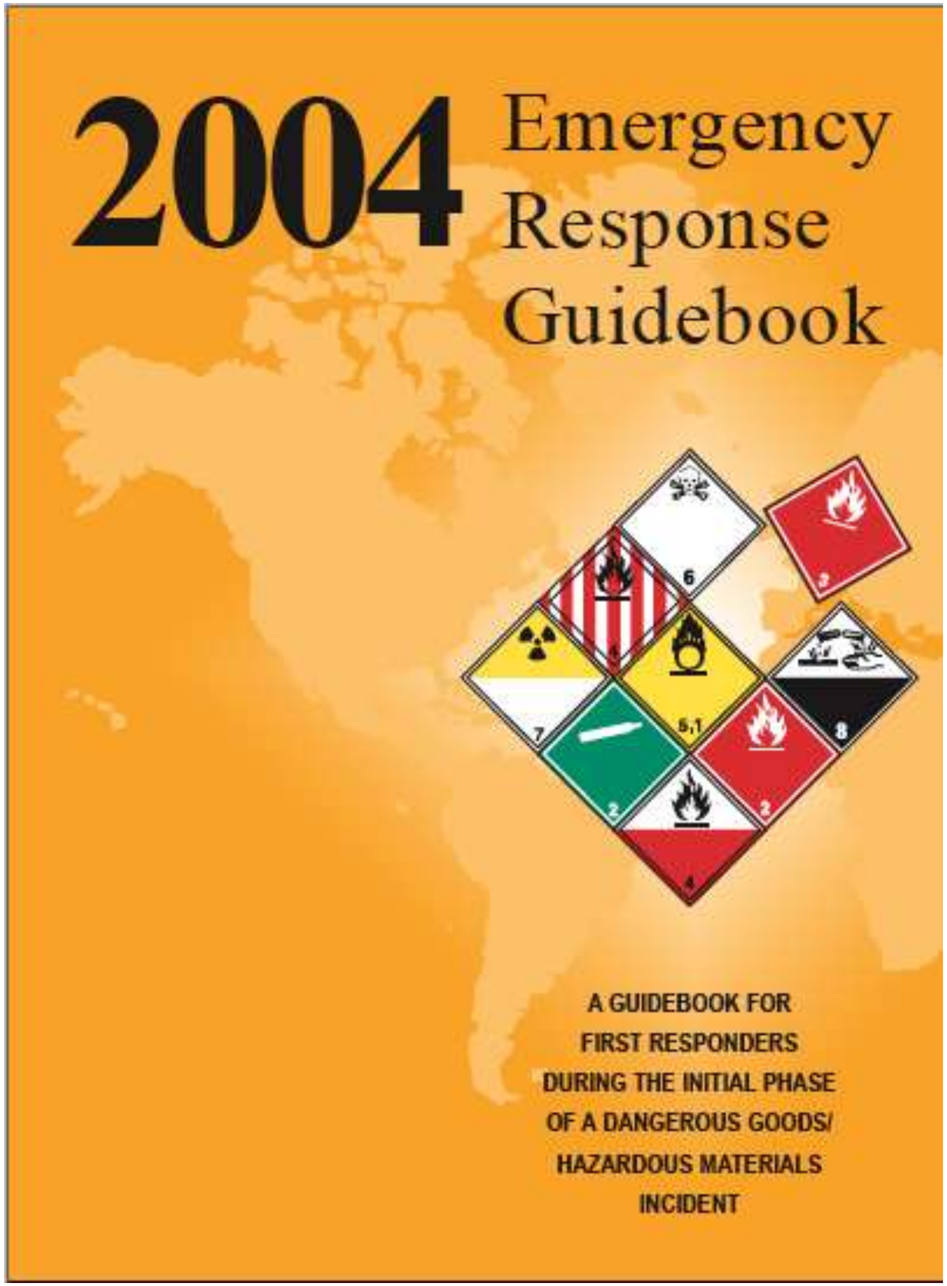
"The Office of Hazardous Materials Safety within the United States Department of Transportation's Research and Special programs Administration, is responsible for coordinating a national safety program for transportation of hazardous material by air, rail, highway and water.

http://hazmat.dot.gov/hazhome.htm

Depart. of Transportation - Risk Issues



Know what to
Do with every
chemical
and hazard.



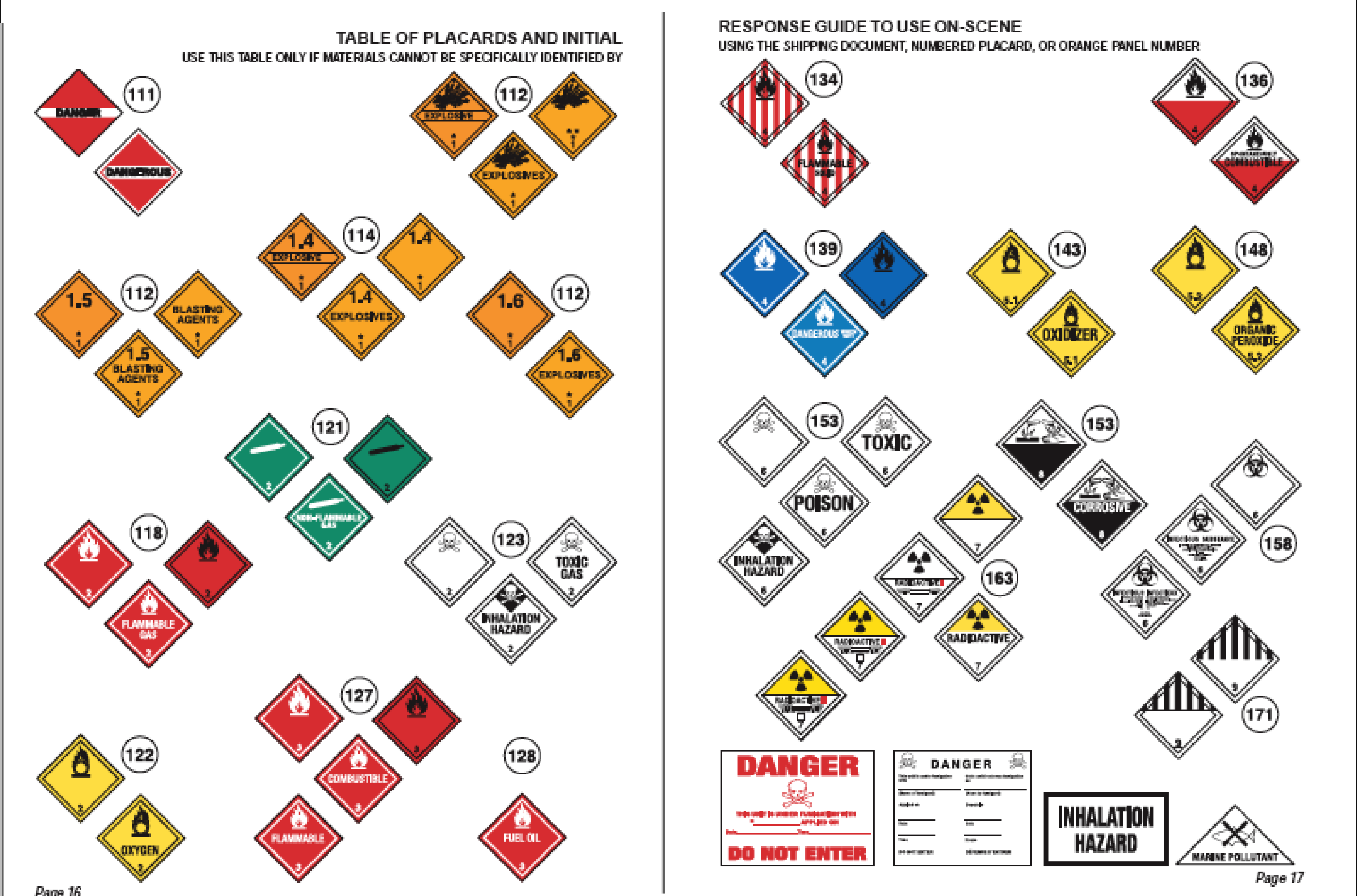
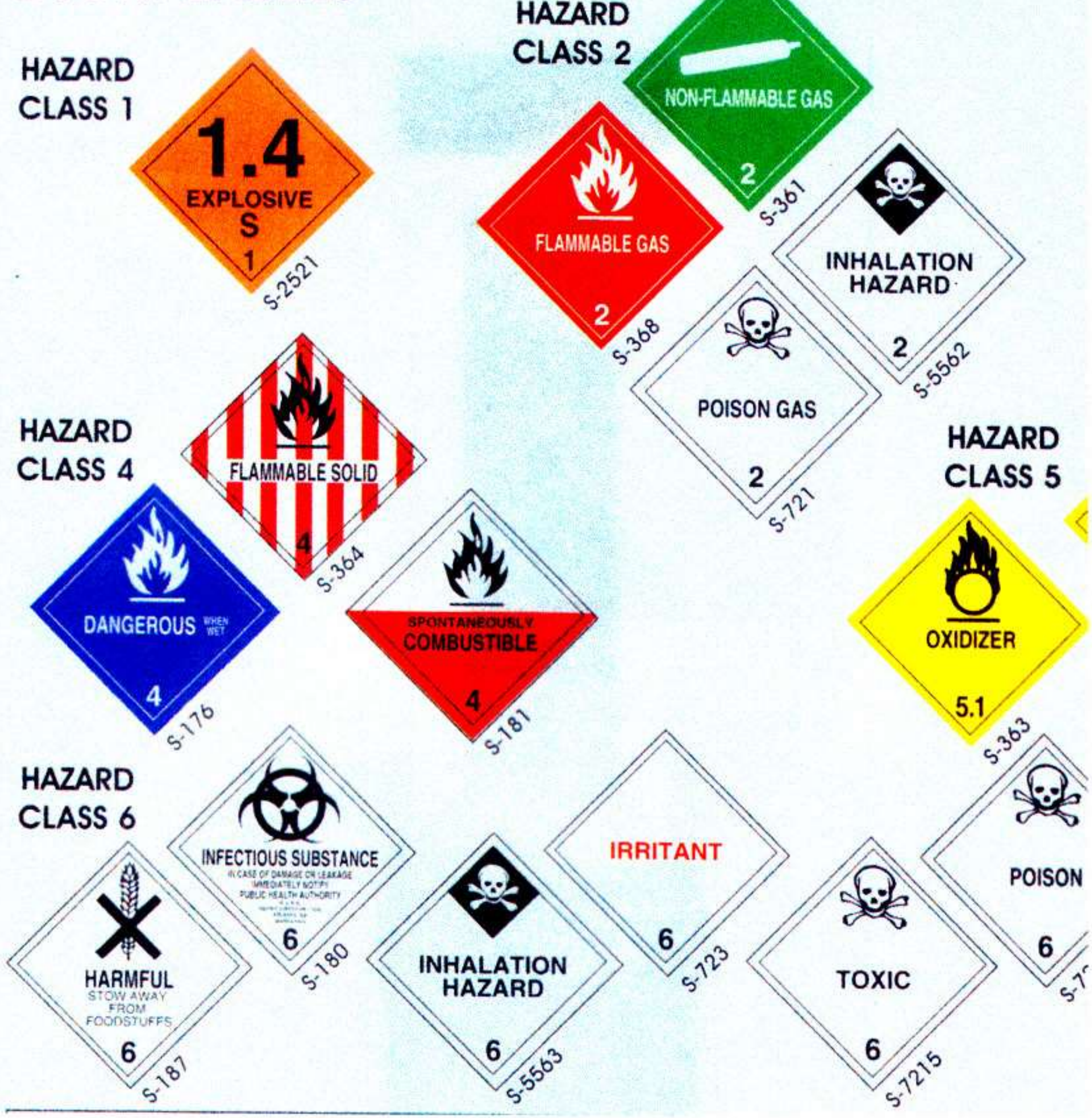


TABLE OF PLACARDS AND INITIAL
USE THIS TABLE ONLY IF MATERIALS CANNOT BE SPECIFICALLY IDENTIFIED BY
RESPONSE GUIDE TO USE ON-SCENE
USING THE SHIPPING DOCUMENT, NUMBERED PLACARD, OR ORANGE PANEL NUMBER
111
DANGER
DANGEROUS
112
EXPLOSIVES
114
1.4
1.5
BLASTING AGENTS
1.6
121
NON-FLAMMABLE GAS
118
FLAMMABLE GAS
123
TOXIC GAS
INHALATION HAZARD
127
COMBUSTIBLE
FLAMMABLE
122
OXYGEN
128
FUEL OIL
Page 16
134
FLAMMABLE SOLID
136
139
DANGEROUS
143
OXIDIZER
148
ORGANIC PEROXIDE
153
TOXIC
POISON
CORROSIVE
158
163
RADIOACTIVE
171
DANGER
DO NOT ENTER
INHALATION HAZARD
MARINE POLLUTANT
Page 17

D.O.T. LABELS



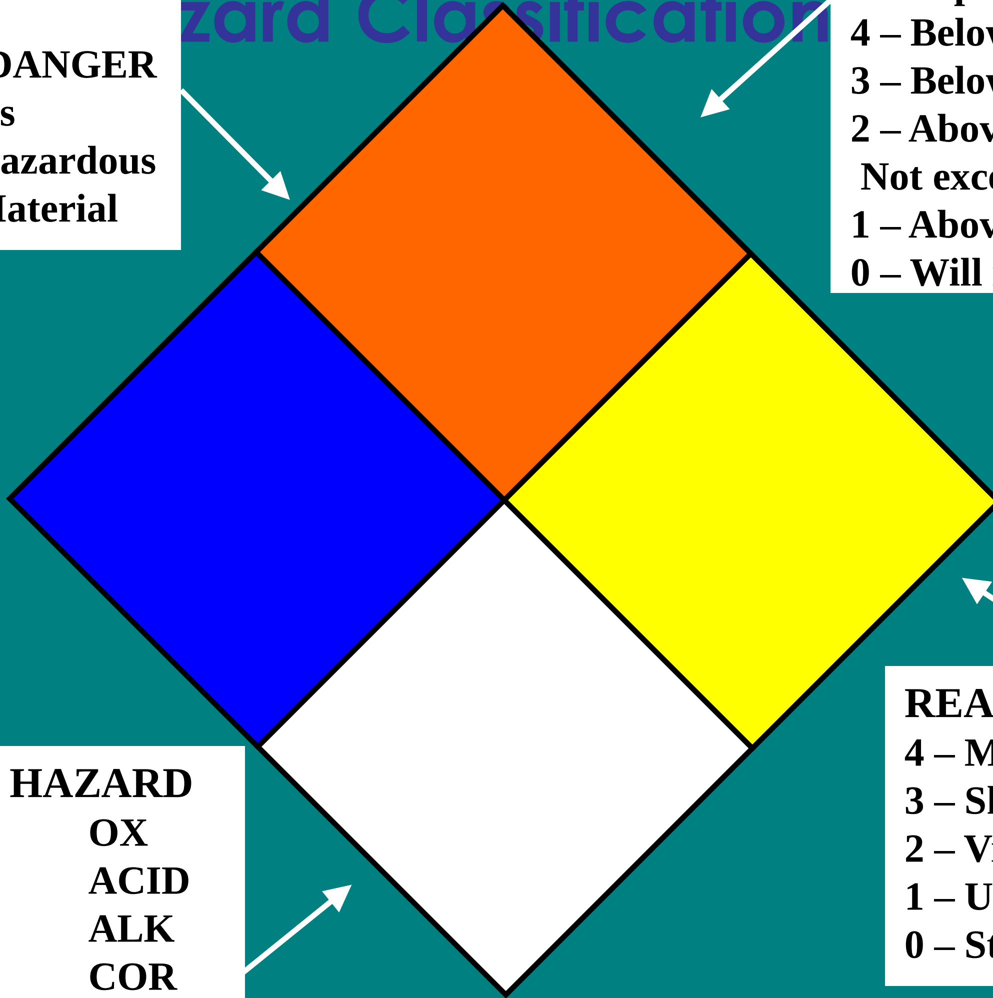
HAZARD CLASS 1
1.4
EXPLOSIVE
S
1
S-2521
HAZARD CLASS 2
NON-FLAMMABLE GAS
2
S-361
FLAMMABLE GAS
2
S-368
INHALATION HAZARD
2
S-5562
POISON GAS
2
S-721
HAZARD CLASS 4
FLAMMABLE SOLID
4
S-364
DANGEROUS WHEN WET
4
S-176
SPONTANEOUSLY COMBUSTIBLE
4
S-181
HAZARD CLASS 5
OXIDIZER
5.1
S-363
HAZARD CLASS 6
INFECTIOUS SUBSTANCE
6
S-180
HARMFUL
STOW AWAY FROM FOODSTUFFS
6
S-187
INHALATION HAZARD
6
S-5563
IRRITANT
6
S-723
TOXIC
6
S-7215
POISON
6

HEALTH	3
FLAMMABILITY	0
REACTIVITY	1
PERSONAL PROTECTION	J

zard Classification

HEALTH HAZARD
- 4 – Deadly
- 3 – Extreme DANGER
- 2 – Hazardous
- 1 – Slightly Hazardous
- 0 – Normal Material

FIRE HAZARD
Flash points
- 4 – Below 73°F
- 3 – Below 100°F
- 2 – Above 100°F, Not exceeding 200°F
- 1 – Above 200°F
- 0 – Will not burn



REACTIVITY
- 4 – May detonate
- 3 – Shock & heat may detonate
- 2 – Violent chemical change
- 1 – Unstable if heated
- 0 – Stable

SPECIFIC HAZARD

Oxidizer	OX
Acid	ACID
Alkali	ALK
Corrosive	COR
Use No Water	W
Radioactive	

DOT Hazard Classifications

Class 1 - Explosives

Division 1.1	Explosives with a mass explosion hazard
Division 1.2	Explosives with a projection hazard
Division 1.3	Explosives with predominantly a fire hazard
Division 1.4	Explosives with no significant blast hazard
Division 1.5	Very insensitive explosives; blasting agents
Division 1.6	Extremely insensitive detonating articles

Class 2 - Gases

Division 2.1	Flammable gases
Division 2.2	Non-flammable, non-toxic* compressed gases
Division 2.3	Gases toxic* by inhalation
Division 2.4	Corrosive gases (Canada)

Class 3 - Flammable liquids (and Combustible liquids [U.S.])

Class 4 - Flammable solids; Spontaneously combustible materials; and Dangerous when wet materials

Division 4.1	Flammable solids
Division 4.2	Spontaneously combustible materials
Division 4.3	Dangerous when wet materials

Class 5 - Oxidizers and Organic peroxides

Division 5.1	Oxidizers
Division 5.2	Organic peroxides

Class 6 - Toxic* materials and Infectious substances

Division 6.1	Toxic* materials
Division 6.2	Infectious substances

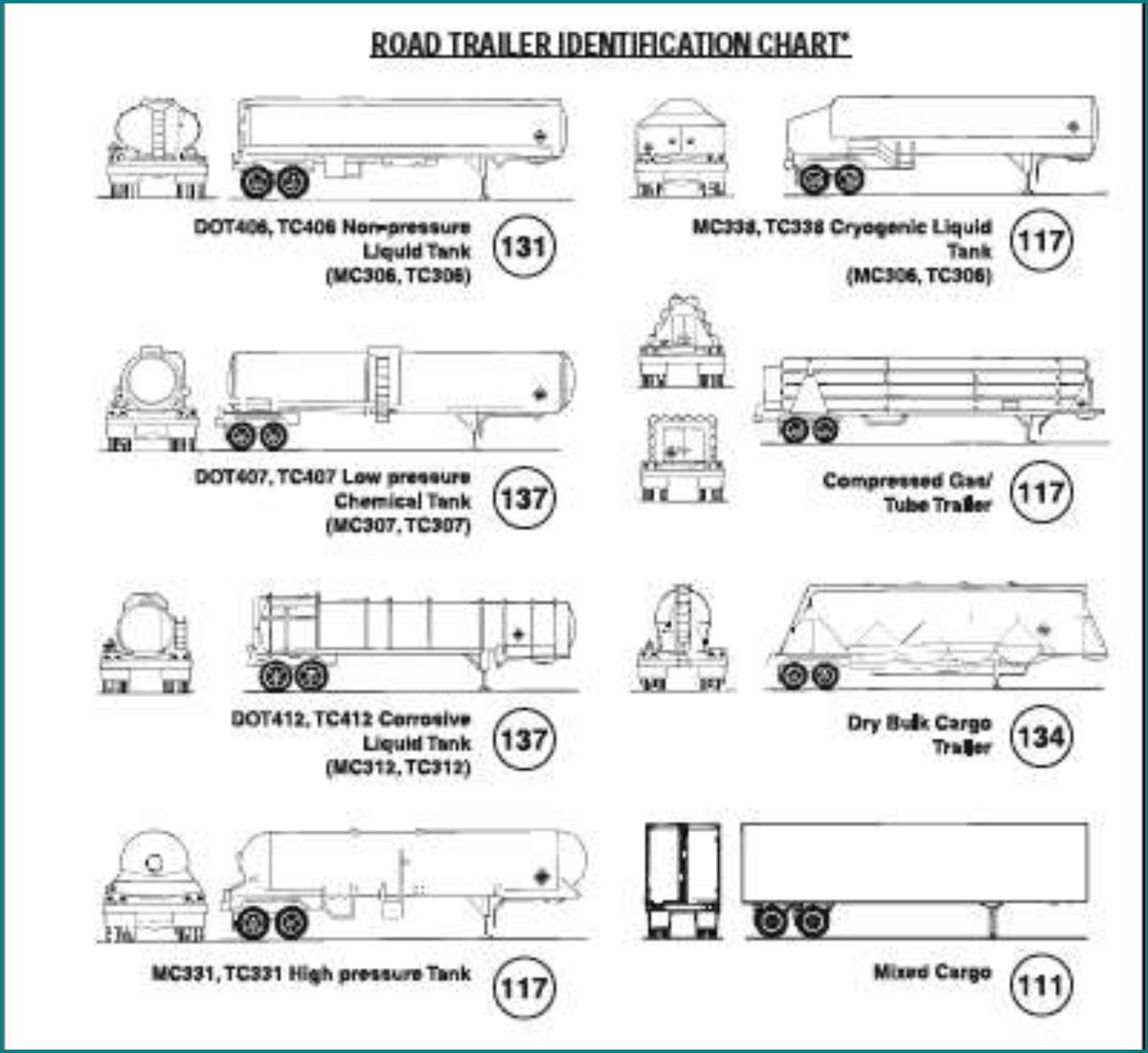
Class 7 - Radioactive materials

Class 8 - Corrosive materials

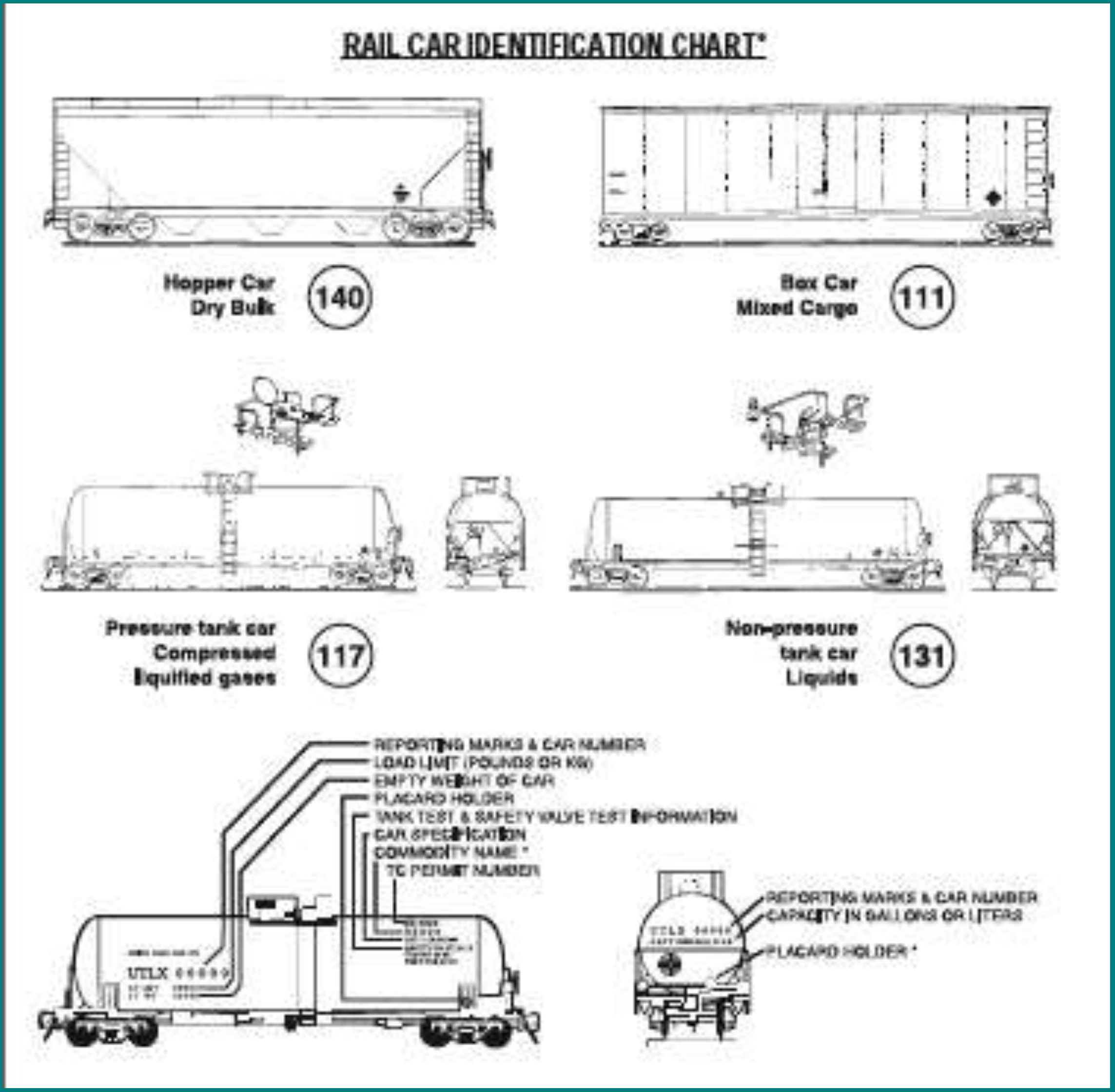
Class 9 - Miscellaneous dangerous goods

Division 9.1	Miscellaneous dangerous goods (Canada)
Division 9.2	Environmentally hazardous substances (Canada)
Division 9.3	Dangerous wastes (Canada)

Road Trailer Identification Chart



Train Car Identification Chart



Hazardous Materials Transportation

Risk Management

PROGRAM

THE FOLLOWING BRIEFING PROVIDES A CONCISE OVERVIEW OF THE HAZARDOUS MATERIALS TRANSPORTATION SAFETY PROGRAM

Risk Based Decision Making in the Hazardous Materials Safety Program

U.S. Department of Transportation
Research and Special Programs Administration

July, 1998

U.S. DOT - Risk Management

Federal Hazardous Materials Transportation Law

"The Secretary of Transportation shall designate material or a group or class of material as hazardous when the Secretary decides that transporting the material in commerce in a particular amount and form may pose an unreasonable risk to health and safety or property."

U.S. DOT - Risk Management

Federal Hazardous Materials Transportation Law, cont.

"The Secretary shall prescribe regulations for safe transportation of hazardous materials in intrastate, interstate and foreign commerce."

U.S. DOT - Risk Management

The Resulting Hazardous Materials Safety Program and Regulations:

- Are risk based
- Use data, information, and experience to define hazardous materials and manage the risk hazardous materials present in transportation
- Are prevention oriented

U.S. DOT - Risk Management

The Hazardous Materials Program is a Risk Management System that is:

- Focused on identifying and communicating hazards and risks
- Designed to reduce the probability and quantity of a hazardous material released and mitigate release consequences

U.S. DOT - Risk Management

The Hazardous Materials Program is a Risk Management System that is:

- Designed to address a very broad set of hazardous materials, all modes of transport (except bulk marine and pipeline) and all routes
- A minimum standard which does not specifically address all risk management parameters a shipper or carrier may need to employ in its risk management program

U.S. DOT - Risk Management

Risk Management is the systematic application of policies, practices and resources to the assessment and control of risk affecting human health and safety and the environment. Hazard, risk and benefit/cost analysis are used to support development of risk reduction options, program objectives, and prioritization of issues and resources. Performance measures are monitored to support performance evaluation.

U.S. DOT - Risk Management

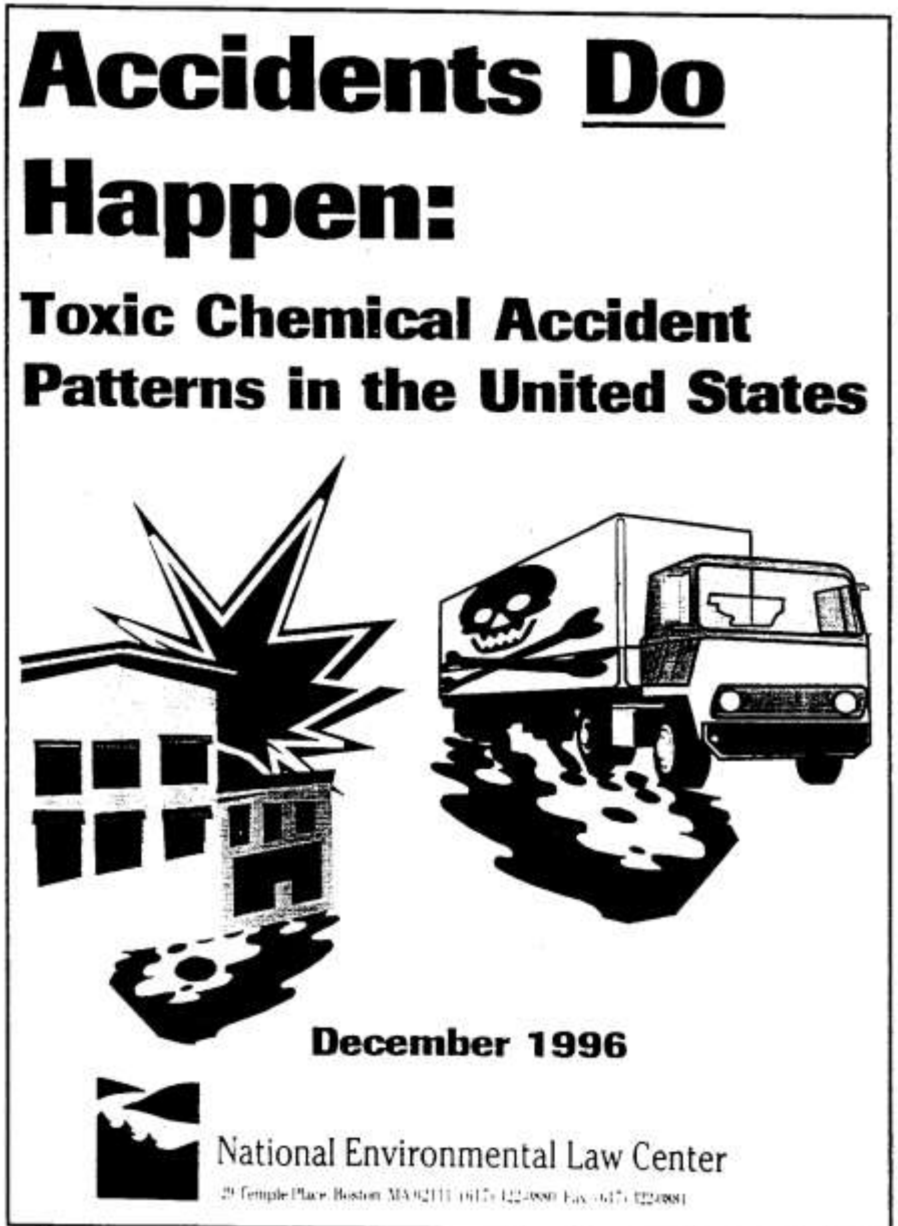
Program Elements:

<u>Risk Assessment</u> --Addresses Hazards, Consequences, and Probability in Hazardous Materials Transportation:

- **Classification system is a hazard analysis system. (Explosives, Flammable Gases, Oxidizers, Radioactive Material, Corrosives, Poisons, Infectious Substances, etc.)**

- **Consequences and probability are addressed by:**

  Hazardous Materials Information System (DOT 5800.1)
  Commodity Flow Survey
  Chemical/Substance Manufacturing, Use, Transportation Studies
  Special Analysis (e.g., National Transportation Risk Analysis, Aircraft Cargo, Shipment Counts)
  Public Comments on Rulemakings


Accidents Do Happen:
Toxic Chemical Accident Patterns in the United States
December 1996
National Environmental Law Center