U.S. Department
of Transportation
Federal Railroad Administration

Hazardous Materials Transportation in Tank Cars

Analysis of Risks — Part I

Office of Research and Development
Washington D.C. 20590

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16. **Abstract**

This report covers the development of a methodology to evaluate the potential national public risk arising from the transportation of hazardous materials in tank cars on the US Railroads. The analysis is intended to assess the relative changes in the overall risk when (structural) safety devices are provided on tank cars. Also the relative risks of transporting different chemicals in a specified DOT class tank car can also be determined.

An analysis of tank car accident data (maintained by the Railway Progress Institute and the Association of American Railroads) was made and statistics on tank car puncture sizes were developed. The hole size probability distribution was found to be similar for all DOT class tank car. The average puncture diameter was found to be 0.35 m and 0.29 m, respectively, for DOT 111 A and DOT 105 tank cars. No significant correlations were found between hole size and train speed; however, the provision of head shields and shelf couplers reduced the hole size.

The risk model developed takes into account the characteristics of tank cars, the puncture probability, properties of the hazardous material released and its behavior in the environment, occurrence of the accident in different population density areas under different types of weather conditions at the time of the accident, etc. Toxicity, fire and explosion behavior of the chemicals have been considered. The focus of application of the model has been to the transportation of poison-by-inhalation (PIH) and flammable materials.

The results of the risk assessment model have been presented as a matrix of frequency and consequence classes indicated by MIL standard 882 B. It is seen that the transportation of PIH in highly protected, higher strength tank cars, such as the DOT 105, provides about an order of magnitude reduction in the overall public risk compared to the transportation of the same material in DOT 111 A class of tank car.

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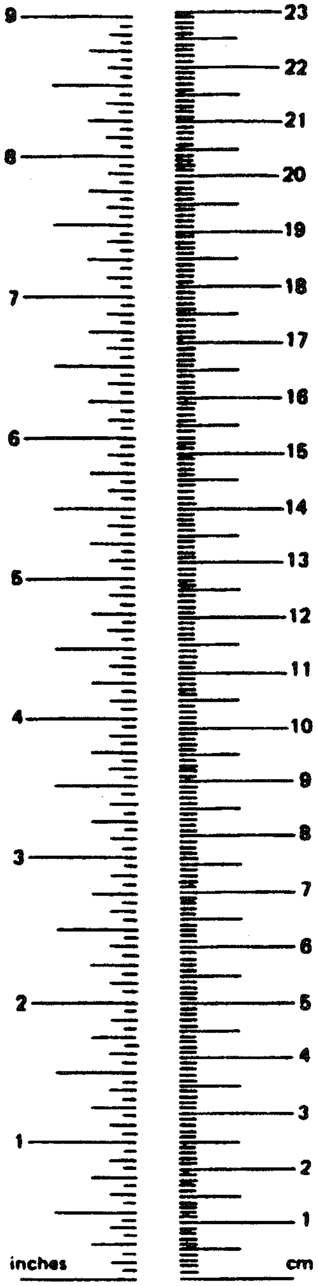
METRIC CONVERSION FACTORS

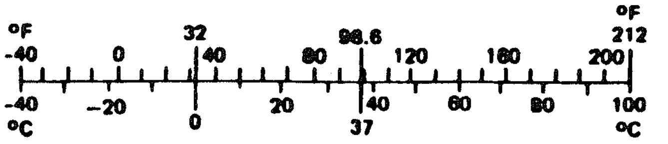
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.50	centimeters	cm
ft	feet	30.00	centimeters	cm
yd	yards	0.90	meters	m
mi	miles	1.60	kilometers	km
		AREA		
in^2	square inches	6.50	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.80	square meters	m^2
mi^2	square miles	2.60	square kilometers	km^2
	acres	0.40	hectares	ha
		MASS (weight)		
oz	ounces	28.00	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.90	tonnes	t
		VOLUME		
tsp	teaspoons	5.00	milliliters	ml
Tbsp	tablespoons	15.00	milliliters	ml
fl oz	fluid ounces	30.00	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.80	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.40	inches	in
m	meters	3.30	feet	ft
m	meters	1.10	yards	yd
km	kilometers	0.60	miles	mi
		AREA		
cm^2	square centim.	0.16	square inches	in^2
m^2	square meters	1.20	square yards	yd^2
km^2	square kilom.	0.40	square miles	mi^2
ha	hectares (10,000 m^2)	2.50	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.10	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	36.00	cubic feet	ft^3
m^3	cubic meters	1.30	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32	Fahrenheit temperature	°F



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* 1 in. = 2.54 (exactly)

Acknowledgment

This project was performed by Technology & Management Systems, Inc ("TMS") under the contract number DTFR53-91-C-00003 from the Federal Railroad Administration of the U.S. Department of Transportation. Mr. Jose Pena of the Equipment and Operating Practices Research Division (RDV-32) was the Contracting Officer's Technical Representative monitoring the technical work on this project. Dr. Phani K. Raj of TMS was the project manager and principal investigator of this study. In addition, the project team consisted of Mr. Clayton Turner, III and Mr. Jason Herrick. The report was typed by Ms. Tamara DeGray.

TMS and the project team extend sincere thanks to Mr. Jose Pena for many valuable suggestions and technical assistance he provided the team throughout the performance of this project. He was helpful in arranging for TMS to receive valuable technical assistance from the Association of American Railroads (AAR). We also extend our thanks to AAR for providing TMS with the tank car accident data. Mr. Earl Phillips of AAR, Chicago, needs special thanks for his help in processing the AAR/RPI database on tank car accidents and providing TMS data in a format useful for this study. This project would not have been a success if it were not for Mr. Phillips' commitment and interest in this project and the extra effort he put in (once he even cut short his vacation in Florida for this purpose) to speed up the approval process within AAR to get the data to us as quickly as possible.

We acknowledge with thanks many stimulating technical discussions the team members have had with Mr. James Rader of the FRA, Office of Safety. He helped us clarify many issues related to tank car regulations. Our thanks also are due to Mr. James O'Steen of the Hazardous Materials Division of RSPA for his helpful suggestions on different risk analysis approaches. The willingness, enthusiasm and timely help of Dr. Tony Policastro of Argonne National Laboratories to share the chemical properties data at his disposal is gratefully acknowledged. Finally, but not the least TMS expresses its gratitude to Mr. Woodall of Union Tank Car Company who very willingly provided certain information on maximum tank car capacities for various chemicals.

EXECUTIVE SUMMARY

PURPOSE

The principal purpose of the study was to develop a rational risk analysis methodology with which the U.S. Federal Railroad Administration (FRA) can evaluate the potential risk to the public arising from the transportation of hazardous materials in tank cars on the nation's railroad systems. The same analysis is also intended to be used to assess the relative reduction in risk and improvement in safety in the transportation of a hazardous material if a different tank car is used which has additional safety features compared to the tank car(s) authorized under current regulations.

A secondary purpose was to review the 49 CFR and HM-181 Regulations related to the bulk transport of hazardous materials in rail tank cars and evaluate any deficiencies.

Technology & Management Systems, Inc. (TMS) conducted this study on behalf of the Office of Research & Development of FRA. The study was initiated in January 1991 and technical analyses were completed in September 1992.

BACKGROUND

The National Transportation Safety Board (NTSB), in many of its reports, has recommended that risk analysis studies be performed to assess the adequacy of current regulatory requirements related to the container and lading compatibility. In a recent (1989) report, NTSB recommended that the Secretary of US DOT:

> Evaluate present safety standards for tank cars transporting hazardous materials by using safety analysis methods to identify the unacceptable levels of risk and the degree of risk from the release of hazardous material, and then modify existing regulations to achieve an acceptable level of safety of each product/tank car combination (Class II, Priority Action) (R-89-80).

The NTSB, in a letter dated 12 February, 1990 to the Secretary of Transportation, identified several important issues that needed to be addressed in regard to hazardous materials transportation in general, and tank car safety standards, in particular. The letter specifically recommended that the analyses be performed to:

- Evaluate and prescribe an acceptable level of risk;
- Determine the risk levels associated with the release of lading from a container in an accident;
- Assess the degree of protection needed to reduce identified risks to an acceptable level; and
- Modify existing regulations to achieve an acceptable level of safety for the transportation of all hazardous materials.

In 1991 the NTSB issued a report in which the Board recommended that US DOT modify existing regulations to disallow the transportation of flammable gases and toxic materials in DOT 111A class tank cars.

The Federal Railroad Administration concurs with the NTSB's recommendation to conduct safety studies using risk analysis methodology and the review of the tank car regulations. This study was initiated by the FRA to develop a risk assessment methodology to evaluate the relative safety of different classes of tank cars in transporting hazardous materials on rail.

CURRENT REGULATIONS

Current federal regulations governing the shipment of hazardous materials in tank cars on the U.S. railroad system are found in Title 49 of the Code of Federal Regulations (49 CFR). These regulations are the result of development of good acceptable practices in hazardous materials transportation, numerous modifications, additions and amendments over many decades. Because of this long history of development these regulations tend to be complex and difficult to use.

In order to correct many of the deficiencies (related to safety, complexity, inflexibility of packaging standards and incongruities between the U.S and international regulations) in the hazardous material transportation regulations, the FRA and the Research and Special Programs Administration (RSPA) have issued new regulations, under docket HM-181. These rules entitled, "Performance Oriented Packaging Standards: Miscellaneous Proposals" were published in the Federal Register on 21 December 1990. A revision document was issued in the Federal Register on 20 December 1991. Various provisions of the HM-181 Regulations are phased in over a period of 1 October 1991 to 1 October 1996 by which time all of the regulations will be in effect. The requirements governing hazard classification and communication for new explosives, and for the identification of poison by inhalation (PIH) materials on shipping papers came into effect on 1 October 1991.

49 CFR Part 173 of Regulations as amended by HM-181 specify the requirements for tank cars to transport different classes of hazardous materials and lists the authorized classes of tank cars for these hazardous materials. Specifically, these regulations relate to the strength of the tank car and relief valve pressure ratings.

STUDY APPROACH

This study was conducted in three different phases:

1. Review of the tank car regulations;
2. Collection and analysis of historical tank car accident data; and
3. Development of a risk assessment methodology. The risk methodology was exercised to determine the potential single tank car national risks arising from the transport of five example chemicals in two different classes of tank cars.

Hazardous materials which meet the definition of PIH and Flammable materials were the focus of this study.

Review of Regulations

As a part of its regulations review, TMS developed a database of different PIH and flammable materials and the corresponding authorized tank cars. It was found that only two PIH chemicals, namely, ethylene oxide and methyl bromide, are allowed to be transported in DOT 111A class tank cars. Not all of the PIH materials authorized are actually transported on the US railroad system, in bulk.

The review of hazardous materials regulations included those contained in 49 CFR Parts 172, 173, 174 and 179 applicable to rail tank car transportation prior to HM-181. Special emphasis was placed on Parts 173 and 179 dealing with container/lading relationships. The principal focus of this review was on identification of inconsistencies and conflicting requirements within 49 CFR and the HM-181 amendment. Several inconsistencies that were found during the initial part of this study were corrected in the HM-181 revisions issued in December 1991. Most of these related to the bulk packaging tank car authorizations and authorizations prescribed in the special provisions.

Temperature dependent thermodynamic property data for a number of PIH and flammable chemicals were gathered from public sources. Detailed calculations were also performed to compare the relief valve set-to-discharge pressure rating on various tank cars and the vapor pressures of the chemicals carried in them. For most of the compressed liquefied gases the ratio of valve set-to-discharge pressure to the chemical vapor pressure at reference temperature ranged from 1.00 (for perchloryl fluoride), and 1.06 (sulfuryl fluoride and anhydrous ammonia) to 22.5 (nitrogen tetroxide).

Tank Car Accident Data Analysis

Historical data on tank car accidents and the extent of damage sustained by the cars are maintained jointly by the American Association of Railroads (AAR) and the Railway Progress Institute (RPI). Data on the performance of specific classes of tank cars in accidents were requested from AAR. The following types of data requested by TMS were extracted by AAR from the tank car accident database for the period 1965-1988.

- Number of tank cars sustaining different degrees of damage (leading to the release of lading) by the magnitude of the puncture size, by the speed of the train prior to accident and by the class of tank car involved.

- Ratio of the number of tank cars releasing lading to the number damaged in derailment accidents, during the period 1965-1988, classified according to the safety improvements present on the cars.

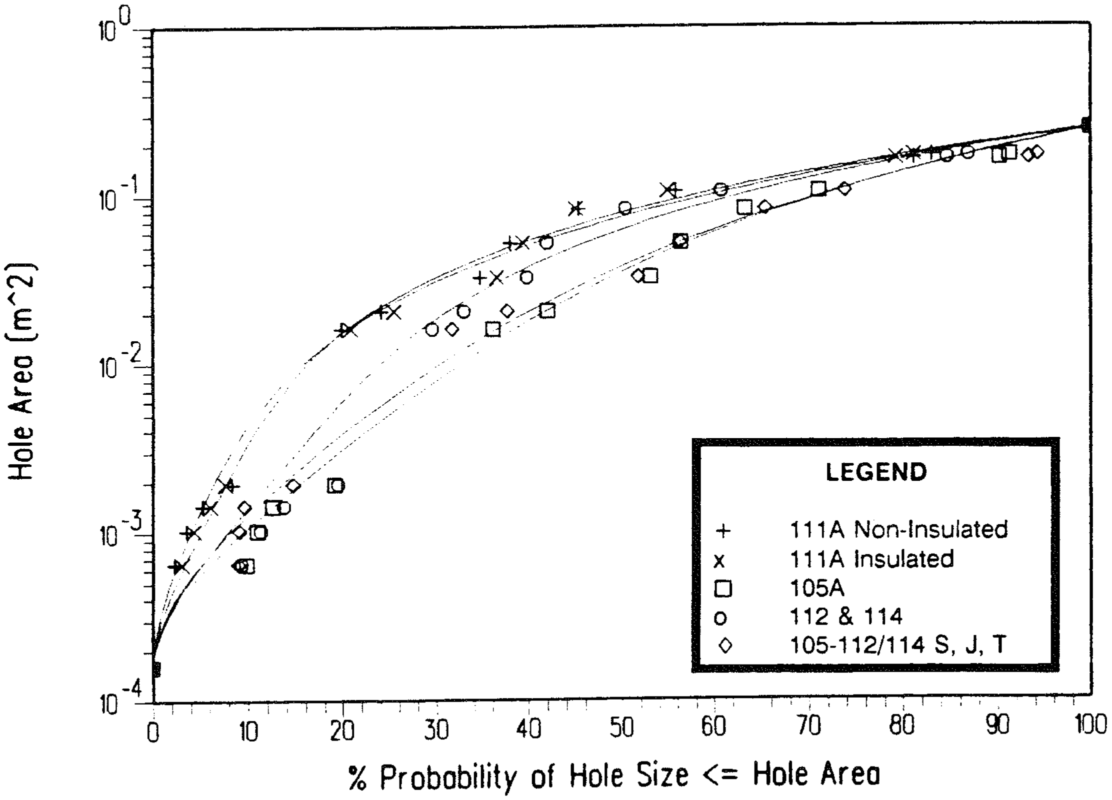
The puncture data in the tank car accident database are categorized into several hole shapes encompassing different sizes. These puncture data were analyzed and expressed in the form of probabilities of occurrence of different puncture sizes (hole areas) on a continuous scale. The release probabilities obtained from the data were coded into a program for easy evaluation based on specified tank car class and safety appurtenances. The relationship between puncture size and train accident speed was also examined.

The analysis of the tank car puncture data shows that hole sizes vary from equivalent diameters of 0.15 cm to about 0.56 m. The latter is about one-fourth the diameter of the shell of a tank car. The size of hole vs probability of occurrence of a hole of size equal to or smaller than a specified size is indicated in Figure Ex.1. It is seen that, in general, the hole size probability distribution is similar for all tank cars studied and that there is not a very significant difference in the average hole size between the DOT 111A type car (with mean size of 0.35 m in diameter) and the sturdier DOT 105 car (mean hole diameter 0.29 m).

It was also found that there are no statistically significant correlations between the hole size on tank cars and the train speed before the accident.

FIGURE Ex.1

Cumulative Probability vs. Hole Area



Risk Model

A risk model, in the context of rail transport of hazardous materials seeks to provide an answer to the question:

> What is the annual probability of exposing a specified number of people in the United States to the harmful effects of a hazardous material due to its release from tank cars involved in rail accidents?

The risk assessment model calculates two distinct sets of parameters which together constitute risk to the public from chemical releases. These are (i) the occurrence probabilities of a sequence of different events which leads to the exposure of certain sections of population to the harmful effects of a chemical and (ii) the extent to which the chemical is harmful. The second parameter in the risk equation indicates the degree or the severity of the accident and, therefore, has a bearing on the number of people exposed.

Probabilities of Occurrence of Accident Events

In the development of the risk model, the approach taken in this study was to identify the probabilities of the various types of events. These included the probability of a tank car being derailed and suffering damage, the conditional probability that the damaged car leaks the chemical, the probability the size of the hole of a given size for a punctured car, the probability of occurrence of the release accident in a given weather condition and in a locality with a specified magnitude population density. These conditional probabilities are calculated for a number of accident, weather and locality conditions.

Hazardous Material Behavior Types

The severity of the accident is determined by the size of the hole in the tank car, nature of the chemical, hazardous behavior type exhibited by the chemical and environmental conditions. Four types of hazardous chemical behavior have been postulated; these include,

- formation of a plume or a large down wind moving cloud of toxic vapors. This phenomenon poses toxic exposure threat to the population down wind of the release location.

- development of a pool of flammable liquid on the ground near the tank car, ignition and burning of the liquid pool in the form of a large turbulent pool fire. This poses a thermal radiation hazard to the persons exposed to the fire.

- ignition and burning of a flammable vapor cloud, the flammable vapor-air mixture being ignited at some down wind point. This type of fire poses a threat to all persons and objects who are within the path of the vapor fire.

- ignition and rapid burning of a vapor cloud that is partially or significantly confined. Such a phenomenon <u>may</u> lead to a vapor cloud detonation.

Not all chemicals pose all of the above types of hazards. In fact, most PIH chemicals only pose the toxic hazard. When a chemical poses multiple hazards the particular hazard posed in any given accident depends on both the chemical and the environmental conditions. In Table Ex.1 we have indicated our best estimates for the probabilities of the chemical posing different types of hazards once it is released from the tank car.

Chemical hazard behavior mathematical models available in the literature and coded into TMS' SAFEMODE computer code were used to determine the hazard areas for several chemicals for each type of hazard behavior. The areas calculated depend very strongly on the criteria used for the hazard level "exposure."

TABLE Ex.1

Conditional Probabilities of Multi Hazard Behavior of Selected Chemicals

CHEMICAL NAME	CHRIS CODE	HAZARD TYPE AND CHEMICAL PHASE	HAZARD CLASS OR DIVISION NO.	PROBABILITY OF DIFFERENT BEHAVIORS			
				TOXIC VAPOR	POOL FIRE	EXPLO-SION	VAPOR FIRE
Ammonia, Anhydrous (I)	AMA	Poison Gas	2.3	1.00*	0.00	0.00	0.00
Ammonia, Anhydrous (D)	AMA	Non-Flammable Gas	2.2	1.00	0.00	0.00	0.00
Chlorine	CLX	Poison Gas	2.3	1.00	0.00	0.00	0.00
Ethylene Dibromide	EDB	Poison Liquid	6.1	1.00	0.00	0.00	0.00
Ethylene Oxide	EOX	Poison Gas	2.3	0.50	0.10	0.20	0.20
Gasoline	GAT	Flammable Liquid	3	0.00	0.90	0.05	0.05
Hydrogen Chloride, Anhydrous	HDC	Poison Gas	2.3	1.00	0.00	0.00	0.00
Liquefied Petroleum Gas	LPG	Flammable Gas	2.1	0.00	0.05	0.30	0.65
Nitric Acid, Fuming	NAC	Corrosive	8	1.00	0.00	0.00	0.00
Sulfuric Acid, Fuming	SFA	Corrosive	8	1.00	0.00	0.00	0.00
Sulfur Dioxide	SFD	Poison Gas	2.3	1.00	0.00	0.00	0.00
Sulfur Trioxide	SFT	Corrosive	8	1.00	0.00	0.00	0.00
Vinyl Chloride	VCM	Flammable Gas	2.1	0.00	0.70	0.10	0.20
Xylene	XLM	Flammable Liquid	3	0.00	0.50	0.50	0.00

Note: Above values do not represent relative ranking among materials. Above values were developed by TMS based on intuitive engineering judgement.

*Ammonia vapors mixed with air can burn under special circumstances including partial or full confinement of the gases. Results from field experiments indicate that ammonia vapors do not burn in the open, much less explode. Since the scenarios of concern to this study are tank car releases in the open, the burning characteristics of ammonia vapors are ignored.

Exposure Criteria for Chemical Hazards

The criteria for chemical hazard exposure used in this risk assessment study are those which are generally recognized to be the threshold levels of chemical effects, i.e., a person exposed for a relatively short duration of time will not suffer any serious permanent or irreparable injury. Literature is full of conflicting and confusing criteria for the "tolerable concentrations" of human exposure to toxic chemical vapors. Similarly, it is uncertain what level of thermal radiation heat flux can be considered "safe" for exposing human beings to short duration fires resulting from accidents. The value of tolerable level in each of toxic and thermal exposures is a highly nonlinear function of the duration of exposure.

In the case of toxic vapor exposure we have used the Immediately Dangerous to Life & Health (IDLH) concentration values published by the National Institute of Occupational Safety & Health (NIOSH) as the toxic exposure criterion. This value is properly adjusted for duration of exposure as follows:

$$C_{TL} = \begin{cases} 2 * C_{IDLH} & \textit{for } t_{\exp} < 15 \text{ min} \\ (30/t_{\exp}) * C_{IDLH} & \textit{for } 15 \le t_{\exp} \le 60 \text{ min} \\ 0.5 * C_{IDLH} & \textit{for } t_{\exp} > 60 \text{ min} \end{cases}$$

where,

C_{TL} = Airborne concentration (toxic limit) for exposure (kg/m^3 or ppm)

C_{IDLH} = IDLH concentration for the chemical

t_{exp} = duration over which a person is exposed to a vapor cloud (with concentration greater than 0.5 x C_{IDLH})

The criteria used for other types of hazards include the thermal radiation level from fires indicated in 49 CFR, 193.2057. The criterion of hazard from vapor cloud explosions is puncture of the lung due to an over-pressure wave. The exposure threshold criteria for different types of hazards are indicated in Table Ex.2.

TABLE Ex.2

Exposure Criteria Values Used for Hazard Area Calculations

HAZARD TYPE	EXPOSURE CRITERION
Toxic Vapor Inhalation	0.5 * IDLH; IDLH; or 2 * IDLH
Pool Fire Thermal Radiation	Maximum exposure heat flux = 5 kW/m^2
Vapor Fire	Lower flammability limit concentration
Vapor Cloud Explosion	Threshold lung damage (6 psi over pressure)

RISK MODEL RESULTS

The risk results calculated by the model developed in this study are expressed in terms of the parameters specified in MIL-Standard 882B ("System Safety Program Requirements"). This is because the MIL Standard also provides guidance on the acceptability or non-acceptability of various risk categories.

The MIL Standard identifies four categories of severity, namely, catastrophic (I), critical (II), marginal (III), and negligible (IV). Similarly, the frequency of occurrence of detrimental events is classified into five (5) categories namely, frequent (A), probable (B), occasional (C), remote (D), and improbable (E). Broad definitions are provided as a guide to these classifications. Figure Ex.2 illustrates the "Risk Matrix" and the regions of various levels of acceptability of the system from a risk perspective.

The risk model developed in this study first calculates the numerical values of the probability of occurrence of tank car accidents resulting in chemical releases of different sizes and volumes. The numerical value of the population exposure is also calculated. Unfortunately, the MIL Standard does not provide any guidance as to the relationship between numerical probability values and its categories of frequency of occurrence nor is there any guide on the equivalence of numerical values of people exposure and the severity categories. Using best engineering judgment, TMS has developed Risk Category Equivalency Values for both probabilities and consequence categories to correspond with the MIL Standard categories. These are indicated in Table Ex.3a & Table Ex.3b.

In the risk calculations certain assumptions are made regarding the occurrence probabilities of the accident in different localities and the average population density in these "types" of localities. We have divided the nation into three representative population zones, namely, (i) rural, (ii) suburban, and (iii) urban. The approximate range of population densities in each of these regions assumed in this study are indicated in Table Ex.4. Also assumed is the probability of accidents occurring in these localities. These are based on the best estimate of the length of miles of mainline rail track passing through these localities. It is also assumed that the accident rate per unit length of track is independent of its location. Figure Ex.3 shows the resulting distribution of mainline derailment accidents in various locations in the U.S.

FIGURE Ex.2

Risk Assessment Matrix

FREQUENCY OF OCCURRENCE	UNDESIRED EVENT CATEGORIES			
	I CATASTROPHIC	II CRITICAL	III MARGINAL	IV NEGLIGIBLE
(A) FREQUENT	IA	IIA	IIIA	IVA
(B) PROBABLE	IB	IIB	IIIB	IVB
(C) OCCASIONAL	IC	IIC	IIIC	IVC
(D) REMOTE	ID	IID	IIID	IVD
(E) IMPROBABLE	IE	IIE	IIIE	IVE

<u>**RISK INDEX**</u>

IA, IB, IC, IIA, IIB, IIIA	■	UNACCEPTABLE
ID, IIC, IID, IIIB, IIIC	▤	UNACCEPTABLE (MANAGEMENT DECISION REQUIRED)
IE, IIE, IIID, IIIE, IVA, IVB	□	ACCEPTABLE WITH REVIEW BY MANAGEMENT
IVC, IVD, IVE	▥	ACCEPTABLE WITHOUT REVIEW

TABLE Ex.3a

Relationship Between Numerical Risk Values and MIL Standard 882B Categories Probability Categories

MIL STANDARD PROBABILITY CATEGORIES	NUMBER OF EVENTS ASSUMED TO OCCUR PER YEAR (NOTE 1)	MEAN FREQUENCY OF EVENTS #/YEAR (NOTE 2)	EVENTS OCCUR APPROXIMATELY ONCE IN	RATIO OF EVENT FREQUENCY TO THAT OF "FREQUENT"	
				RANGE	MEAN (NOTE 2)
Frequent	>500	500	a day	>1	1
Probable	10 - 500	70	a week	$2x10^{-2}$ to 1	$1.4x10^{-1}$
Occasional	1 - 10	3	a season	$2x10^{-3}$ to $2x10^{-2}$	$6.3x10^{-3}$
Remote	0.1 - 1	0.3	3 years	$2x10^{-4}$ to $2x10^{-3}$	$6.3x10^{-4}$
Improbable	0.01 - 0.1	0.03	30 years	$2x10^{-5}$ to $2x10^{-4}$	$6.3x10^{-5}$

TABLE Ex.3b

Relationship Between Numerical Risk Values and MIL Standard 882B Categories Severity Categories

MIL STANDARD CATEGORIES	NUMBER OF PERSONS EXPOSED		RATIO OF EXPOSURES TO CATASTROPHIC	
	RANGE (NOTE 1)	MEAN (NOTE 2)	RANGE	MEAN (NOTE 2)
Catastrophic	>1000	1000	>1	1
Critical	30 - 1000	170	0.33 to 1	$170x10^{-3}$
Marginal	1 - 30	6	10^{-3} to $3.3x10^{-1}$	$5.5x10^{-3}$
Negligible	≤1	<1	$<10^{-3}$	$<10^{-3}$

Note 1: TMS' definitions

Note 2: Represents the logarithmic mean of the extremum values of the range.

TABLE Ex.4

Census Population Density by Geographical Areas

AREA CATEGORY	NUMBER OF PERSONS RESIDING PER		LOG MEAN IN NUMBER PER SQ. KM. (SEE NOTE 3)	FRACTION OF TOTAL US MAINLINE TRACK MILES IN DIFFERENT REGIONS (%) (SEE NOTE 4)
	SQUARE MILE (SEE NOTE 1)	SQUARE km (SEE NOTE 2)		
Rural	25 - 300	10 - 100	30	80
Suburban	800 - 2,000	300 - 800	500	15
Urban/City Metro	8,000 - 12,000 (max. 65,000)	3,000 - 5,000 (max. 25,000)	4,000	4
Very Congested Cities	12,000 - 65,000	5,000 - 25,000	10,000	1

Note 1: TMS estimates based on US census data indicated in "County and City Data Book", US Bureau of Census, US Department of Commerce, 1988.

Maximum density refers to Manhattan, NY

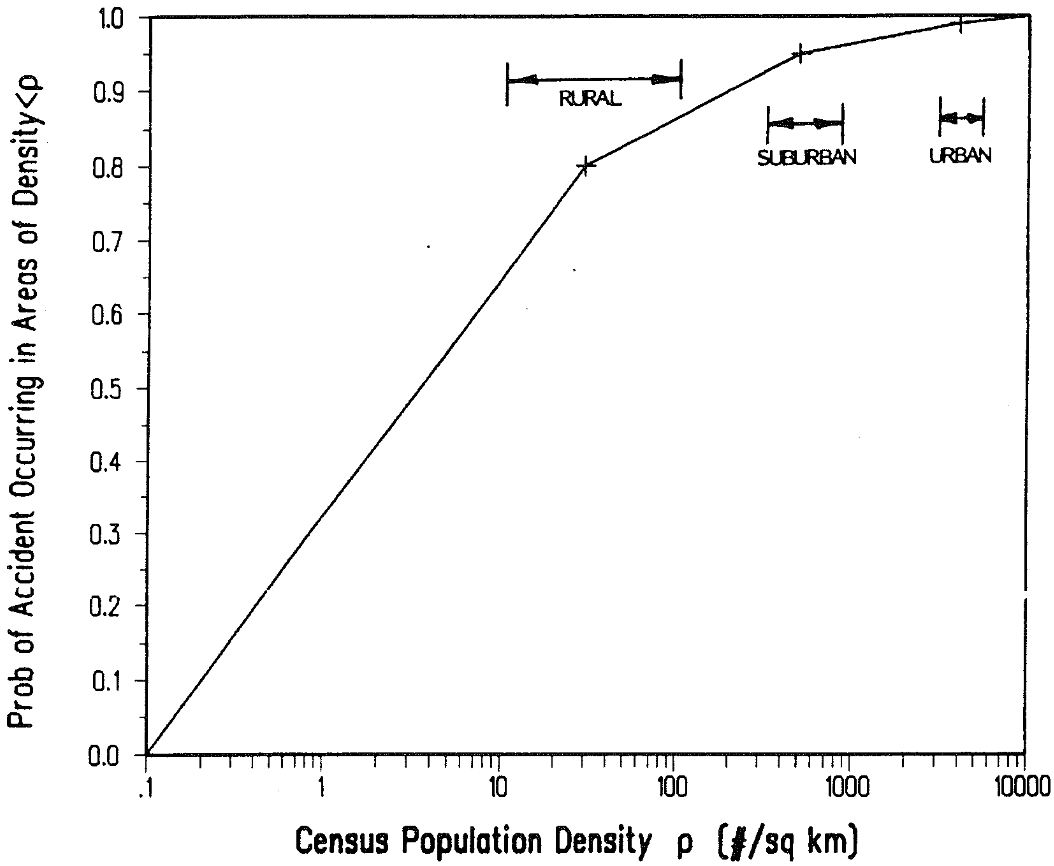
Note 2: Approximate values expressed in $\#/(\text{km})^2$

Note 3: Approximate values of the log mean. Log mean is the square root of the product of the range extremum values.

Note 4: TMS estimates based on the assumption that 80% of mainline track mileage is in rural areas, 15% in suburban, and 4% in cities. The very high population density areas may comprise 1% of track (an extremely conservative estimate).

FIGURE Ex.3

Probability Distribution of Mainline Accidents in Various Population Density Areas



Based on historical rail accident data published by the FRA we have estimated the average probability of a tank car being involved in a derailment accident and suffering damage. This probability is estimated from accident data for the period 1985 - 1990 and takes into consideration the number of hazardous material tank cars in service during this period. This probability number is estimated to be 3.85×10^{-3}.

The above event probabilities are used together with the results from the consequence analysis model to determine the overall probability of exposing a given number of persons. This is achieved by assuming the occurrence of a hole of a specific size on the tank car following a derailment accident. The probability of this hole size occurrence is recorded. Knowing the chemical in the tank car and its thermodynamic and other properties the release rate from this hole and the consequent hazard areas for the possible different types of hazards are determined under each assumed condition of weather. The probability of occurrence of the weather is noted. The population exposed to each type of hazard is calculated assuming the accident to take place in each of the three locality types. The probabilities of the accident occurring in each of the localities are noted. Then the overall probability of the accident occurring and exposing a specific number of persons is calculated by multiplying all of the conditional probabilities. The corresponding exposure values are noted as well. The calculations are repeated for a number of tank car hole sizes within the range of sizes discussed earlier. The results are organized by increasing values of exposures. The probabilities and the exposure values are then plotted in the form of the MIL Standard risk parameters.

Figure Ex.4 shows a risk profile plot presented in MIL Standard risk categories for ethylene oxide. Ethylene oxide is a PIH material authorized under HM-181 for continued transportation in DOT 111A100W4 and DOT 111J100W tank cars. The figure shows the results for transportation in an unprotected DOT 111A tank car and in a DOT 105J500W tank car. The risk results shown are the national risk values for a single tank car transportation. Similar single tank car national risk results for the rail transportation of gasoline, a flammable material, are indicated in Figure Ex.5. Gasoline is authorized to be transported in a number of different classes of tank cars including DOT 111A.

FIGURE EX.4

Single Tank Car Leak: ETHYLENE OXIDE National Risk Comparison for Different Car Classes

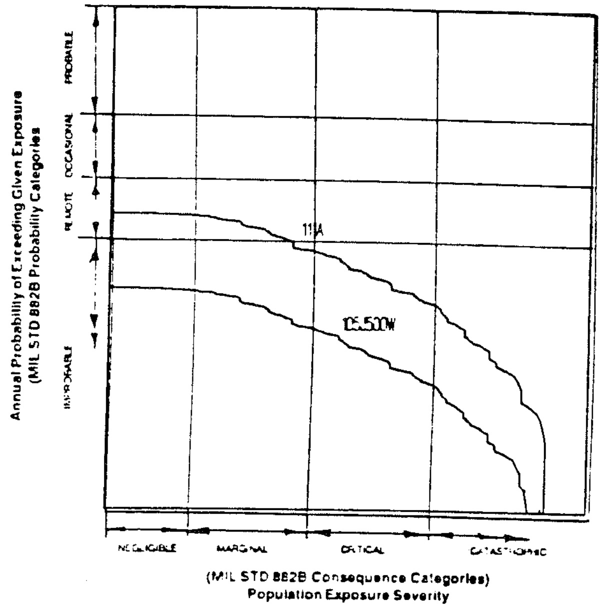
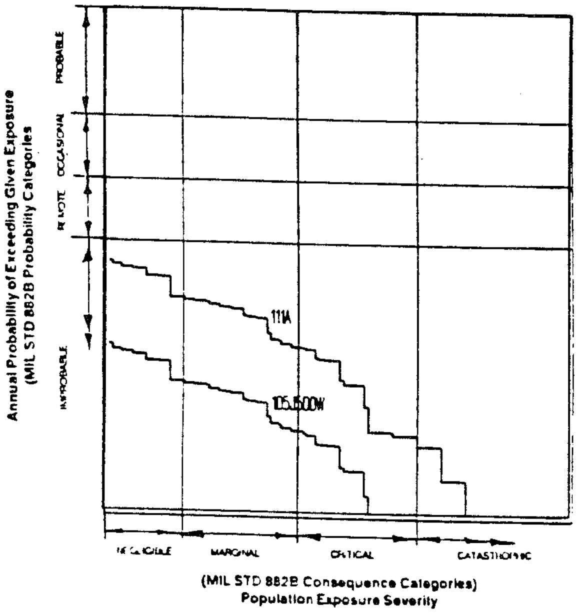


FIGURE EX.5

Single Tank Car Leak: GASOLINE National Risk Comparison for Different Car Classes



It is seen that, in general, there is an overall reduction of risk by about one MIL Standard probability category when a chemical which is normally transported in DOT 111A car is transported in a fully protected DOT 105 tank car. A reduction of one MIL Standard category is about an order of magnitude reduction in probability. The exposure category extends from the negligible to catastrophic; however it should be noted that catastrophic events are in the region of "extremely improbable." The risk curves are generally in the "improbable" to "remote" probability category.

There are substantial differences between the risks presented by a PIH material and a flammable material. First, the probability category decrease rate (with increased population exposure) is much higher in the case of a flammable material than for a PIH material. Second, the absolute level of risk probability is smaller for a flammable material. Third, the occurrence of "catastrophic" category of exposure is very rare in the case of flammable material.

The overall national risk from the transportation of each chemical can be obtained by multiplying the ordinate of each figure by the number of tank cars of the given class that are in service in a given year and which carry the designated chemical.

OVERALL FINDINGS FROM THE STUDY

1. Only two PIH materials are authorized under the HM-181 regulations for transportation in DOT 111A tank cars. These are ethylene oxide and methyl bromide.

Valve Settings

2. The ratio of valve set-to-discharge pressure to vapor pressure is considerably greater than one for sixteen of the eighteen PIH materials investigated. (The greater this value compared to unity the higher is the level of safety from over pressure discharge of the PIH chemical vapors into the atmosphere). Of the remainder, the ratio for Perchloryl Fluoride is unity and the ratio for Carbonyl Sulfide (1.02), Sulfuryl Fluoride (1.05) and Anhydrous Ammonia ranges from 1.06 to 1.08.

3. For liquid PIH materials and liquid flammable materials the ratio of valve set-to-discharge pressure to the vapor pressure is far higher than 1.

Tank Car Puncture Susceptibility in Accidents

4. Tank cars in mainline derailment accidents can sustain punctures varying in size from 1.5 cm equivalent diameter to 0.56 m equivalent diameter (large hole). The statistical mean size of holes range from about 0.35 m for DOT 111A cars to 0.29 m for DOT 105 cars.

5. There appears no correlation between the speed and the size of the puncture in the data examined. The standard deviation in hole area is larger than the mean hole area for almost all of the tank cars investigated.

Accident Probabilities & Exposure Areas

6. The rail accident data for the years 1985 - 1990 indicate that on the average <u>any</u> hazardous material tank car in service has a probability of 1.68×10^{-2} per year of being involved in a derailment accident and a 3.85×10^{-3} per year probability of being derailed and damaged. Probability of tank car being derailed <u>and</u> damaged may be reduced be selective tank car placement in a train consist. For an individual tank car, the value of this probability also depends on the distance the tank car travels in a year. The average probability of leak from a derailed and damaged tank car in a mainline accident is 15.74 %.

7. The release probability can be reduced by as much as a factor of 10 providing safety features such as head shields, shelf type of couplers, thermal insulation jackets and increased shell thickness.

8. Hazard areas arising from toxic vapor dispersion can be one to two orders of magnitude greater than those from fire thermal radiation, vapor fires or vapor explosions. However, these areas depend on the properties of the chemical, weather and other environmental conditions.

9. There is considerable uncertainty about what values are to be used for chemical hazard concentration levels in determining the population exposure hazard areas. The levels of risk predicted will depend, quite sensitively, on the values chosen for chemical concentrations which will constitute a "hazard" to people for short term exposure.

10. It is uncertain what fraction of the population within the area of hazard is actually affected by the detrimental effects of the chemical. There is information in the literature which indicates that the positive effects (of sheltering) provided by buildings, automobiles and of emergency evacuation action reduces the fraction exposed by as much as an order of magnitude.

Risk Results

11. In general, the low consequence risk values (expressed in annual probabilities of causing a level of exposure equal to or greater than the "negligible" category) for most PIH and flammable chemicals are within one order of magnitude of each other for transport in similar class of tank cars. However, the reduction in risk with increase in exposure level is significant with flammable materials compared to those from PIH materials due to the relatively smaller hazard area in the former chemicals.

12. The reduction in the single tank car risk between the transport of a chemical in a DOT 111A tank car and a DOT 105J500W tank car is approximately one order of magnitude for the same level of population exposure.

    The reduction in the most severe category of exposure risk is more pronounced in the case of flammable materials than in the case of PIH materials when the chemical is transported in a higher strength tank car.

13. The overall national risk depends on the number of tank car shipments in any given year transporting the specified chemical and the distance traveled by the tank cars.

CONCLUSIONS

The following conclusions can be drawn from the results of this study.

1. The adequacy of the safety provided by the currently authorized valve set-to-discharge pressure setting on tank cars in carbonyl sulfide, perchloryl fluoride, sulfuryl fluoride, and anhydrous ammonia services needs to be further investigated. The ratio of this valve set-to-discharge pressure to the vapor pressure of these PIH chemicals is very close to unity.

2. Transportation of hazardous materials in highly protected and higher strength cars such as DOT 105 class provides approximately an order of magnitude improvement in the probability part of the public risk over the transportation of the same material in an unprotected DOT 111A class tank car. These protections, however, will not reduce the exposure consequence should a large hole occur in the tank car.

3. The risk assessment model (and the associated computer program) developed in this study can be used very beneficially to evaluate the relative risks of transporting the same chemical in different classes of tank cars or to compare the relative risks posed by different chemicals. For example, gasoline is acceptable for shipment in either a DOT 111A or a DOT 105J tank car, using the system developed. For ethylene oxide, the DOT 105J is acceptable; the 111A is acceptable only with review. The 111A may be a candidate for an orderly transition to a car of greater integrity. Note: Present regulations provide that DOT 105J100W is acceptable for ethylene oxide service.

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CHAPTER 1

Introduction & Scope of Study

1.1 BACKGROUND

1.1.1 Hazardous Materials Transportation

Significant quantities of hazardous materials ("HazMat") are transported on the U.S. railroad system each year. The U.S. Department of Transportation (US DOT) through the Federal Railroad Administration (FRA), enforces the transportation of hazardous materials on the US railroads. Of the over 30,000 hazardous materials transported there are only a few hundred chemicals which are transported in bulk in tank cars.

In 1990 the total volume of transport of hazardous materials exceeded 1.4 million car loads. Hazardous materials are transported by rail in various types of rail cars, i.e., tank cars, covered hoppers, gondolas, box cars, and trailers and/or containers on flat cars (TOFC/COFC). About 72% of materials move in tank cars (AAR 1990) and about 77% of these account for 25 hazardous commodities which are used extensively as feed stock chemicals in process industries, in agriculture, as industrial solvents, and for other general purposes. Three of the chemicals in this top 30 commodities list meet the definition of Poison by Inhalation (PIH). Also, there are a number of flammable and combustible liquids and corrosive materials.

Rail accidents involving the release of hazardous chemicals are uncommon. Even more rare are accidents in which citizens are involuntarily exposed to the hazardous effects of chemicals resulting in injury or death. However, many accidents have occurred in which injuries (and in some incidents fatalities) have resulted. In some cases evacuation of a large number of people from the vicinity of accidents had to be undertaken to protect the public from the effects of chemicals where there were leaks of chemicals from tank cars or potential for releases after the accident. Both the Federal Government and the rail industry continue to conduct research to improve the safety in the transportation of hazardous chemicals in the United States. Enhancement of safety in the transportation of hazardous chemicals on rail have come from implementation of modifications in the operational, procedural, technical and hardware design aspects of railroading.

1.1.2 NTSB Reviews & Recommendations

Major rail accidents, especially those involving the release of hazardous chemicals and those resulting in injury and/or fatality (to both railroad personnel and public) are investigated by the National Transportation Safety Board (NTSB). In many of its reports the NTSB has recommended that risk analyses types of studies be performed to assess the adequacy of current regulatory requirements related to the container and lading relationships. For example, in a recent report (NTSB, 1989) recommended to the Secretary of US DOT to:

> Evaluate present safety standards for tank cars transporting hazardous materials by using safety analysis methods to identify the unacceptable levels of risk and the degree of risk from the release of hazardous material, and then modify existing regulations to achieve an acceptable level of safety of each product/tank car combination (Class II, Priority Action) (R-89-90).

In addition, the NTSB, in a letter dated 12 February, 1990 to the Secretary of Transportation, has pointed out several important issues needing attention in regard to hazardous materials transportation and tank car safety standards. Further more, the letter recommends that the DOT perform a risk analysis of HazMat transportation to evaluate the adequacy of the regulations in view of the significant changes that have occurred since these regulations were developed. The NTSB has specifically recommended that the following analyses be performed to:

- Evaluate and prescribe an acceptable level of risk;
- Determine the risk levels associated with the release of lading from a container in an accident;
- Assess the degree of protection needed to reduce identified risks to an acceptable level; and
- Modify existing regulations to achieve an acceptable level of safety for the transportation of all hazardous materials.

1.1.3 Current Regulations

Current DOT regulations are contained in Title 49 of the Code of Federal regulations (49 CFR) and these have been developed based on industry practice and experience. A need has arisen to review the adequacy and consistency of these regulations. This is because several of the factors have changed since the regulations were developed originally. These include (i) the age of these regulations, (ii) significant changes in both the volume of transport and degree of hazard represented by currently used industrial and agricultural chemicals, (iii) changes in demographics and, (iv) the deregulated environment in which the railroads are operating.

On April 15, 1982, RSPA published an Advance Notice of Proposed Rulemaking (ANPRM), entitled "Performance Oriented Packaging Standards: Miscellaneous Proposals," in docket number HM-181. Review of public comments eventually resulted in the Final Rule of HM-181 being published in the Federal Register on December 21, 1990 and the revision documentS issued on December 20, 1991 and October 1, 1992.

HM-181 compliance dates extend to October 1, 1996 by which time the entire HM-181 regulations will be in effect. The first date was October 1, 1991 for implementation of requirements governing hazard classification and communication for new explosives, and for the identification of PIH materials on shipping papers.

1.1.4 Impetus for Undertaking the Study Described

In a very recent report entitled, "Safety Study - Transport of Hazardous Materials by Rail" (NTSB, 1991), the National Transportation Safety Board has recommended to the Research and Special Programs Administration, U.S. DOT:

> Establish a working group, with the assistance of the Federal Railroad Administration, the Association of American Railroads, the Chemical Manufacturers Association, the American Petroleum Institute, and the National Fire Protection Association, to expeditiously improve the packaging of the more dangerous products (such as those that are highly flammable or toxic, or pose a threat to health through contamination of the environment) by (a) developing a list of hazardous materials that should be transported only in pressure tank cars with head

shield protection and thermal protection (if needed); and (b) establishing a working agreement to ship the listed hazardous materials in such tank cars. (Class II, Priority Action) (R-91-11) (Supersedes R-85-105)

In order to address the various issues raised by the NTSB in its various recommendations related to the hazardous material transportation in tank cars, the US Federal Railroad Administration Office of Research and Development contracted with Technology & Management Systems, Inc (TMS) to review recently passed HM-181 Regulations and to develop a risk assessment methodology that can be used for evaluating the relative safety performance of different tank cars in transporting hazardous chemicals. This report provides the details of the data collected, analyses performed, risk model developed, and the results obtained from the application of the risk model to a sample of chemicals.

1.2 OBJECTIVES

The objectives of this project were to:

- Conduct a review of the HM-181 and the hazardous materials Regulations pertaining to the transportation of hazardous materials in tank cars and assess the adequacy of tank car-chemical compatibility regulations.

- Develop a safety analysis/risk assessment methodology to evaluate the relative risks to the public from the shipments of hazardous chemicals in different classes of tank cars.

1.3 SCOPE OF THE STUDY

In order to achieve the above objectives the following tasks were performed. The scope of the study was focussed primarily on the materials meeting the definition of poison by inhalation (PIH) and the flammable materials since these pose the largest potential hazards to the public.

Task 1: Review of the current HazMat Regulations

In this task we reviewed the current 49 CFR and HM-181 Regulations pertaining to the rail transportation of hazardous materials. The review included regulations contained in 49 CFR parts 172, 173, 174 and 179. Special emphasis was on parts 173 and 179 which deal with container/lading relationships.

Task 2: Tank Car Lading Compatibility & Tank Car Damage Data

The primary work in this task related to the evaluation of the compatibility of a tank car with its lading and the susceptibility of the tank car to puncture in an accident. In the performance of the work in this task we conducted the following subtasks.

Subtask 2.1: The PIH and Flammable materials were identified and cataloged from the HM-181 regulations. These were then expressed in the form of a database of information on the chemical and the tank cars authorized to transport them in the US.

In addition, we gathered the chemical property parameters for determining the temperature dependent thermodynamic properties of the chemicals. These parameters were represented in the form of a properties database.

The chemical properties database and the chemical database were then used to determine the vapor pressure of the lading at the regulatory reference temperatures of 41 °C and 46 °C, respectively for the non insulated and insulated tank cars. The valve set-to-discharge pressure in relation to the lading vapor pressure was determined.

Subtask 2.2: As part of this subtask we gathered the tank car damage and puncture data from the Association of American Railroads (AAR). This was facilitated by specifying to the AAR exactly the type of data we needed for this study. AAR then filtered the relevant data from the Tank Car Damage Database that AAR and the Railway Progress Institute (RPI) maintain jointly.

From these data the probabilities of different levels of damage occurrence to a tank car in a derailment accident were estimated. The correlations developed were then used to evaluate the leak rates of chemicals in different severity accidents.

Task 3: Development of a Risk Assessment Methodology

In this task a model was developed to assess the risks to the public from the potential release of hazardous materials from tank cars in main line accidents. The first part of the work consisted of evaluating the conditional probabilities of occurrence of various events following a derailment accident. Also evaluated were the probability of occurrence of derailment accidents and damage to a tank car.

In the second part of the task we calculated the hazard areas for a number of release scenarios, weather conditions, and tank lading. The toxic hazard areas, thermal hazard areas from pool fires, vapor fire hazard areas and the explosion areas (if the hazardous material was flammable with a potential for explosive burning) were determined. Simple correlations of the toxic hazard area with tank car hole sizes were developed for different PIH materials.

As a final part of the work in this task, the numerical values of the probability and the severity consequences were compared to the probability and the severity categories of the MIL Standard 882-B. Equivalency tables were developed to express numerical results obtained in units of the qualitative indices of the MIL Standard.

Task 4: Application of the Risk Model to Selected Chemicals

In this task the model developed in task 3 was used to calculate the overall risk from a specified tank car carrying a specified chemical. Three PIH materials and two flammable materials were selected for assessment. The national risk profiles were developed.

The risk model was also computerized so that by merely selecting the tank car and the chemical the risk profile could be calculated automatically. The program also provides a check on whether the selected tank car - chemical combination is authorized under the HM-181 regulations.

1.4 LIMITATIONS OF THE STUDY

While the study conducted in this project has considered many variables and parameters that have an effect on the potential risk to the public, it is needless to state that the work presented has also some limitations. Some of these limitations are indicated below.

1. This study has focussed on main line accidents only. This is because of the "a priori" assumption that main line derailment accidents are more severe and pose a higher risk than other types of accidents. The methodology presented can, however, be extended to other types of accidents without significant effort.

2. Only acute effects are considered. That is, the principal exposure criterion is the harmful effect of the hazardous material on people. Also, this exposure is considered to be of a relatively short duration. Long term effects on people are NOT considered nor are the effects of releases on the environment considered.

3. The study is limited to the consideration of PIH and Flammable materials. Also, only a limited set of hazardous materials whose thermodynamic and hazard property values were readily available have been included in the study.

4. The chemical - tank car "compatibility" studied in this project is limited to evaluating the valve set-to-discharge pressure and its relationship to the lading vapor pressure and the tank integrity to withstand the lading vapor pressure. Compatibility in terms of chemical corrosion of the metal of the tank car or metal strength reduction due to fatigue or stress corrosion are NOT considered.

5. The study has not made any proposals or recommendations related to the policy issues of what level of societal risk is acceptable in regard to the transportation of hazardous materials on U.S. railroads.

1.5 ORGANIZATION OF THE REPORT

The details of the work performed and analysis made in this project are presented in the following 7 chapters. Chapter 2 discusses the current 49 CFR and HM-181 amendments and identifies the requirements under different sections of the two regulations. Where there are conflicts in requirements between the two, these are highlighted.

The compatibility of HazMat and tank cars is discussed in Chapter 3. The PIH database developed is discussed as also the chemical properties database. The details of the various authorized tank cars for different chemicals are identified and their valve set-to-discharge pressure values are given. These are then compared to the lading vapor pressures and the ratios of these pressures determined are discussed. Safety factors related to the various combinations of chemicals and tank cars are discussed. The chemicals that are on the border line of valve pressure setting are identified. Detailed listing of the databases for the PIH and flammable materials as well as the authorized tank cars are provided in Appendix A.

Chapter 4 discusses in detail the tank car accident and puncture data. Different types of punctures that are formed and their probability of occurrence in different tank cars and speed conditions are discussed. Only limited raw data are presented. However, processed information and probability correlations are presented.

The probabilities of the various events that occur following a derailment accident and which result in the exposure of a certain number of people to the hazardous effects of the chemical released are discussed in Chapter 5. Accident occurrence probability, conditional probability of the tank car sustaining damage, the probability of leak (and its dependence on the safety devices on the tank car), etc., are presented in this chapter. The population density values assumed and the probabilities of occurrence of mainline derailment accidents in various types of localities are discussed. Also, the risk model is developed.

The different types of hazardous behavior of chemicals when released from a tank are discussed in Chapter 6. The procedure by which the different types of hazard areas are evaluated are indicated and the model assumptions provided. One of the important issues in the evaluation of people exposure to the effects of the chemicals is the level at which "detrimental effects" occur in human beings. The different standards used for toxic vapor exposure are discussed and the reasons why a particular criterion (in the case of PIH chemicals, the IDLH concentrations) was selected is indicated. Also provided are the hazard area results from the exercise of the consequence models for a selected number of chemicals under indicated conditions. The methodology for defining exposure limits for toxic vapors taking into consideration the time of exposure is indicated in Appendix B.

The probability evaluations indicated in Chapter 5 and the consequence results presented in Chapter 6 are synthesized into the risk model in Chapter 7. The risk model is exercised for a set of five example hazardous materials (three PIH and two flammable chemicals). The risk results are expressed as the probability per year of exceeding a given level of exposure plotted against the level of exposure. The MIL Standard risk approach is discussed. Also, the procedure by which the numerical risk values calculated by our model are converted into the qualitative risk categories of the MIL Standard is presented.

The overall findings from this study, the conclusions drawn from the results and the recommendations arising out of this study are indicated in Chapter 8.

CHAPTER 2

Review of Current Regulations and Tank Car Test Data

2.1 OVERVIEW OF HAZMAT/TANK CAR REGULATIONS

The Hazardous Material Regulations (HMR) apply to the interstate and intrastate transportation of hazardous materials in commerce. The HMR govern the safety aspects of hazardous materials transportation and include requirements for material classification, packaging, hazard communication, material handling, incident reporting, and transportation requirements by air, rail, road, and vessel. The regulations, originating from the Explosive and Combustibles act of 1908, originally administered by the Interstate Commerce Commission, are currently issued pursuant to the Hazardous Materials Transportation Act (HMTA) of 1974 administered by the Department of Transportation and published in 49 CFR, Subtitle B, Chapter 1, Subchapter C, Parts 171 thru 199. Parts 171, 172, 173, 174, 178, and 179 of 49 CFR are directly applicable to the railroad industry. These sections and their contents are briefly discussed below. The remaining parts, 175, 176, 177, and 180, deal with transportation of hazardous materials by aircraft, vessel, and motor vehicle, respectively, and prescribe regulations for the design, construction, and continuing qualification and maintenance of packages other than tank cars; these parts are not discussed in this report.

2.1.1 49 CFR Requirements under Parts 171, 172, 173, 174, 178, and 179

Part 171 of 49 CFR, "General Information, Regulations, and Definitions," includes a listing of requirements incorporated by reference (literature which is part of, but not specifically set forth in the regulations), definitions of terms and abbreviations used throughout the regulations, and procedural requirements related to the reporting of hazardous material incidents, and requirements related to import and export shipments of hazardous materials.

Part 172, "Hazardous Materials Tables, Hazardous Materials Communication Requirements, and Emergency Response Information Requirements," contains the Hazardous Materials Table §172.101 which provides a listing of hazardous materials, their shipping names, hazard classes, United Nations (U.N.) or NA identification numbers, required labels, packaging sections, and other pertinent regulations. Also included are requirements for shipping paper descriptions, marking and labeling of packages, placarding of vehicles and bulk packaging, and emergency response communication.

Part 173, "Shippers-General Requirements for Shipments and Packaging," provides packaging preparation and class and material definition information for poison gases and liquids, flammable, combustible, and pyrophoric liquids, oxidizers, corrosives, compressed and liquified gases, cryogenic liquids, and a variety of other classes of materials, some of which may not be transported in tank cars (i.e. blasting agents, radioactive materials, etc.). Also included are names of DOT packages authorized for specific materials as well as packaging exceptions and special packaging requirements. Part 173 also lists regulations governing the qualification, maintenance, and use of tank cars.

Part 174, "Carriage by Rail," prescribes requirements for hazardous materials transportation by rail. General requirements are provided for specifying unacceptable hazardous material shipments, responsibility for compliance, inspection of tank cars, handling and loading of materials, and a number of other general requirements. Requirements for the handling of placarded tank cars are provided as well as detailed requirements for the transportation of specific classes of materials (liquified gases, flammable materials, etc.).

Part 178, "Specifications for Packagings," contains specification requirements for the design and manufacture of containers generally used in transportation by highway or water. These containers are also used in rail transportation.

Part 179, "Specifications for Tank Cars," contains requirements and specifications for the design and construction of a variety of DOT class tank cars. Included are regulations specifying dimensional, structural, and material of construction requirements as well as requirements for insulation and thermal protection, jacketing, and devices such as pressure relief valves, loading and unloading valves, manway closures, couplers, head shields, etc. Detailed requirements for tank cars carrying specific materials such as Chlorine, refrigerated Carbon dioxide, and Bromine, as well as a number of other materials, are also provided. Part 179 also lists time interval requirements and specifications for the testing of tanks and safety relief devices. A discussion of the characteristics of various DOT tank cars is presented in Appendix A.

2.1.2 The HM-181 Regulations and Significant Changes

On April 15, 1982, RSPA published an Advance Notice of Proposed Rule Making (ANPRM), entitled "Performance Oriented Packaging Standards: Miscellaneous Proposals," in docket number HM-181. The goal of that notice and supplemental Notice of Proposed Rule Making's (NPRM) was to simplify and reduce the volume of the regulations, provide greater flexibility in the design and construction of packaging to accommodate advances in packaging technology, promote safety in transportation through the use of better packages, reduce the need for exemptions, and facilitate international commerce by aligning the HMR with international hazardous material regulations. Review of public comments eventually resulted in the Final Rule of HM-181 issued in the Federal Register December 21, 1990 and the revisions document issued December 20, 1991.

The final rule makes significant changes to the HMR with regard to format of the HMR, classification of materials, hazard communication provisions and bulk and non-bulk packaging requirements. These changes include:

- Consolidation of 49 CFR Hazardous Material Tables §172.101 and §172.102 into one table.

- General replacement of U.S. customary units of measure with SI, the standard international units of measure. In some cases, U.S. customary units are include in parentheses following SI units.

- General alignment of hazard class definitions with U.N. recommendations using the same numerical nomenclature (example: "flammable liquids" are "Class 3" materials, "flammable solids" are "Division 4.1" materials). Certain U.S. DOT hazard classes are retained.

- Inclusion of gases in the hazard communications requirements for identifying poisonous by inhalation materials (PIH). Also included are criteria for defining categories of gases which are poisonous by inhalation.

- Enhancement of bulk packaging provisions with respect to filling limits and re-closing pressure relief devices for flammable or poisonous by inhalation materials.

- Replacement of material specific packaging sections with generic packaging sections.

HM-181 compliance dates extend to October 1, 1996 by which time the entire regulatory requirements will be in effect. The first date was October 1, 1991 for implementation of requirements governing hazard classification and communication for new explosives, and for the identification of PIH materials on shipping papers.

2.1.3 Specific Modifications to the Regulations for HazMat Transportation in Tank Cars

A number of modifications, specific to the transportation of hazardous materials in tank cars, have been implemented with the introduction of HM-181. The majority of the modifications, contained in parts 172 and 173, have been created to regulate the rail transportation of materials meeting the definition of PIH. This category of chemicals, mainly consisting of poisonous gases (Division 2.3) and poisonous liquids (Division 6.1), comprise the most toxic of the materials listed in the Hazardous Materials Table §172.101. These modifications include:

- **Inclusion of section 172.102 special provisions.** Special provisions, indicated in Table §172.101 column 7, provide, among other requirements, tank car bulk packaging requirements in addition to those prescribed in subparts A and B of part 173. Examples include provision B14 requiring insulating material with a thermal conductance of not more than 0.075 $\text{Btu/hr}\cdot\text{ft}^2\cdot{}^\circ\text{F}$ on tank cars carrying PIH materials and provision B74 which effectively requires all liquid PIH materials to be carried in tank cars with tank test pressures of 300 psi or greater.

- **Authorizations for the use of tank cars other than of a specific class without the need for exemptions.** Sections 173.240 through 173.244, referred to in Table §172.101 column 8c, provide a listing of authorized DOT and AAR tank car classes based on the hazard of the material in question. Use of tank cars belonging to any of the listed classes, such as DOT 105, 109, 112, and 114 tank cars specified by §173.244, are authorized subject to the requirements of subparts A and B of Part 172 and the bulk packaging special provisions listed in section 172.102.

- **Addition of requirements for the determination of minimum authorized tank test pressure for liquified gases.** Section 173.31(a)(14)(i) has been modified to include specifications for the determination of the minimum required tank test pressures for the transportation of liquified gases. The requirement prescribes that the minimum tank test pressure must be equal to or greater than the greater of

  a) 133% of the sum of the lading vapor pressure at 46 °C for non-insulated cars or 41 °C for insulated cars plus static head and padding pressure,

  b) 133% of the maximum loading or unloading pressure, whichever is greater, or

  c) the minimum pressure prescribed in Part 179 for the chemical in question.

- **Outage requirements for PIH materials in tank cars.** Section 173.24b has been added to require that all PIH materials be loaded in tank cars such that the outage is at least five percent of the total capacity of the tank at 46 °C for non-insulated tanks or 41 °C for insulated tanks. Non-PIH liquids and liquified gases must be loaded such that the outage is at least one percent of the total tank capacity at 46 °C for non-insulated tanks or 41 °C for insulated tanks.

- **Modification of insulation requirements for DOT 112 and 114 class tank cars.** Section 179.101-1, "Individual Specification Requirements," has been modified to allow insulation on 112A200W, 112A340W, 112A400W, 112A500W, 114A340W, and 114A400W tank cars. The insulation requirements for these cars have been changed from "none" to "optional." This change makes possible the use of these cars for the transportation of PIH materials.

2.2 REVIEW OF CURRENT TANK CAR REGULATIONS

Parts 171, 172, and 173 of 49 CFR were reviewed. A listing of PIH materials and corresponding bulk packaging authorization sections, as well as special bulk provisions and hazard class and labeling requirements, were compiled and entered into a data base (see Chapter 3, section 3.1.1). Tank car authorizations were reviewed for PIH materials. This work was also performed for flammable gases and liquids appearing on the 1990 AAR Top 125 Commodities List[1].

The compatibility of lading and authorized tank cars based on the chemical vapor pressure and authorized tank car valve set-to-discharge pressure was determined for PIH materials and flammable liquids and gases. The details of this analysis are discussed in Chapter 3 of this report.

Part 174 was briefly reviewed. No conclusions were drawn from the review of this section. Part 179 was reviewed for regulations governing DOT 105, 112, and 114 tank cars (Part 179 Subpart C). Specifically, requirements for insulation, thermal protection, head shields, safety relief valves, and shelf couplers were reviewed. Similar regulations governing DOT-111 cars were also reviewed (Part 179 Subpart D).

Most of the problems that existed in the December 21, 1990 issue of HM-181 were brought to the attention of FRA during the early stages of this project. These included inconsistencies between bulk packaging tank car authorizations and authorizations prescribed in the bulk special provisions, as well as improper bulk packaging sections for a number of PIH materials shipped as compressed liquified gases (where packaging sections were other than §173.314). These problems were in fact under consideration at that time and were corrected and published in the December 20, 1991 HM-181 corrections document.

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[1] *The AAR publishes an annual census of tank car movement by commodities. This list is ranked using the number of car movements as the key. The list generally consists of 125 commodities.*

The provisions of §173.31(a)(14)(i), however, may only be adequate if a number of criteria are met. These regulations set requirements for determining the minimum tank test pressure for transporting a particular commodity. Specifically, the requirements state that the tank test pressure must be equal to or greater than 133 percent of the sum of lading vapor pressure at the reference temperature of 46°C for non-insulated tank cars or 41°C for insulated tank cars plus static head and gas padding pressure in the ullage space or dome of tank.

Since the industry standard for safety valves is to set the release pressure at 75 percent of the tank test pressure, the regulation essentially requires that the minimum safety valve set pressure be equal to or greater than (.75)*(1.33)*(vapor pressure at reference temperature). Since .75*1.33 is equal to 1.0, the regulations prescribe that the minimum safety valve pressure be at least equal to the chemical vapor pressure at the reference temperature. Similar requirements are prescribed by the ASME Code for pressure vessels. ASME requires that the valve set-to-discharge pressure is equal to or less than the vapor pressure of the lading at a reference temperature. This is adequate only if a) the tank lading temperature is maintained during the shipping duration or b), where the vapor pressure of the materials at ambient temperature exceeds the relief valve setting, the lading is cooled to a point which insures that its temperature does not exceed the reference temperature over the shipping route.

A number of significant changes, specific to the railroad industry, were identified in this chapter. Also discussed were requirements for determining the proper tank test pressure to be used in transporting a particular commodity. In the next chapter we discuss the compilation of the PIH, flammable liquids and gases, and tank car data bases. Also discussed is the analysis of tank car/chemical product compatibility via a comparison of tank safety valve pressure to the chemical vapor pressure at a reference temperature. This analysis was performed for both PIH and non-PIH flammable gas and liquid materials. A listing of authorized car/chemical combinations along with the resulting valve/vapor pressure ratios was compiled. A discussion of the analysis is provided.

CHAPTER 3

Compatibility of HazMat Chemicals and Tank Cars

Tank cars authorized to carry PIH and non-PIH flammable gases and liquids must be capable of containing their contents under normal yard and shipping conditions. Aside from an accident in which the structural integrity of the safety valve is compromised, or an event in which the tank is exposed to the high temperatures of a fire, the safety relief devices of tank cars should not prematurely discharge their contents into the atmosphere. To preclude the possibility of product discharge under normal operating conditions, the ratio of the safety valve set-to-discharge pressure to the product chemical vapor pressure at the highest ambient temperature (to which a tank car may be exposed, under the worst ambient temperature conditions during normal transportation) should be greater than unity. In fact, to insure a factor of safety, the ratio should exceed unity by a reasonable magnitude.

In light of this, TMS analyzed PIH and non-PIH flammable liquid and gas tank car compatibility by a comparison of tank car safety valve pressure to lading vapor pressure. Specifically, for those PIH and non-PIH flammable liquids and gases for which physical properties were available, the lading vapor pressures at the specified reference temperature were determined. The reference temperatures used are those indicated in 49 CFR §173.31. These are 41 °C (105 °F) for insulated tank cars and 46 °C (115 °F) for non-insulated tank cars. The vapor pressures determined at these temperatures were compared to the safety valve set-to-discharge pressures of tank cars authorized for the transportation of the hazardous materials under consideration. A listing of authorized car/lading combinations was compiled and the valve pressure setting/vapor pressure ratios were determined for these chemical/tank car combinations. These results are discussed in this chapter.

3.1.1 Database of PIH Chemicals

Poison by Inhalation ("PIH") chemicals are listed in Table §172.101. These PIH chemicals are identified in this table by an entry of numbers 1, 2, 3 or 4 in column 7. The total number of chemicals identified as PIH in this table is 163. Of these, 71 are gaseous (at ambient temperature and pressure) and the remaining 92 are liquids. These chemicals also include those materials identified as "n.o.s." (i.e., not otherwise specified).

PIH materials listed in Table §172.101 are primarily poisonous but may also belong to one or more of the following hazard classes.

1. Division 2.3 - poisonous gases (hazard zone A-D)
2. Division 2.1 - flammable gases
3. Division 6.1 - poisonous liquids (packing group I, zone A&B)
4. Class 3 - flammable liquids[1]
5. Division 4.2 - spontaneously combustible materials[1]
6. Division 5.1 - oxidizers[1]
7. Class 8 - corrosives.[1]

In most cases, the material is identified as either a poison gas or poison liquid (Division 2.3 or 6.1, respectively) and may or may not have a secondary hazard in one of the remaining 5 classes listed above (Class 3, Class 8, or Division 2.1, 4.2, or 5.1).

Eight of the PIH materials, anhydrous ammonia, chlorine, ethylene oxide, sulfur dioxide, hydrogen chloride, oleum, hydrocyanic acid (refrigerated liquid), and hydrogen fluoride (refrigerated liquid) appear on the Association of American Railroads Top 125 Commodities list (1990). The AAR list is presented in Table A.1 of Appendix A and lists the chemical name and rank, Standard Transportation Commodities Code (STCC), DOT hazard class, and number of 1990 tank car movements. Figure 3.1 illustrates the distribution of the number of car movements as a function of rank based on the AAR list. The eight PIH materials have been indicated. Note that two of these materials, anhydrous ammonia and chlorine, are ranked in the top five.

A database containing PIH materials from Table §172.101 was developed using dBase IV. Table 3.1 lists the structure and a description of each field in this database. Each record of the data base consists of, among other parameters, fields containing the chemical name, UN or NA identification number, hazard class and required hazard labels, bulk packaging section, special bulk shipping provisions, chemical vapor pressures (if available) at the reference temperature of 41 °C and 46 °C and reference numbers indicating tank cars authorized for their transportation.

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[1] *"+" in HM-181 Table 172.101 Column 1 only*

FIGURE 3.1

Distribution of AAR Top 125 Commodity Shipments as a Function of Rank

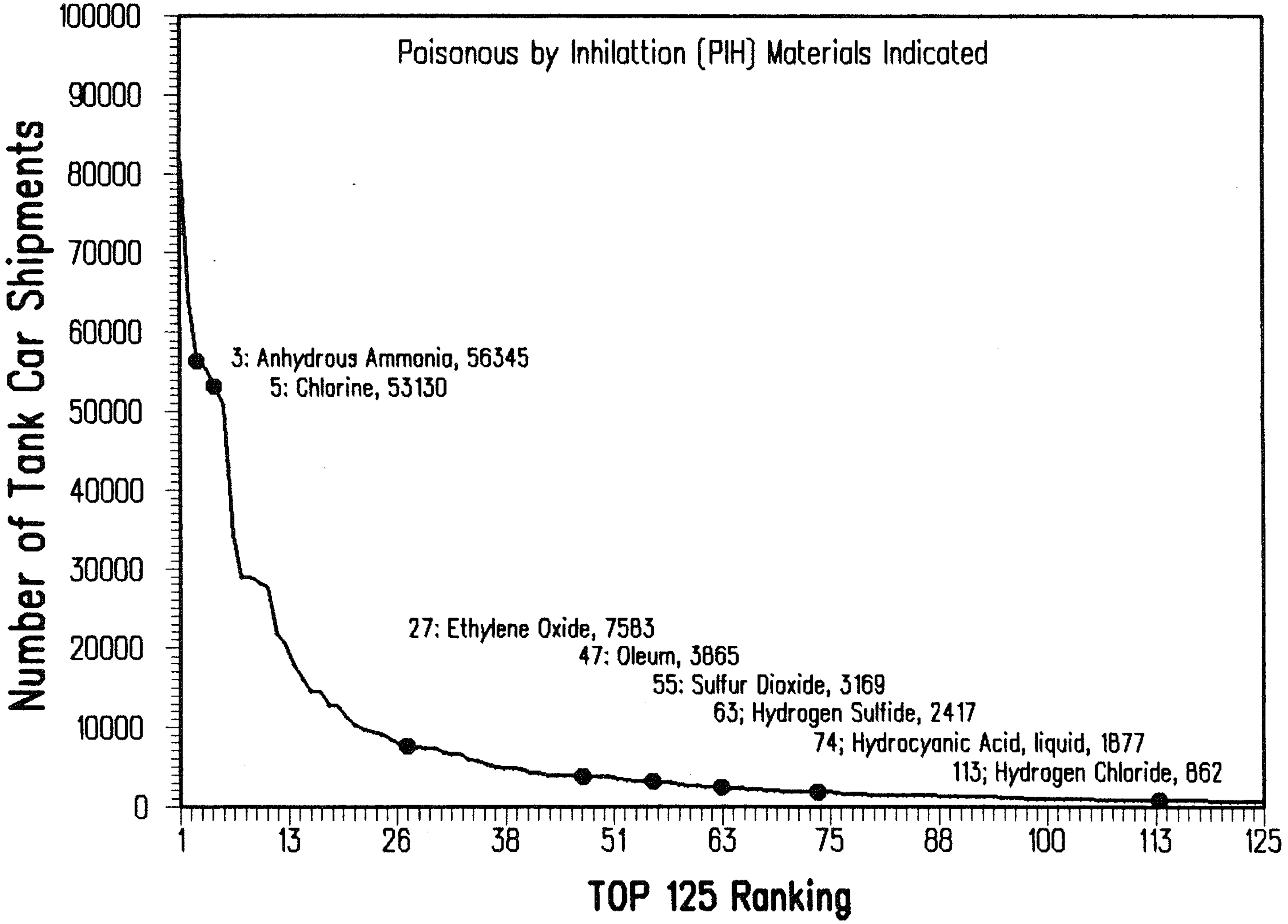

TABLE 3.1

HM-181 PIH Database Structure

FIELD	FIELD NAME	TYPE	DESCRIPTION
1	CHEM_NAME	Character	PIH chemical name
2	CLASS	Character	HM-181 hazard class
3	BULK_PACK	Character	HM-181 bulk packaging section
4	BULK_SPROV	Character	HM-181 bulk packaging special provisions
5	CARNUMB	Character	Reference number of authorized cars
6	VAPOR_41C	Character	Chemical vapor pressure at 41 °C
7	VAPOR_46C	Character	Chemical vapor pressure at 46 °C
8	ID_NO	Character	UN or NA ID number
9	REQ_LABELS	Character	Required hazard marking, labels, or placards
10	PIH_CODE	Character	PIH code number 1, 2, 3, or 4, from column 7 of HM-181 §172.101
11	REQ_RATIO	Character	Required minimum valve/vapor pressure ratio (per HM-181 §173.31)
12	MIN_RATIO	Character	Minimum valve setting/vapor pressure ratio
13	TOP125_90	Logical	Chemical appears on AAR 1990 Top 125 Commodities List
14	TOP125RNK	Character	AAR 1990 Top 125 ranking

The "Carnumb" field contains the authorized DOT specification tank cars identified by a two or three digit number. Each reference number corresponds to one and only one tank car in the tank car data base (discussed in Section 3.2). Reference numbers were included for cars of the same class having greater tank test pressures and more protective equipment than those authorized (per §173.31). In other words, if 105A500W cars were authorized for a particular chemical, 105J500W, 105A600W, and 105J600W cars were also listed. The HM-181 PIH Database is linked to a table giving the relationship between the car number values in the Carnumb field and the DOT specification of tank car. This table is provided as Table A.6 in Appendix A[2].

The database also lists the minimum safety valve pressure setting/lading vapor pressure ratio. This ratio is provided for those chemicals for which the vapor pressure was determinable. In the case of liquids a reference tank ullage pressure was assumed. The determination of this pressure ratio is discussed in Section 3.3. A listing of the PIH database is provided in Table A.2 and Table A.3 of Appendix A.

Columns 7 (special bulk packaging provisions) and 8c (bulk packaging authorization section) in Table §172.101 of HM-181 were inspected to determine tank cars authorized for transporting the lading in question. As an example, allyl alcohol is packaged under §173.244 and lists, among others, bulk packaging provisions B14 and B74. While §173.244 authorizes DOT Class 105, 109, 112, and 114 tank cars, provisions B14 and B74 state that notwithstanding §173.244, the only cars authorized are insulated 105J300W, 112T340W, 114T340W, and 105J340ALW cars[3] (and cars of the same class having higher tank pressure and/or increased protection). This provision therefore drastically limits the number of tank cars authorized to transport the product. Based on this methodology, a listing of PIH materials and corresponding tank car authorizations was compiled.

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[2] *Table A.2, A.3, etc. referred to in this chapter are the tables provided in Appendix A.*

[3] *When this report refers to 112T or 114T cars, 112J and 114J cars of the same or greater test pressure are also authorized.*

Vapor pressures of materials shipped as compressed liquefied gases were determined at a reference temperatures of 41 °C and 46 °C. If available, the vapor pressures (in units of psig) were entered in the VAPOR_41C and VAPOR_46C fields. The chemical thermodynamic and other property data were collected from a number of sources from which the vapor pressures were determined (e.g., Reid, 1986; Cushmac, 1991; MicroHACS, 1990; Matheson, 1971; Daubert & Danner, 1989). Liquid PIH materials were assumed to have vapor pressures less than 15 psia (i.e., less than the ambient atmospheric pressure) at ambient temperatures; the vapor pressures for these materials have been entered as "< 15" in these columns.

PIH materials and tank car authorizations (pre 1990) from 49 CFR were also compiled and entered into a database. For consistency, all hazardous material appearing in Table A.2 were included. Table 3.2 lists the structure of the 49 CFR PIH data base. The contents of this data base are presented in Table A.4 of Appendix A. Tank car reference numbers listed in the CARNUMB field, lading classes listed in the CLASS field, and bulk packaging sections listed in the BULK_PACK field were obtained from the 1989 or earlier issues of 49 CFR Table §172.101 and therefore differ from the entries in the CARNUMB, CLASS, and BULK_PACK fields of the HM-181 PIH data base presented in Table A.2.

Since the effective date of HM-181 tank car authorizations for PIH materials is October 1, 1993 no analysis was performed regarding valve pressure/vapor pressure compatibility for pre-HM-181 tank car authorizations.

3.1.2 Database of Non-PIH Flammable Gases and Liquids

A data base was compiled from 49 CFR Table §172.101 for non-PIH flammable liquid (Class 3) and gas (Division 2.1) materials appearing on the AAR Top 125 Commodities list for 1990. The data base, listed in Table A.5 of Appendix A, contains fields listing the chemical name, class, UN number, minimum safety valve pressure of authorized tank cars, chemical vapor pressures if available, and the minimum safety valve/vapor pressure ratio. Also included is a field containing integers specifying the DOT tank cars authorized for transporting each chemical listed. Table 3.3 lists the structure of this data base and a description of each field.

TABLE 3.2

49 CFR PIH Database Structure

FIELD	FIELD NAME	TYPE	DESCRIPTION
1	CHEM_NAME	Character	PIH chemical name
2	ID_NO	Character	UN or NA ID number
3	CLASS	Character	Hazard class
4	BULK_PACK	Character	Bulk packaging section
5	CARNUMB	Character	Reference number of authorized cars
6	VAPOR_41C	Character	Chemical vapor pressure at 41 °C
7	VAPOR_46C	Character	Chemical vapor pressure at 46 °C
9	TOP125_90	Logical	Chemical appears on AAR 1990 Top 125 Commodities List
10	TOP125RNK	Character	AAR 1990 Top 125 ranking

TABLE 3.3

HM-181 Flammable Gases and Liquids Database Structure

FIELD	FIELD NAME	TYPE	DESCRIPTION
1	CHEM_NAME	Character	PIH chemical name
2	ID_NO	Character	UN or NA ID number
3	CLASS	Character	Hazard class
6	BULK_PACK	Character	Bulk packaging section
7	PACK_GROUP	Character	Packing group
8	BULK_SPROV	Character	Bulk packaging special provisions
9	CAR_NOTE	Character	DOT tank car class reference number
14	VAPOR_41C	Character	Chemical vapor pressure at 41 °C
15	VAPOR_46C	Character	Chemical vapor pressure at 46 °C
16	MIN_VALVE	Character	Minimum valve pressure setting of authorized cars
17	REQ_RATIO	Character	Required minimum valve/vapor pressure ratio
18	RATIO_41C	Character	Valve setting/vapor pressure ratio at 41 °C
19	RATIO_46C	Character	Valve setting/vapor pressure ratio at 46 °C
21	TOP125RNK	Character	AAR 1990 Top 125 ranking

For materials shipped as compressed liquefied gases and for which vapor pressures were available, the pressures at 41 °C (insulated cars) and 46 °C (non-insulated cars) were determined and entered in the respective VAPOR_41C and VAPOR_46C fields.

Columns 7 and 8c of 49 CFR 172.101 were inspected to determine the tank cars authorized for the bulk transportation of each PIH (Classes 2.3, 6.1, Pkg Gr 1) and flammable material. For materials listed in Table A.5, the car authorizations in HM-181 were class specific and specified entire classes of DOT cars without referring to bulk packaging provisions to limit the number of cars authorized (in comparison to PIH materials where the bulk packaging provisions were used extensively to limit the number of tank cars authorized). In order to simplify the task of designating the authorized tank cars, a code numbering system was used to relate the chemical name to the group of authorized cars. Table 3.4 presents the reference number codes used.

In Table 3.4, the column entitled "Reference Number" contains integers delineating the classes of tank cars authorized for the flammable materials considered (integers under this column correspond to those under the CAR_NOTE field of Table A.5). Table 3.5 also lists the class of cars assigned to each integer, the minimum safety valve pressure setting the authorized cars, and the HM-181 packaging section which authorizes the tank cars. For example, Acetaldehyde is assigned the integer 3 under the CAR_NOTE column of Table A.5. Table 3.4 assigns to this integer the following classes of tank cars: Class DOT 103, 104, 105, 109, 111, 112, 114, and 115. Table 3.4 also lists the HM-181 packaging section as §173.243 and indicates that the minimum safety valve pressure setting these cars is 35 psig. The minimum safety valve pressure setting in this Table also corresponds to the MIN_VALVE entry for each material in Table A.5.

For some materials, the minimum safety valve pressure listed in Table A.5 is not compatible with the commodity if carried in non-insulated cars setting. In these cases, the value of the vapor pressure at the reference temperature of 46°C is greater than that of the safety valve pressure. In order to satisfy requirements prescribed in 49 CFR 173.31, a tank car utilizing a higher safety valve pressure must be used. This is discussed in further detail in Section 3.3.

TABLE 3.4

Tank Car Reference for Non-PIH Flammable Gas and Liquids Database

REFERENCE NUMBER[1]	HM-181 PACKAGING SECTION	AUTHORIZED TANK CAR CLASSES	MINIMUM VALVE PRESSURE (PSIG)[2]
1	173.241	DOT CLASS 103, 104, 105, 109, 111, 112, 114, 115; AAR CLASS 203W, 206W, 211W	35
2	173.242	DOT CLASS 103, 104, 105, 109, 111, 112, 114, 115, AAR CLASS 206W	35
3	173.243	DOT CLASS 103, 104, 105, 109, 111, 112, 114, 115	35
4[3]	173.314	DOT 105J, 112T, 114T, 112J, 114J (Notes 4, 13, & 23 of 173.314 apply)	75

(1) Reference numbers refer to integers in "CAR_NOTE" field of Table A.5

(2) Valve pressures are entered in "MIN_VALVE" field of Table A.5

(3) 105A100W, 111A100W4, 112A200W, 112A340W (min. valve pressure = 75 psig) also authorized for Ethyl Chloride and Ethyl Methyl Ether if built before 1/1/91 (B63 of 172.102)

3.2 TANK CAR DATABASE AND SAFETY VALVE SET-TO-DISCHARGE PRESSURES

Tank cars currently listed in the re-test tables of 49 CFR and the GATX tank car manual were compiled and entered into a data base utilizing DBASE IV. Table 3.5 lists the fields in the tank car data base and provides a description of each field. Each record in the data base contains a specific DOT or AAR tank car specification (CARSPEC) along with the tanks safety valve set-to-discharge pressure (VALVE_PSIG). For tanks with valves, the valve set to discharge pressure is equal to 75% of the tank test pressure. For cars without valves, it was assumed that the pressure relief device consists of a frangible disk that ruptures at 100% of the tank test pressure. In these cases, 100% of the tank test pressure was used to represent the valve set to discharge pressure. The NUM_PIH field lists the number of PIH materials authorized in each car based on Table §172.101 tank car authorizations.

Each tank car in the data base was assigned a unique two or three digit reference number. The reference number for each car was entered in the CARNUMB field and matches the reference numbers in the CARNUMB field of the PIH data base. This methodology forms an efficient way of identifying tank cars authorized to carry the hazardous materials listed in the data base. The contents of the tank car data base are listed in Table A.6 of Appendix A.

3.3 COMPARISON OF CHEMICAL VAPOR PRESSURES AND SAFETY VALVE SET TO DISCHARGE PRESSURES

Chemical vapor pressures listed in the PIH data base were compared to the safety valve set to discharge pressures of authorized tank cars. For each car/chemical combination, the ratio of the valve pressure to the chemical vapor pressure was determined. This ratio "r_v" is defined as

$$r_v = \frac{P_{valve}}{P_{vapor}} \tag{3.1}$$

Where:

P_{valve} = Tank Car Safety Valve Set to Discharge Pressure

P_{vapor} = Chemical Vapor Pressure at reference temperature

TABLE 3.5

Tank Car Database Structure

FIELD	FIELD NAME	TYPE	DESCRIPTION
1	CARNUMB	Character	Tank car reference number
2	CARSPEC	Character	DOT tank car specification
3	VALVE_PSIG	Character	Tank safety valve set-to-discharge pressure (psig)
4	NUM_PIH	Character	Number of PIH materials authorized to be transported

Since the industry standard for safety valves is to set the release pressure at 75 percent of the tank test pressure, the regulation essentially requires that the minimum safety valve set pressure be equal to or greater than (.75)*(1.33)*(vapor pressure at reference temperature). Since .75*1.33 is equal to 1.0, the regulations prescribe that the minimum safety valve pressure be at least equal to the chemical vapor pressure at the reference temperature. In the case of perchloryl fluoride and carbonyl sulfide, the resulting valve/vapor pressure ratio based on a 300 psig tank was less than 1.0 (valve pressure = 225 psig, vapor pressure = 226 psig and 249 psig, respectively). Therefore, tanks of 300 psig test pressure are not authorized for these materials.

A number of car/PIH chemical combinations satisfied the 1.0 criterion by a small margin. For anhydrous ammonia, a valve setting/vapor pressure ratio of 1.06 at the reference temperature of 41 °C would result if transported in 300 psig 105A or 105J cars. If transported in 340 psig 112 or 114 cars, the resulting ratio at the reference temperature of 46 °C would be 1.08. Carbonyl sulfide carried in 340 psig 112/114 tanks at the reference temperature of 41 °C resulted in a ratio of 1.02 while sulfuryl fluoride carried in 500 psig tanks resulted in a ratio of 1.05.

For non-PIH flammable liquids and gases for which a vapor pressure was available, the ratio of the minimum valve set to discharge pressure (of the cars authorized) to the lading vapor pressure at 41 °C and 46 °C was determined. Table A.5 list the calculated ratios in columns RATIO_41C and RATIO_46C.

For most gaseous flammable materials analyzed, the minimum safety valve pressure listed in the MIN_VALVE field of Table A.5 is sufficient in light of the materials vapor pressure at 41 °C and 46 °C. However, in accordance with regulations prescribed in HM-181 section §173.31, a safety valve with a higher discharge pressure than those listed in the MIN_VALVE field must be used for isobutane, propylene, and vinyl chloride when transported in non-insulated cars. For these materials, the ratio listed in the RATIO_46C column of Table A.5 has been calculated based on a tank car with a safety valve pressure sufficient to insure that the resulting ratio is greater than 1.0. For example, for propylene, §173.314 authorizes tank cars of the class 105J, 112T, 112J, 114T, and 114J (notes 4 & 23 of §173.314 apply). Although the minimum valve pressure of these classes of cars is 75 psig (100 psig tank), due to the materials vapor pressure at 46 °C (260 psig), a safety valve of at least 300 psig must be used (400 psig tank) to insure that a valve/vapor pressure ratio of less than 1.0 does not occur. To insure a ratio greater than 1.0 for isobutane and vinyl chloride at 46 °C, the minimum safety valve pressure must be at least 150 psig, corresponding to a 200 psig tank.

3.4 SUMMARY OF FINDINGS

An analysis of the compatibility between tank car safety valve set to discharge pressure and chemical product vapor pressure has been performed for materials meeting the criterion of poisonous by inhalation (PIH). The analysis was also performed for non-PIH flammable gas and liquid materials appearing on the 1990 AAR Top 125 Commodities list.

For eighteen (18) PIH and thirteen (13) non-PIH flammable materials for which a vapor pressure was available, the ratio of the safety valve pressure to the chemical vapor pressure at a reference temperature was determined. Car/chemical combinations resulting in ratios less than 1.0 were identified. This study was performed with respect to current HM-181 tank car regulations.

The following discussion summarizes the analysis.

1. Eighteen (18) gaseous PIH materials were analyzed for valve pressure/vapor pressure compatibility. The analysis involved determining the safety valve pressure setting/chemical vapor pressure ratio at a reference temperature (41 °C for insulated cars or 46 °C for non-insulated cars) and comparing it to unity. Initially, all tank cars listed in the bulk packaging sections or bulk special provisions for each material were considered. The minimum ratio was then identified. Cars resulting in ratios less than 1.0 were stricken from the initial list of car/chemical combinations as required by §173.31 (discussed in Section 3.3). Only two tank car/gaseous PIH lading combinations (perchloryl fluoride and carbonyl sulfide in 300 psig tanks) resulted in ratios less than 1.0 before application of requirements contained §173.31.

2. Safety valve pressure/vapor pressure ratios for PIH materials existing as liquids at ambient temperature and pressure were determined based on the minimum valve pressure of the cars authorized and an assumed maximum tank ullage pressure of 15 psia. The minimum pressure ratio of all tank car/liquid PIH materials analyzed was 16.0.

3. Because of its toxicity and frequency of shipment, the safety valve/vapor pressure ratio of 1.06 and 1.08 for anhydrous ammonia at 46°C in 105A300W (or 105J300W) cars and 112/114 J or T cars, respectively, may not provide an adequate level of safety. Although it is recognized that the temperatures at which these ratios are calculated would represent a very rare ambient temperature, a ratio multiplier requirement such as that prescribed in HM-181 special bulk provisions B30 and B32 for cargo tanks would provide an additional factor of safety.

4. Eight (8) PIH materials, anhydrous ammonia, chlorine, ethylene oxide, oleum, sulfur dioxide, hydrogen sulfide, hydrocyanic acid, and hydrogen chloride, appear on the 1990 AAR Top 125 Commodities List. Two of these materials, anhydrous ammonia and chlorine, rank in the top 5 on the 1990 AAR Top 125 Commodities List with 56,345 and 53,130 shipments, respectively.

5. Thirteen (13) non-PIH flammable materials were analyzed for valve pressure setting/vapor pressure compatibility. For each material, the analysis was performed by identifying the minimum safety valve pressure of authorized tank cars and comparing it to the chemical vapor pressure at both 41°C and 46°C (both insulated and non-insulated cars are authorized for non-PIH flammable materials). The ratio of valve pressure to vapor pressure was determined and compared to the ratio 1.0. Initially, all tank cars listed in the bulk packaging section for each material were considered. The minimum ratio was then identified. Cars resulting in ratios less than 1.0 were stricken from the initial list of car/chemical combinations as required by §173.31. Only 3 materials, isobutane, propylene, and vinyl chloride, resulted in valve pressure/ vapor pressure ratios less than 1.0 before application of requirements of §173.31.

6. Tank cars authorized in bulk special provisions of §172.102 (tank cars listed in these provisions would supersede all cars authorized in standard bulk packaging sections) did not result in a valve pressure/vapor pressure ratio less than 1.0.

CHAPTER 4

Analysis of Tank Car Accident and Puncture Data

4.1 INTRODUCTION

An accident involving a freight train that has in its consist tank cars containing hazardous materials can have an number of outcomes depending on the nature and speed of the accident. These outcomes range from minor events such as freight cars jumping the rail (one wheel leaving the track) to major events in which several tank cars are derailed, damaged, and one or more leak their hazardous material content. The severity of the consequences of hazardous material releases into the environment will depend on the physical and chemical properties of the hazardous materials released, the quantity released (or alternately, the rate of release), the number of tank cars releasing, weather condition, etc.

Two parameters that have a significant effect on the magnitude of the hazard area are the rate of release of the chemical from the tank car and the total quantity of the chemical released. The amount of chemical released depends on the total volume of the chemical carried in the tank cars and on the location of the hole relative to the liquid level. In the case of a pressurized chemical, a substantial fraction of the cargo may be released irrespective of the hole location. The rate of hazardous material release from a given tank car in an accident depends on the size and nature of the damage which the tank car suffers. It is found that certain safety appurtenances (such as head shields, shelf couplers, and thermal insulation) enhance the puncture resistance capability of the tank car and may even eliminate the occurrence of punctures in several types of accidents.

In order to compare the puncture resistance characteristics of tank cars, it is necessary to evaluate the types of punctures that have occurred historically, in different classes of tank cars, their size and probability of occurrence, and their dependence on speed at which an accident may occur. This chapter discusses available data on tank car punctures and the results from an analysis of these data.

4.2 TANK CAR ACCIDENT DATABASE

The FRA, the Railway Progress Institute (RPI), and the Association of American Railroads (AAR) have collectively developed and maintained a database of tank car accidents that have occurred in North America (USA and Canada) since 1965. The database is currently maintained by the RPI and AAR Tank Car Safety Research and Test Projects. This database, entitled "Tank Car Accident Database" (Phillips 1983), captures the details of the tank cars and accidents in which tank cars suffer structural damage as a direct result of a railroad accident. Only those accidents in which a tank car incurs damage to a component unique to a tank car (such as the shell, fittings, jackets, insulation, etc.) are included in this database. Damage to tank cars caused by fire or the mechanical forces of a derailment or collision are included. Damages such as fatigue cracks, buckling of stub sill, corrosion holes, loose rivets, etc., which are common to all freight cars are excluded from the database.

A number of parameters related to the accident, tank car damage, lading, and consequences of lading leak are captured in the database. A sample record from the Tank Car Accident Database for an accident in which a hazardous material is released to the environment is indicated in Table 4.1. It is seen that each record contains, in different fields, the following categories of data:

1. Accident date, location, and description of what happened;
2. Tank car ID number, DOT class specification, total volume of tank car, and volume of lading (gallons) released;
3. Name and hazard class of chemical in the tank car (whether released or not);
4. Consequences of the hazardous material release (number of people evacuated, injured, killed, etc., due to the accident); and
5. Train make up, speed, total number of cars derailed, etc.

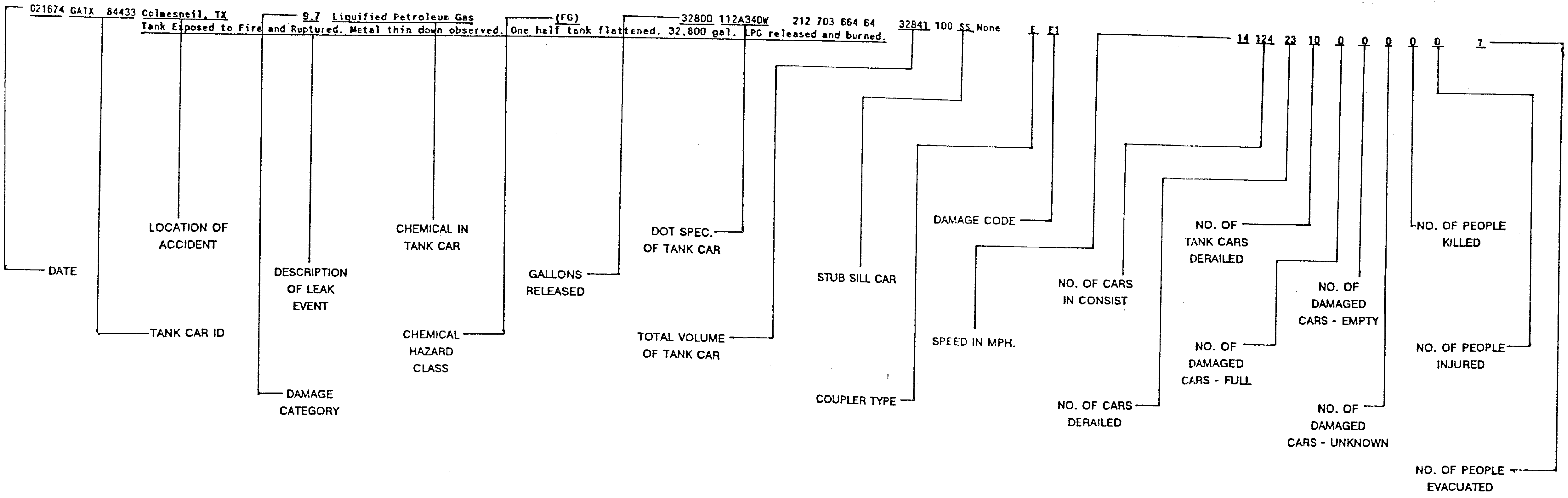
4.2.1 Statistics on Tank Car Puncture Accidents

Using this database, RPI/AAR has extracted (Phillips 1992) the total number of damaged tank cars involved in accidents during the period 1965-1988 carrying hazardous materials and suffering a lading loss due to puncture or appurtenance malfunction. Also, some preprocessing was done by RPI/AAR to preserve the confidentiality of raw data.

These preprocessed and summarized data were provided to TMS under a confidentiality agreement. Two types of data have been provided. The first type indicates the number of tank cars during this period that suffered punctures in main line accidents resulting in loss of lading. These data are segregated by tank car types, train speed before the accident, and damage type (size class of hole). The second type of data are the summary of the ratio of tank cars suffering punctures to the number derailed in mainline and yard accidents. These latter numbers are segregated by the effect of protective devices and provide information on the reduction in puncture probability when providing different types of protective devices on tank cars.

TABLE 4.1

Sample Record from the Tank Car Accident Database



(Source: Phillips, 1992)

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Table 4/2 shows a sample of the format in which the distribution of hole types, by speed and tank car is presented. The number in each cell represents the total number of tank cars (of the DOT class indicated in the table) that suffered the given type of puncture damage identified in the speed range during 1965-1988. Tank car puncture data have been aggregated by the following types of tank cars[1]:

- DOT 111 Non-Insulated
- DOT 111 Insulated
- DOT 105
- DOT 112, 114
- DOT 105, 112, 114 (S, J, T)

Table 4.3 shows a sample of data on the percent of derailed tank cars that suffered lading loss. The data are segregated by tank car class, damage location, and the effect of head shields and thermal insulation. The "base case" refers to the tank car condition when no improvements are made (i.e., head shields and insulation are not provided and the shell and head wall thicknesses are nominal). The last column in Table 4.3 shows the cumulative ratio of punctured cars to derailed cars for the base case. Referring to Table 4.3 and car type 1A, it is seen that 19.08% of the derailed cars of type 1A (and base case) suffer leak damage, when the effects of size, location of damage, and train speed are all aggregated.

RPI/AAR has indicated that not all of the puncture probability values provided (in the form of Table 4.3) are based directly on raw accident data. The effects of shelf couplers, jackets on non-pressure cars, and thickness of non-pressure cars in reducing the puncture probability were based on actual accident data. Both accident data and engineering judgement form the basis of determining the puncture probability values provided for the effects of jackets, head shields, top and bottom fitting protections for pressure cars, and, where applicable, for non-pressure cars. Significant engineering judgement and extrapolations form the basis of puncture probability numbers for the non-pressure cars with different heights of head shields.

In the sections to follow, these data are analyzed and conditional probability values for tank car puncture for the occurrence of different size holes are determined.

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[1] *Data aggregated include accidents occurring in the time span during which certain tank cars are required to have safety appurtenances. Shelf couplers and head shields have been mandatory after 1 January 1978 for DOT 112 and DOT 114 class cars (49 CFR 179.105-5) and after 1 September 1981 for DOT 105 class cars (49 CFR 179.106-2). Since the data provided spans the 1965 through 1988 period, they contain the effects of presence of safety devices and also their absence on tank cars. There is, unfortunately, no way of segregating the accident data received by TMS into pre and post dates of mandatory provisions of safety devices on tank cars.*

TABLE 4.2

Sample of Tank Car Puncture Data by Tank Car Class, Damage Type, Speed, and Location of Puncture

TYPE OF TANK CAR

111 NON - INS

RPI/ AAR CAT.	DAMAGE TYPE	# OF TANK CARS WITH GIVEN DAMAGE							TOTAL
		SPEED RANGE, MPH							
		0-10	10-20	20-30	30-40	40-50	>50	?	
6.1	Head Punct. Only (Size)								
	< 8"	9	3	3	2	5	1	9	32
	8" - 18"	11	2	8	3	7	1	10	42
	> 18"	10	2	8	14	13	0	7	54
	?	13	8	10	11	25	6	22	95
6.2	Shell Punct. Only (Size)								
	< 8"	3	0	7	0	0	1	3	14
	8" - 18"	3	1	3	0	1	0	1	9
	> 18"	3	1	5	9	9	1	0	28
	?	7	12	24	34	40	9	23	149
6.9	H + S Punct. Only (Largest Size)								
	< 8"	0	0	0	0	0	0	0	0
	8" - 18"	0	0	1	1	0	0	0	2
	> 18"	1	3	3	5	2	1	1	16
	?	2	2	1	5	1	6	1	18
6.4	Fittings Loss Top or Bottom Gal								
6.5	< 100	53	15	10	11	10	3	28	130
6.9	100 - 1000	64	18	35	27	13	2	31	190
	> 1000	30	28	55	37	61	17	18	246
	?								
6.9	H or S Punct. + Fittings (Largest Punct.)								
	< 8"	2	1	6	4	1	1	0	15
	8" - 18"	0	1	1	2	6	0	2	12
	> 18"	1	1	5	8	13	2	0	30
	?	4	2	11	11	10	10	4	52

NOTES: 1 Period covered, 1965 - 1988
2 Loaded cars only - empty or unknown if loaded not counted
3 Punctures of unknown location assumed to be shell not head

Source: AAR (Phillips, 1992)

TABLE 4.3

Sample Data on the Ratio of Number of Tank Cars Suffering Lading Loss to the Number Derailed in Main Line Accidents

Car Type	Ins	HS	H			S			T		B		M		Σ
			Thickness			Thickness									
			Base	+1/8"	+1/4"	Base	+1/8"	+1/4"	Base	Pro-tected	Base	Improve prot/ elim	Base	w/ RRO	Base γ
1A	No (base)	0	3.61	2.13	0.70	4.11	2.43	1.60	6.76	4.68	0.00	0.00	4.60		19.08
		1/2	1.19	0.70	0.23										
		full	0.77	0.45	0.15										
	Yes	0	2.13	0.70	0.50	2.43	1.60	0.75	6.76	4.68	0.00	0.00	4.60		
		1/2	1.19	0.39	0.28										
		full	0.77	0.25	0.18										
1B	No (base)														
	Yes	0													
		1/2													
		full													
2A	Yes (base)	0													
		1/2													
		full													
2B	Yes (base)	0													
		1/2													
		full													

Base Car Types

1A	111A NI w/o B
1B	111A NI w/ B
2A	111A I w/o B
2B	111A I w/ B
2C	111J w/o B, 1/2 HS
2D	111J w/ B, 1/2 HS
3	112(114)A340W
4A	105A300W
4B	105A500W
5A	105S300W, 1/2 HS
5B	105S500W, 1/2 HS
5C	105J300W, 1/2 HS
5D	105J500W, 1/2 HS
5E	112(114)S340W, 1/2 HS
5F	112(114)J340W, 1/2 HS
5G	112(114)T340W, 1/2 HS

Note: The probabilities in this table are reported to have been developed by RPI/AAR assuming that the ratio of number of cars derailed to number of cars that qualify for inclusion in the RPI/AAR database as damaged (and without release) to be 2.5. In effect, this table actually indicates the probability of release, given that a tank car is <u>derailed</u> (not necessarily damaged) in a mainline derailment accident.

Source: *AAR (Phillips, 1992)*

4.2.2 Types and Size of Tank Car Punctures

It is possible for a derailed tank car to suffer a variety of punctures both in shape and size of hole depending on the severity of the accident, the thickness of the shell, nature of the ground and, perhaps, the metallurgical age of the tank car. The severity of the accident is generally measured by the speed prior to the accident. In the RPI/RPI/AAR tank car damage database the shapes and sizes of tank car punctures are identified by "shape codes" and "puncture location codes." Figure 4.1 illustrates, schematically, the nomenclature for the hole shapes and locations used in the database. It is seen that there are three different hole shapes, namely (i) nearly circular, (ii) elongated, and (iii) crack. The overall dimensions of these holes are also indicated in Figure 4.1.

The number of tank cars suffering a particular type of puncture is provided in the summarized database of the type shown in Table 4.2; however, the exact hole size is not given but only the hole size/shape category. Therefore, it is not possible to evaluate the distribution of exact hole sizes within a specified hole size/shape category. Because of the lack of this information, we have assumed that the distribution of hole sizes within a specific category of puncture is uniform. That is, the "average" hole sizes are used to represent the puncture category. Table 4.4 shows the "average" hole puncture area for a hole determined by mean dimensions within a category. These average areas are indicated for the different hole types. This table also indicates the assumptions we have used on the hole length and shape in calculating the average area. These puncture areas are used later in the risk analysis to determine the potential hazard areas.

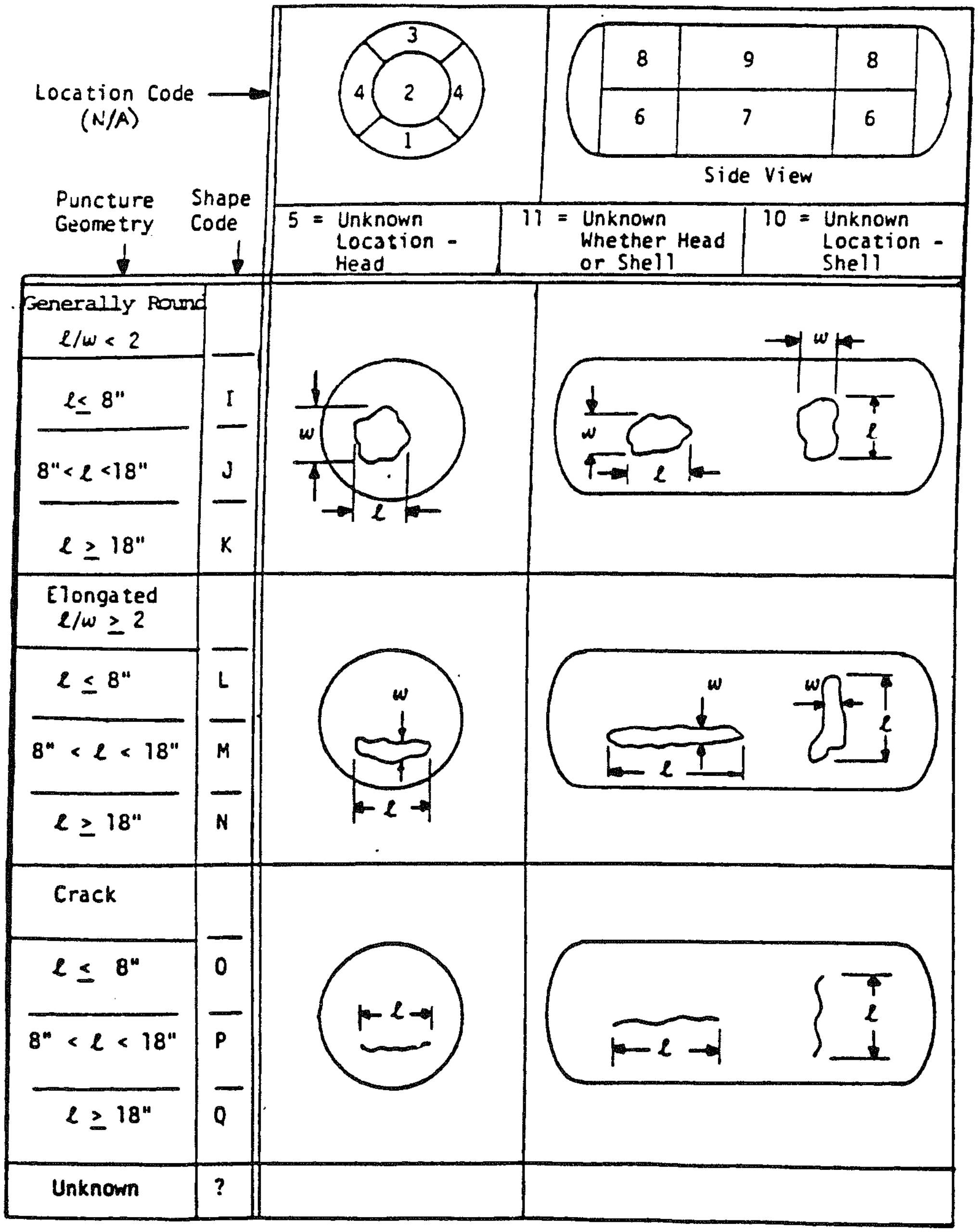
4.3 PROBABILITY OF OCCURRENCE OF DIFFERENT PUNCTURE SIZES IN TANK CARS

In this section we discuss the methodology by which the probabilities of occurrence of different hole sizes were calculated. Tank car types and speed have been used as variables.

The raw data on the number of tank cars damaged within a speed range and suffering a particular type of hole puncture are not presented because of the confidentiality agreement with RPI/AAR.

FIGURE 4.1

Tank Car Puncture Types and Locations Nomenclature



Source: (Phillips, 1991)

TABLE 4.4

Tank Car Puncture Categories and Mean Hole Sizes

FROM AAR INFORMATION			ASSUMPTIONS	HOLE AREA	
HOLE TYPE	GEOMETRY REQUIREMENT	HOLE LENGTH ℓ		(in^2)	(m^2) 10^{-4} x
I	$\ell/w < 2$	$\ell \leq 8"$	1. hole is round 2. hole diameter is equal to 4" 3. hole area = $\pi(4"/2)^2$	12.6	81.3
J	$\ell/w < 2$	$8"<\ell<18"$	1. hole is round 2. hole diameter is equal to 13" 3. hole area = $\pi(13"/2)^2$	132.7	856.1
K	$\ell/w < 2$	$\ell \geq 18"$	1. hole is round 2. hole diameter is equal to 22" 3. hole area = $\pi(22"/2)^2$	380.0	2451.6
L	$\ell/w \geq 2$	$\ell \leq 8"$	1. hole length ℓ is equal to 4" 2. hole width w is equal to .25ℓ or 1" 3. hole area = ℓ*w = 4"*1"	4.0	25.8
M	$\ell/w \geq 2$	$8"<\ell<18"$	1. hole length ℓ is equal to 13" 2. hole width w is equal to .25ℓ or 3.25" 3. hole area = ℓ*w = 13"*3.25"	42.3	272.9
N	$\ell/w \geq 2$	$\ell \geq 18"$	1. hole length ℓ is equal to 22" 2. hole width w is equal to .25ℓ or 5.5" 3. hole area = ℓ*w = 22"*5.5"	121.0	780.6
O	Crack	$\ell \leq 8"$	1. hole length ℓ = 4" 2. crack width w = .125" 3. hole area = ℓ*w = 4"*.125"	0.5	3.2
P	Crack	$8"<\ell<18"$	1. hole length ℓ = 13" 2. crack width w = .125" 3. hole area = ℓ*w = 13"*.125"	1.625	10.5
Q	Crack	$\ell \geq 18"$	1. hole length ℓ = 22" 2. crack width w = .125" 3. hole area = ℓ*w = 22"*.125"	2.75	17.7

4.3.1 Hole Occurrence Probability vs. Hole Size: Speed Aggregated

In this section we have analyzed the RPI/AAR data with a view to obtaining a relationship between the hole area and its probability of occurrence. These probabilities are then compared for different classes of tank cars to evaluate the puncture susceptibility of each class of car. The probability evaluated is to be construed as the conditional probability of occurrence of a specified hole area given that the tank car is punctured in the accident (the data of the type presented in Table 4.2 are for punctured tank cars only).

(a) Methodology

In calculating the puncture probabilities, we counted only those holes that occurred on the body of the tank car. That is, accidents involving the loss of lading due to the top or bottom fitting failures were not counted.

We define first the following parameters:

P(C,HT) = Conditional probability that a tank car of class "C" suffers a hole damage of type "HT," given that a rail accident has occurred in which the tank car suffers a puncture type of damage

"C" = Tank car class which includes:

- DOT 111 Insulated
- DOT 111 Non-Insulated
- DOT 105, 112/114, 105, 112/114 (S, J, T)

"HT" = Hole Type represented by the letters I, J, K, L, M, N, O, P, and Q (see Figure 4.1)

Then the total number of cars of a given class suffering a specified size damage is given by,

$$N(C,HT) = \begin{array}{c} N(C,HT,Head) + N(C,HT,Shell) + \\ N(C,HT,H+S) + N(C,HT,H \text{ or } S) \end{array} \qquad (4\text{-}1)$$

where, for a given car class C:

N(C,HT) = the total number of tank cars with holes of type HT occurring at all speeds and tank locations

N(C,HT,Head) = the number of tank cars with holes occurring at all speed ranges at the location of the tank head

N(C,HT,Shell) = the number of tank cars with holes occurring at all speed ranges at the location of the tank shell

N(C,HT,H+S) = the number of tank cars with holes occurring at all speed ranges at the location of the tank shell and head

N(C,HT,H or S) = the number of tank cars with holes occurring at all speed ranges at the location of the tank shell or head.

For a given car class C, the total number of tank cars with holes of all types N(C) occurring at all speeds and tank locations was then determined by summing (N(C,HT) for all hole types:

$$N(C) = \sum_{HT} N(C,HT) \tag{4-2}$$

where the summation is over all types of holes I, J, ... Q.

For a <u>given car class C</u>, the probability of occurrence Pr(C,HT) of a given hole type HT (independent of speed and location) is then determined by dividing the number of tank cars with holes of a given type at all speeds and tank locations by the total number of tank cars suffering holes of all types at all speeds and locations:

$$Pr(C,HT) = N(C,HT)/N(C) \tag{4-3}$$

(b) Results

For the purposes of illustrating the above calculation procedure, we consider the RPI/AAR data for DOT 111 insulated cars with I holes ($\ell \leq 8"$). A total (all speeds) of 7 head punctures, 3 shell punctures, 0 "H+S" punctures, and 5 "H or S" punctures are reported to have occurred in all accidents during the period 1965-1988. The total number of Type I holes occurring at all speeds and locations is therefore 7+3+0+5 or 15. Likewise, the number of type J holes ($8" < \ell < 18"$) occurring at all speeds and locations is 14 and the number of type K holes at all speeds and locations is 26. Similar methodology was applied to Type L, M, N, O, P, and Q holes also, and for DOT 111 Insulated cars. The total number of tank cars with *all hole types* occurring at *all speeds* and *all tank locations* for DOT 111 Insulated cars is 122. The probability of a type I hole occurring, aggregated over speed and location, for a DOT 111 Insulated car in an accident is, therefore, (15/122)*100 or 12.3%. Likewise, the probabilities of a type J and K hole occurring are 11.5% and 21.3%, respectively.

Based on this methodology, and the assignment of discrete hole areas to the different hole types, Table 4.5 was developed. This table lists for each tank car class the hole types I-Q, number of holes of each type, total number of holes, hole area derived from assumptions indicated in Table 4.4, and the percent probability of occurrence independent of speed and tank location. The information in Table 4.5 is organized in the order of increasing hole areas. The probability of occurrence for each hole size is calculated using equation 4.3.

The conditional probability of a specified size of hole occurring in a specified class of tank car (given that the tank car has suffered a puncture) is shown plotted against the hole area in Figure 4.2A. The data shown are the aggregates over all speeds and hole locations. The results for all classes of tank cars analyzed in this project are plotted in the same figure.

In Figure 4.2B, the same results are plotted on a cumulative probability basis. In this figure the hole area is plotted as the ordinate and the cumulative probability on the abscissa. The abscissa gives the value of the probability that a hole occurring has an area equal to or smaller than the area on the ordinate. The x and y coordinates in this plot are juxtaposed compared to traditional probability plots.

(c) Discussions

Examination of Figure 4.2A shows some consistent patterns for all tank cars. We notice that for all tank cars the discrete probability values for the I, J, and K type holes (these are nearly round holes, see Figure 4.1) are higher than the probabilities for other types of holes (L, M, N, and O, P, Q) (if the largest hole probability values are not taken into account). This may be because of the predominance of I, J, K, type punctures for each type of car reported. Table 4.5 clearly shows large numbers of cars with these types of holes.

Assuming that there is no mechanical reason (other than the coupler puncturing the shell) for nature to favor one type of hole formation over another, the data are puzzling, to say the least. One possible reason is that indeed the punctures in all types of tank cars, in a major number of cases, occurred due to the couplers acting as punches in derailment accidents. The database covers the period 1965-1988. Shelf couplers and head shields came into practice only in the late 1970s. Hence, part of the database covers the accident cases in which couplers may have inflicted punctures. The second possible reason may be the bias of the damage examiner in the tank car shop to assign the holes to predominantly the I, J, and K category.

TABLE 4.5[†]

Discrete and Cumulative Conditional Probabilities of Occurrence of Tank Car Punctures of Different Sizes

CAR TYPE: DOT 111 NON-INSULATED

HOLE AREA (m^2) 10^{-4}x	NO. TANK CARS WITH SPECIFIED HOLE TYPE[*]	HOLE TYPE	PERCENT (%) PROBABILITY OF OCCURRENCE	CUMULATIVE PROBABILITY (%)
3.2	13	O	2.3	2.3
10.3	15	P	2.6	4.9
18.1	16	Q	2.8	7.7
25.8	7	L	1.2	8.9
81.3	134	I	23.5	32.4
272.9	21	M	3.7	36.1
780.6	56	N	9.9	45.9
856.1	100	J	17.5	63.4
2451.6	209	K	36.4	100.0
TOTAL	570	–	100.0	–

CAR TYPE: DOT 111 INSULATED

HOLE AREA (m^2) 10^{-4}x	NO. TANK CARS WITH SPECIFIED HOLE TYPE[*]	HOLE TYPE	PERCENT (%) PROBABILITY OF OCCURRENCE	CUMULATIVE PROBABILITY (%)
3.2	12	O	3.1	3.1
10.3	10	P	2.6	5.7
18.1	4	Q	1.1	6.8
25.8	9	L	2.4	9.2
81.3	96	I	25.3	34.5
272.9	10	M	2.6	37.1
780.6	22	N	5.8	42.9
856.1	62	J	16.3	59.2
2451.6	155	K	40.8	100.0
TOTAL	380	–	100.0	–

[†] Average value of hole size in each hole type category is used

[*] Data from 1965-1988 Accidents (Phillips, 1992)

TABLE 4.5[†] (continued)

Discrete and Cumulative Conditional Probabilities of Occurrence of Tank Car Punctures of Different Sizes

CAR TYPE: DOT 105

HOLE AREA (m^2) 10^{-4}x	NO. TANK CARS WITH SPECIFIED HOLE TYPE*	HOLE TYPE	PERCENT (%) PROBABILITY OF OCCURRENCE	CUMULATIVE PROBABILITY (%)
3.2	5	O	10.0	10.0
10.3	1	P	2.0	12.0
18.1	3	Q	6.0	18.0
25.8	4	L	8.0	26.0
81.3	12	I	24.7	50.7
272.9	1	M	2.0	52.7
780.6	4	N	8.0	60.7
856.1	10	J	20.7	81.4
2451.6	9	K	18.6	100.0
TOTAL	50	–	100.0	–

CAR TYPE: DOT 112/114

HOLE AREA (m^2) 10^{-4}x	NO. TANK CARS WITH SPECIFIED HOLE TYPE*	HOLE TYPE	PERCENT (%) PROBABILITY OF OCCURRENCE	CUMULATIVE PROBABILITY (%)
3.2	16	O	9.4	9.4
10.3	7	P	4.1	13.5
18.1	9	Q	5.3	18.8
25.8	8	L	4.7	23.5
81.3	25	I	14.8	38.3
272.9	8	M	4.7	43.0
780.6	35	N	20.5	63.5
856.1	14	J	8.1	71.6
2451.6	48	K	28.4	100.0
TOTAL	170	–	100.0	–

[†] Average value of hole size in each hole type category is used

[*] Data from 1965-1988 Accidents (Phillips, 1992)

TABLE 4.5[†] (continued)

Discrete and Cumulative Conditional Probabilities of Occurrence of Tank Car Punctures of Different Sizes

CAR TYPE: DOT 112/114 - 105 (S, J, T)				
HOLE AREA (m^2) 10^{-4}x	NO. TANK CARS WITH SPECIFIED HOLE TYPE*	HOLE TYPE	PERCENT (%) PROBABILITY OF OCCURRENCE	CUMULATIVE PROBABILITY (%)
3.2	2	O	9.1	9.1
10.3	0	P	0.0	9.1
18.1	1	Q	4.5	13.6
25.8	1	L	4.5	18.1
81.3	7	I	30.3	48.4
272.9	1	M	4.5	52.9
780.6	2	N	9.1	62.0
856.1	6	J	25.8	87.8
2451.6	3	K	12.2	100.0
TOTAL	22	–	100.0	–

[†] Average value of hole size in each hole type category is used

* Data from 1965-1988 Accidents (Phillips, 1992)

FIGURE 4.2A

Discrete Probability of Hole vs. Hole Area

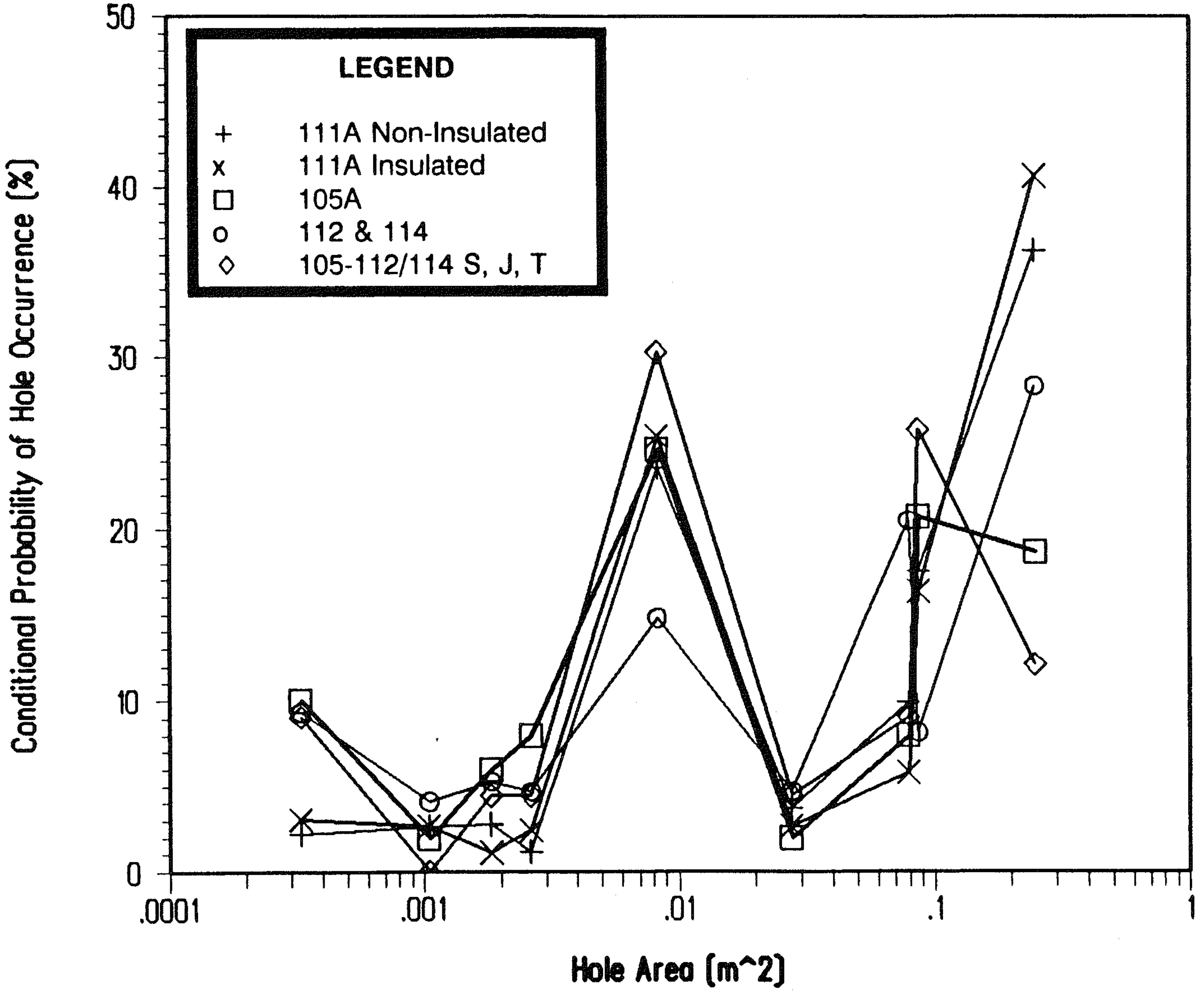
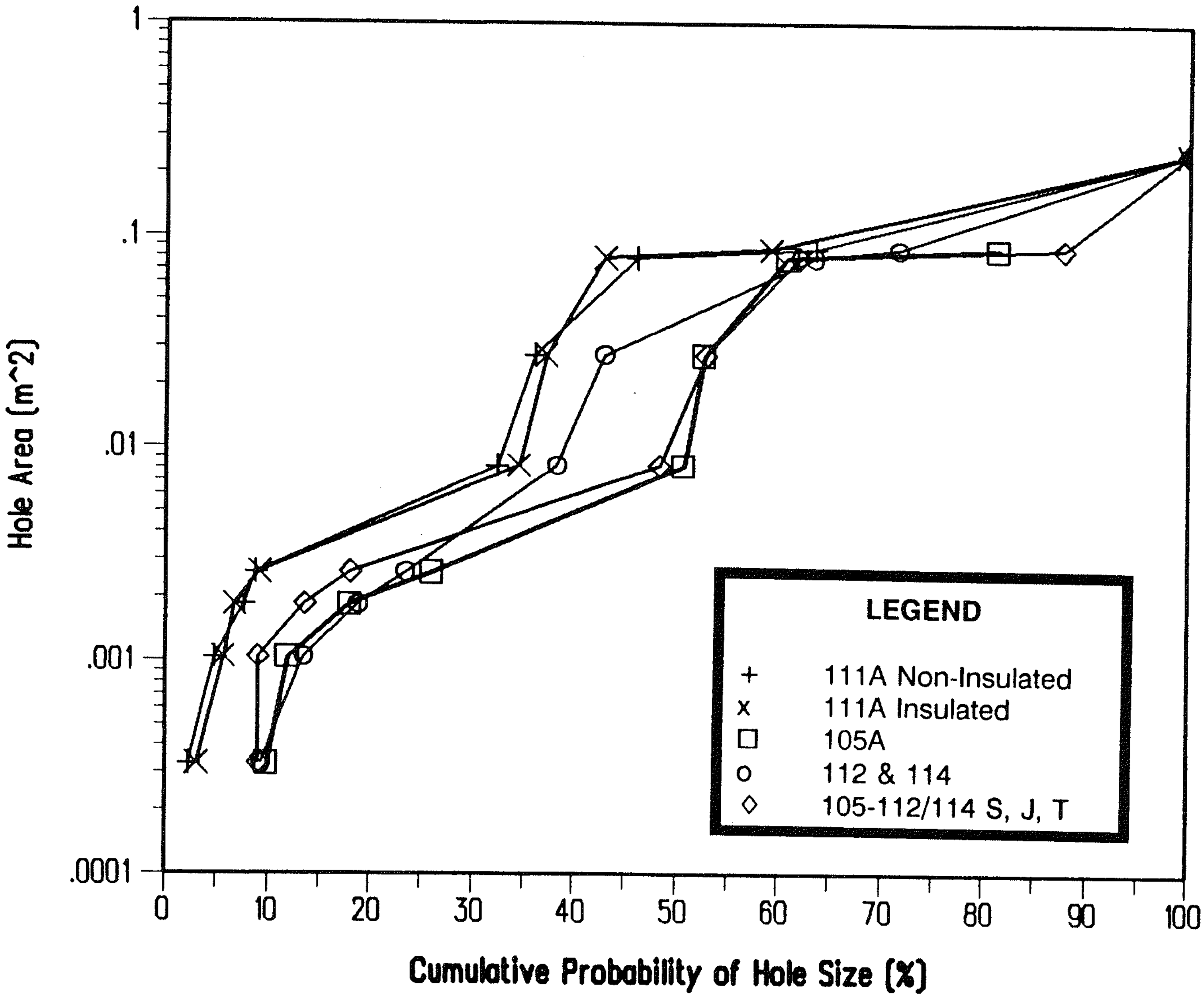


FIGURE 4.2B

Cumulative Probability of Hole vs. Hole Area



The results in Figure 4.2B show major jumps in probability at hole areas corresponding to I and J types of holes (0.008 m^2 and 0.086 m^2). The cumulative probability reaches 100% at the size of K hole (0.25 m^2). The abscissa in this figure represents the probability that given a puncture has occurred on a tank car, the hole area is equal to or smaller than a specified area.

Figure 4.2A and Figure 4.2B were plotted on the assumption that a single (mean) hole area can represent a category of hole shape and that the probability of puncture can be associated with a hole category is distributed over the entire range of hole areas that can be classified within a specific category, we expect to get a better description of the hole size probability distribution. This approach would then remove the bias related to assigning a single hole size for a category and result in a smoother probability distribution. The procedure by which the "continuous" distribution is calculated is described below.

The minimum and maximum areas of holes that can be classified under a specific hole category are indicated in Table 4.6. Also shown in this table are the probabilities of occurrence of different types of holes for DOT 111A insulated car, as an example (see Table 4.5). We <u>assume</u> that all hole areas in the range of minimum and maximum hole areas within a hole category are equally likely to occur in accidents. Based on this assumption, the probability density function between the minimum and maximum area has a constant value. This value (expressed in %/m^2) is shown for each category of holes in the last column of Table 4.6 for a specific tank car. It is noticed that there are overlapping hole areas in several categories. The probability density functions thus calculated for different tank cars are shown in Figure 4.3A.

The cumulative probability is obtained by integrating the hole size probability density distribution from the lowest area value (1.6×10^{-4} m^2) to the hole area of interest, keeping in mind the overlapping probability density functions. The cumulative probability values thus calculated are shown in Figure 4.3B. The results in this figure should be compared to the results shown in Figure 4.2B. It is seen that the probability distribution is significantly smoother, as can be expected.

A least square fit correlation is developed between the probability of occurrence of a hole of area A_H or smaller against the hole size A_H. These correlations, for different classes of tank cars, are expressed as follows:

$$P = a_2 Z^2 + a_3 Z^3 + a_4 Z^4 \tag{4.4}$$

TABLE 4.6

Probability Density Function for Different Categories of Hole Occurrence for DOT 111A Tank Cars

HOLE TYPE	PROBABILITY OF HOLE OCCURRENCE (%)	CATEGORY MINIMUM HOLE AREA					CATEGORY MAXIMUM HOLE AREA					MEAN PROBABILITY DENSITY (%/m²)
		ℓ/W	ℓ (in)	W (in)	A (in²)	A (m²) 10⁻⁴x	ℓ/W	ℓ (in)	W (in)	A (in²)	A (m²) 10⁻⁴x	
I	25.3	2	2	1	1.6	10.3	1	8	8	50	323.9	806.8
J	16.3	2	8	4	25.1	161.9	1	18	18	254	1640.6	110.2
K	40.8	2	18	9	127.2	820.6	1	24	24	380	2451.0	239.9
L	2.4	4	2	0.5	1	6.5	2	8	4	32	206.5	120.0
M	2.6	4	8	2	32	206.5	2	18	9	162	1045.2	31.0
N	5.8	4	18	4.5	81	522.6	2	24	11	264	1703.2	49.1
O	3.1	-	2	0.125	0.25	1.6	-	8	0.125	1	6.5	6326.5
P	2.6	-	8	0.125	1	6.5	-	18	0.125	2.25	14.5	3250.0
Q	1.1	-	18	0.125	2.25	14.5	-	24	0.125	3	19.4	2244.9

FIGURE 4.3A

Probability Density Function vs. Hole Area

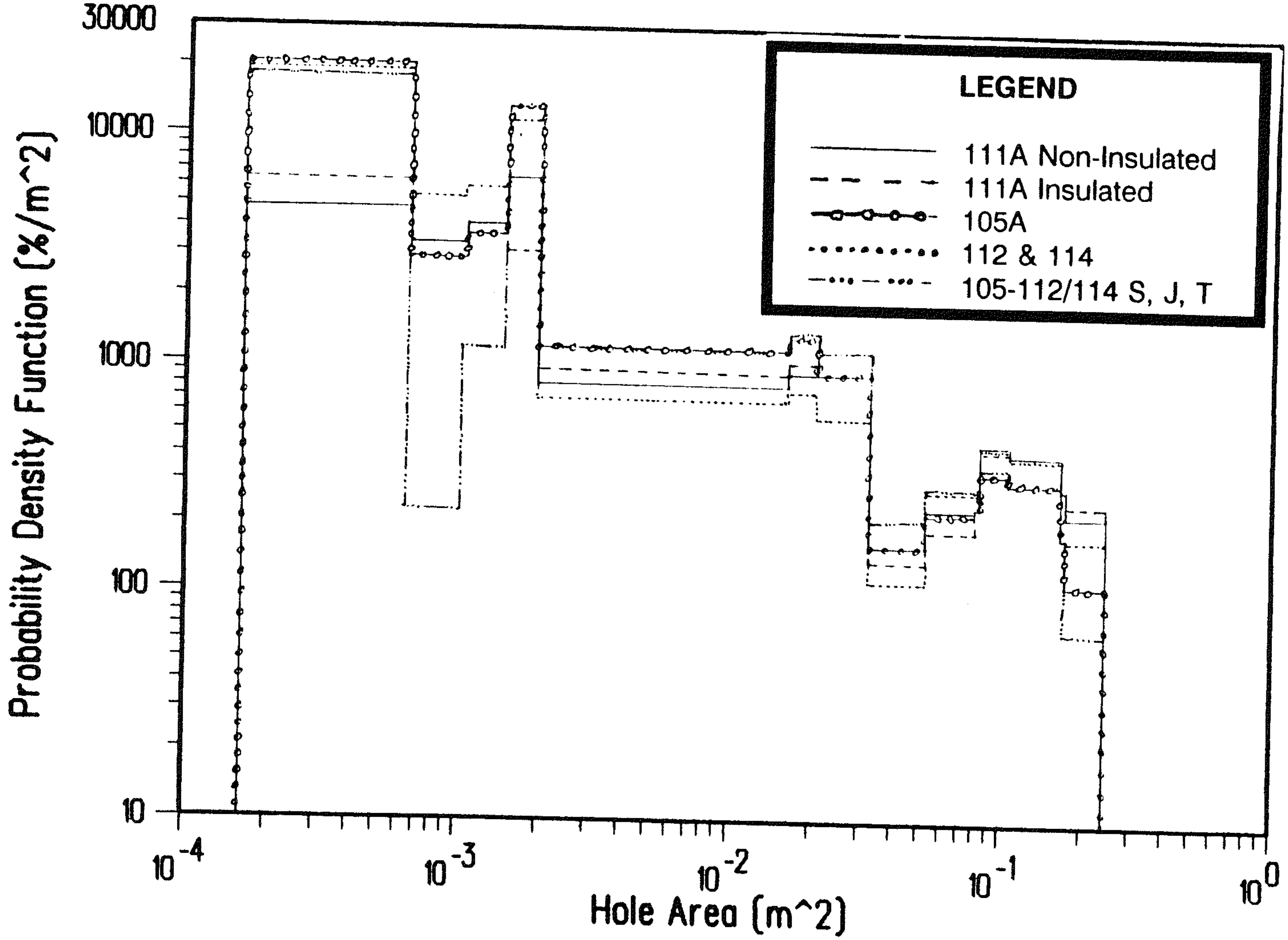
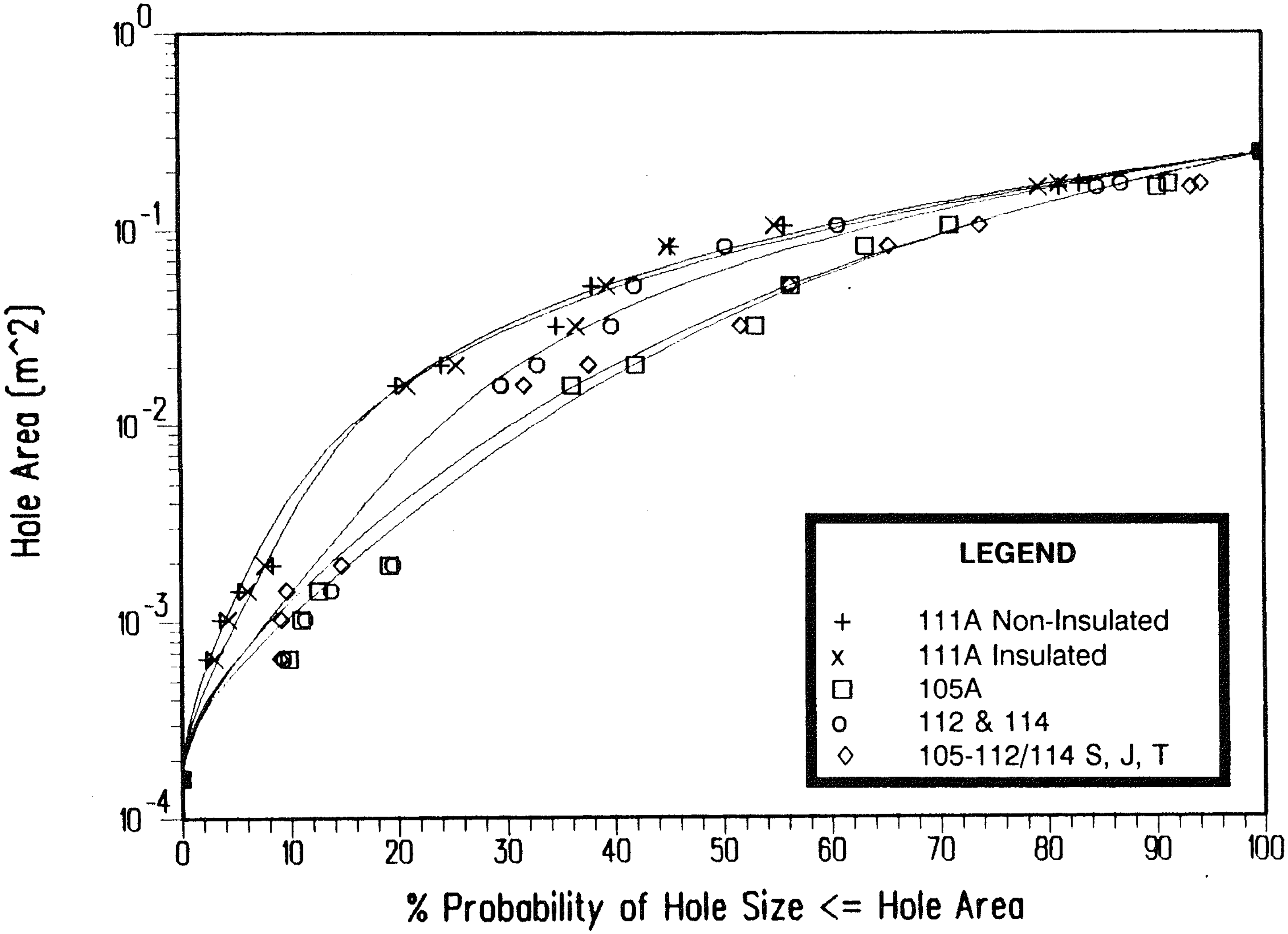


FIGURE 4.3B

Cumulative Probability vs. Hole Area



and,

$$Z = \log_{10} \left[\frac{A_H}{1.6 * 10^{-4}} \right] \tag{4-5}$$

where

P = Conditional probability (expressed as a fraction) that given a hole has occurred on a tank car, the hole area is smaller than or equal to A_H

A_H = Hole area in m^2

Z = Dimensionless area

The following Table 4.7 provides the values of the coefficients a_0, a_1 ... for the various tank car types.

TABLE 4.7

Hole Probability Correlating Equation Parameters and Mean Hole Areas

	a_2	a_3	a_4	MEAN HOLE AREA (m^2) 10^{-4}x	HOLE STD. DEVIATION (m^2) 10^{-4}x
DOT 111A Non-Insulated	10.28	-6.72	2.07	897	1193
DOT 111A Insulated	14.03	-9.79	2.66	915	1357
DOT 105A	21.20	-9.52	1.87	654	1330
DOT 112/114	20.35	-12.22	2.80	816	1475
DOT 112/114-105 (S, J, T)	17.56	-7.25	1.52	672	1210

The mean hole area for each of the tank car types is obtained by determining from the respective curves in Figure 4.3B the hole area corresponding to 50% cumulative probability. These mean area values are indicated in the fifth column of Table 4.7. Also indicated in the last column are the standard deviations of the hole area distribution.

It is seen that there is very little difference between the DOT 111A non-insulated and DOT 111A insulated tank car hole probability distributions. In fact, the mean hole areas formed in an accident have very close values for these two types of tank cars. However, significant difference exists in the distribution of hole sizes between DOT 111A cars and DOT 105 cars.

4.3.2 Tank Car Hole Size Statistics: Speed Dependent, Hole Shape Independent

In this section we examine the correlation, if any, between puncture size and train speed.

(a) Calculations

The statistical "mean area" and the "standard deviation" of hole sizes are calculated for each group of hole shapes for each speed range. For example, for the I, J, K, type of holes:

$$\bar{A}_{IJK} = \frac{N_I A_I + N_J A_J + N_K A_K}{(N_I + N_J + N_K)} \tag{4-6}$$

and

$$\sigma_{IJK} = \left[\frac{N_I(A_I - \bar{A})^2 + N_J(A_J - \bar{A})^2 = N_K(A_K - \bar{A})^2}{(N_I + N_J + N_K)}\right]^{\frac{1}{2}} \tag{4-7}$$

where

$\bar{A}_{IJK}$ = weighted mean area of the punctures in the hole category I, J, K

σ_{IJK} = standard deviation of hole areas in the hole category I, J, K

N_I, N_J, N_K = redistributed[1] number of leaking tank cars in accidents with holes of types I, J, K, respectively, for a particular car type and in train accidents in specified speed range.

A_I, A_J, A_K = mean hole areas for hole type I, J, K, respectively (see Table 4.4)

Similar calculations are made for other hole categories and speed ranges.

The overall mean and standard deviation of hole area for all hole types in a given speed and specified tank car is then determined by

$$\bar{A} = \frac{N_{IJK}\,A_{IJK} + N_{LMN}\,A_{LMN} + N_{OPQ}\,A_{OPQ}}{(N_{IJK} + N_{LMN} + N_{OPQ})} \tag{4-8}$$

and

$$\sigma = \frac{N_{IJK}\,\sigma^2_{IJK} + N_{LMN}\,\sigma^2_{LMN} + N_{OPQ}\,\sigma^2_{OPQ}}{(N_{IJK} + N_{LMN} + N_{OPQ})} \tag{4-9}$$

where

$$N_{IJK} = N_I + N_J + N_K \text{ etc.} \tag{4-10}$$

$$= \textit{total number of punctured cars in IJK hole category}$$

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[1] *In the database there are a number of entries with the type of puncture or the speed at which accident occurred as "unknown". These "unknown" number of tank car punctures were redistributed among the known damage types and speed in the proportion of known damaged car numbers. The term "redistributed" indicates the result of this process.*

(b) Results

Table 4.8 shows the number of cars punctured[2] by specific class of cars, types of puncture, and train speed. Also shown are the average areas and standard deviations of hole area. For each type of tank car and speed range, the average and standard deviation of hole area (averaged over all shapes of holes weighted by their respective numbers of occurrence) are calculated.

Figure 4.4A shows the plot of hole area variation with train speed for DOT Class 111A non-insulated tank cars. The numbers of data points using which the mean and standard deviation statistics are obtained are also shown in the figure. It is seen that the mean hole size does not vary for a train speed lower than 30 mph. However, in the 30-40 mph and 40-50 mph speed ranges, the hole sizes seem to be bigger, by almost a factor of 2.2. For speeds greater than 50 mph, the average hole size is smaller than that in 30-50 mph speed range! This result may be a statistical aberration. It is also noticed from this figure that the standard deviation of hole area is relatively large – almost of the magnitude of the mean area itself. Also, the value of the standard deviation does not seem to vary with speed.

Similar plots of hole area statistics with train speed are shown in Figure 4.4B through Figure 4.4E, respectively for tank cars DOT 111A insulated, DOT 105A, DOT 112 & DOT 114, DOT 112/114 & DOT 105 S, J, T.

(c) Discussions

An examination of the puncture data of unprotected or partially protected cars reveals no trend in the variation of hole area with speed that can be explained with a physical model of the accident. The behavior of decrease in hole area with speed and, in some cases, hole area increase and then decrease with increasing speed cannot be explained by any structural mechanical models. In fact, it is our contention that the results may be indicating the influence of random parameters (such as the ground conditions, height of fall from embankment, mix of freight in the consist, etc.) on the size of puncture that occurs on tank cars. However, one trend is somewhat evident; that is, within the error band represented by the standard deviation, the mean hole area may be considered to be independent of train speed.

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[2] *The reason for the occurrence of fractional numbers in the number of tank cars with product loss in accidents is a statistical aberration. In the database supplied by AAR, there were a number of cars with unknown types of punctures and accidents in which there was no speed data. These numbers for leaking cars have been redistributed into the known hole and speed category class types in the proportion of the number of damaged cars in the known speed ranges and damage types.*

TABLE 4.8

Statistics on Tank Car Puncture Sizes
(Based on 1965–1988 Accident Data)

DOT Tank Car Type	Hole Type	Parameter	Speed Range in mph						Speed Indep Stats
			0-10	10-20	20-30	30-40	40-50	>50	
		Avg Speed (mph)	5	15	25	35	45	55	
111-N	I,J,K	# Punctured Cars	58.6	36.1	82.5	97.5	123.9	41.4	
		Avg: AH (m^2) = 1E-4x	905	802	974	2064	1729	598	
		StdDev: AH(m^2) = 1E-4x	970	824	982	855	917	869	
	L,M,N	# Punctured Cars	13.4	6.6	16.7	21.3	23.0	3.1	
		Avg: AH (m^2) = 1E-4x	403	704	523	709	605	617	
		StdDev: AH(m^2) = 1E-4x	277	182	313	177	273	237	
	O,P,Q	# Punctured Cars	10.1	2.9	12.6	7.1	8.4	3.2	
		Avg: AH (m^2) = 1E-4x	11.1	10.5	9.0	10.4	13.9	12.8	
		StdDev: AH(m^2) = 1E-4x	6.5	0.0	6.0	4.3	5.4	6.7	
	All Holes	# Punctured Cars	82.1	45.6	111.8	125.9	155.3	47.7	568
		Avg: AH (m^2) = 1E-4x	713	738	798	1719	1470	560	1149
		StdDev: AH(m^2) = 1E-4x	887	761	911	1000	980	825	930
111-Ins	I,J,K	# Punctured Cars	26.4	16.8	46.6	82.2	104.3	35.4	
		Avg: AH (m^2) = 1E-4x	1644	1122	1160	1109	1823	1130	
		StdDev: AH(m^2) = 1E-4x	1087	985	1024	1120	919	987	
	L,M,N	# Punctured Cars	6.2	3.0	3.2	14.2	13.2	1.2	
		Avg: AH (m^2) = 1E-4x	365	125	431	685	413	781	
		StdDev: AH(m^2) = 1E-4x	304	121	235	251	320	0	
	O,P,Q	# Punctured Cars	8.2	6.1	1.1	4.8	5.9	0.0	
		Avg: AH (m^2) = 1E-4x	4.8	7.7	3.2	10.5	12.9	NA	
		StdDev: AH(m^2) = 1E-4x	3.0	5.5	0.0	0.0	5.6	NA	
	All Holes	# Punctured Cars	40.7	25.8	50.9	101.2	123.4	36.6	379
		Avg: AH (m^2) = 1E-4x	1122	745	1089	998	1587	1119	1210
		StdDev: AH(m^2) = 1E-4x	1137	947	1010	1048	1018	973	1030

TABLE 4.8 (continued)

Statistics on Tank Car Puncture Sizes
(Based on 1965–1988 Accident Data)

DOT Tank Car Type	Hole Type	Parameter	Speed Range in mph						Speed Indep Stats
			0-10	10-20	20-30	30-40	40-50	>50	
		Avg Speed (mph)	5	15	25	35	45	55	
105	I,J,K	# Punctured Cars	1.3	1.3	3.1	19.0	5.0	2.3	
		Avg: AH (m^2) = 1E-4x	1130	1130	1042	755	1659	1707	
		StdDev: AH(m^2) = 1E-4x	987	987	823	855	1002	990	
	L,M,N	# Punctured Cars	1.0	1.0	2.0	3.0	2.0	0.0	
		Avg: AH (m^2) = 1E-4x	781	781	149	277	403	NA	
		StdDev: AH(m^2) = 1E-4x	0	0	123	356	377	NA	
	O,P,Q	# Punctured Cars	0.0	0.0	4.0	3.0	2.0	0.0	
		Avg: AH (m^2) = 1E-4x	NA	NA	3.2	10.5	17.7	NA	
		StdDev: AH(m^2) = 1E-4x	NA	NA	0.0	5.9	0.0	NA	
	All Holes	# Punctured Cars	2.3	2.3	9.1	25.0	9.0	2.3	50
		Avg: AH (m^2) = 1E-4x	977	977	389	609	1015	1707	726
		StdDev: AH(m^2) = 1E-4x	761	761	676	802	1060	990	840
112	I,J,K	# Punctured Cars	7.2	14.2	16.2	22.5	22.3	4.5	
		Avg: AH (m^2) = 1E-4x	793	1441	1374	1519	1844	1743	
		StdDev: AH(m^2) = 1E-4x	1022	1160	1130	1019	934	793	
	L,M,N	# Punctured Cars	3.1	8.4	10.8	7.1	13.3	8.1	
		Avg: AH (m^2) = 1E-4x	537	540	734	425	591	562	
		StdDev: AH(m^2) = 1E-4x	353	330	147	327	297	294	
	O,P,Q	# Punctured Cars	3.2	8.1	8.8	6.4	4.4	1.0	
		Avg: AH (m^2) = 1E-4x	5.5	12.2	5.7	10.0	8.1	17.7	
		StdDev: AH(m^2) = 1E-4x	3.4	6.1	4.9	6.0	5.9	0.0	
	All Holes	# Punctured Cars	13.5	30.7	35.8	36.0	40.0	13.6	170
		Avg: AH (m^2) = 1E-4x	548	817	844	1034	1224	913	951
		StdDev: AH(m^2) = 1E-4x	829	1012	942	1037	1013	787	974

TABLE 4.8 (continued)

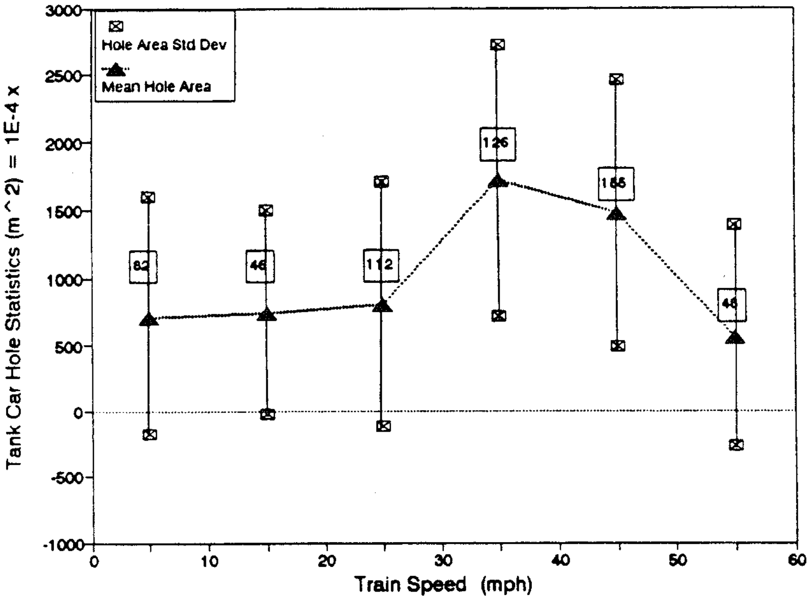
Statistics on Tank Car Puncture Sizes
(Based on 1965–1988 Accident Data)

DOT Tank Car Type	Hole Type	Parameter	Speed Range in mph						Speed Indep Stats
			0-10	10-20	20-30	30-40	40-50	>50	
		Avg Speed (mph)	5	15	25	35	45	55	
105, 112/ 114 S, J, T	I,J,K	# Punctured Cars	0.0	0.0	4.0	5.0	1.0	5.0	
		Avg: AH (m^2) = 1E-4x	NA	NA	868	555	1130	911	
		StdDev: AH(m^2) = 1E-4x	NA	NA	968	949	987	453	
	L,M,N	# Punctured Cars	0.0	0.0	1.0	2.0	1.0	0.0	
		Avg: AH (m^2) = 1E-4x	NA	NA	25.8	526.6	780.6	NA	
		StdDev: AH(m^2) = 1E-4x	NA	NA	0.0	254.0	0.0	NA	
	O,P,Q	# Punctured Cars	0.0	0.0	0.0	1.0	2.0	0.0	
		Avg: AH (m^2) = 1E-4x	NA	NA	NA	3.2	10.5	NA	
		StdDev: AH(m^2) = 1E-4x	NA	NA	NA	0.0	7.3	NA	
	All Holes	# Punctured Cars	0.0	0.0	5.0	8.0	4.0	5.0	22
		Avg: AH (m^2) = 1E-4x	ERR	ERR	699	479	481	911	628
		StdDev: AH(m^2) = 1E-4x	ERR	ERR	929	782	693	453	743

FIGURE 4.4A

Hole Size vs. Train Speed

TANK CAR TYPE: DOT 111A NON-INSULATED



Note: Numbers in boxes indicate the number data records in the 1965-1988 period from RPI/AAR Tank Car Database used in developing the puncture hole area statistics.

FIGURE 4.4B

Hole Size vs. Train Speed

TANK CAR TYPE: DOT 111A INSULATED

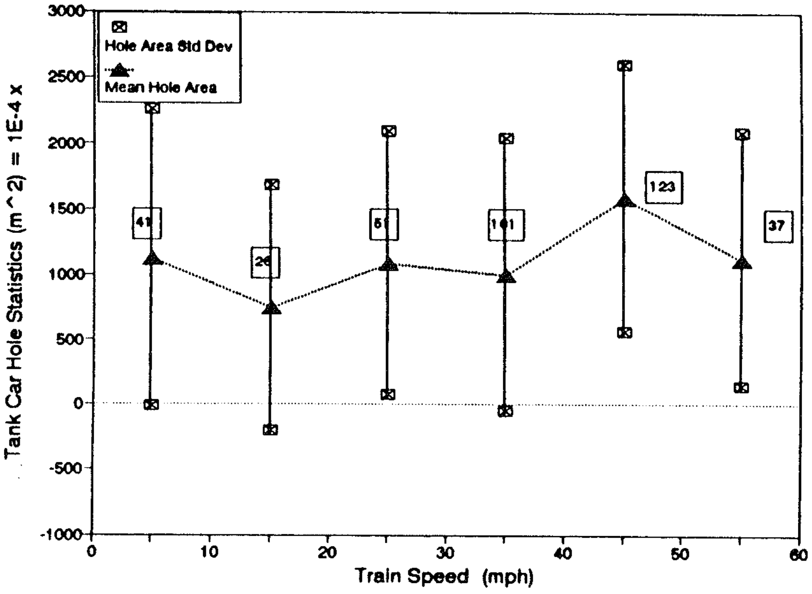


FIGURE 4.4C

Hole Size vs. Train Speed

TANK CAR TYPE: DOT 105A

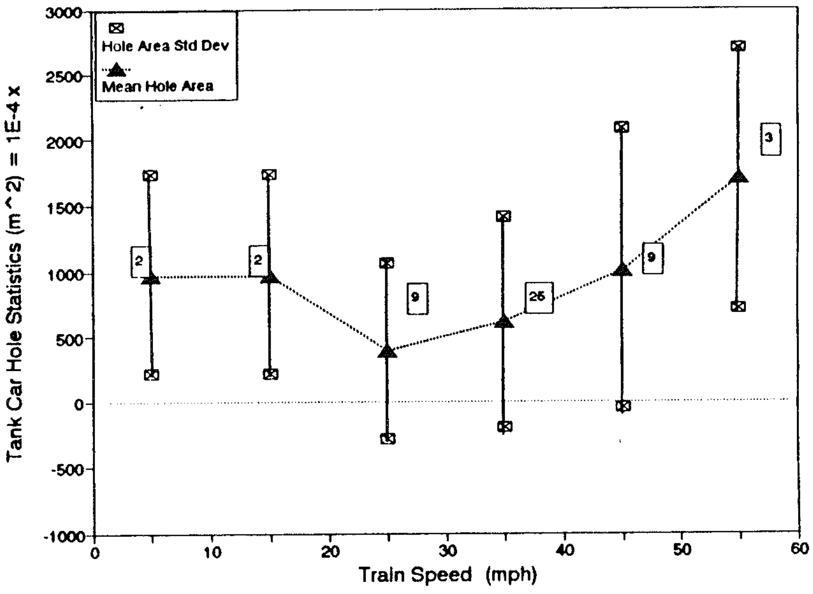


FIGURE 4.4D

Hole Size vs. Train Speed

TANK CAR TYPE: DOT 112 & 114

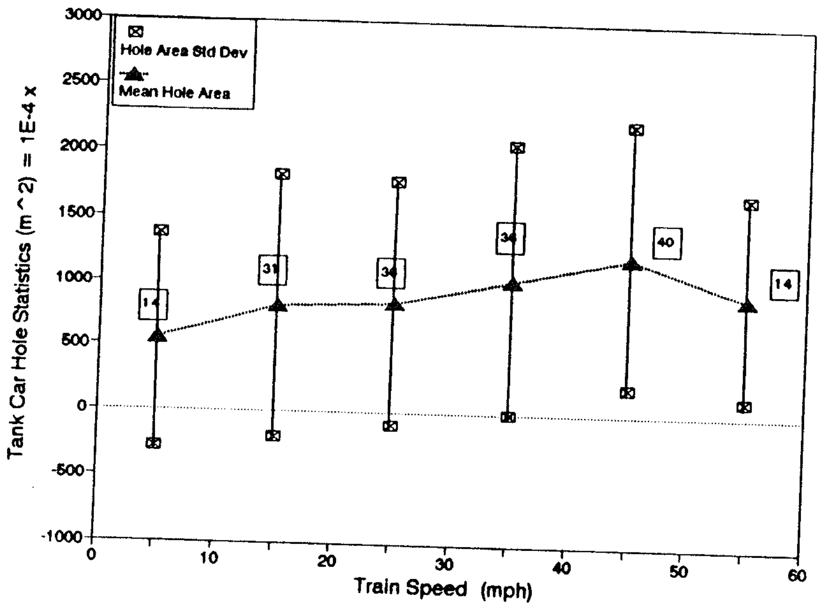
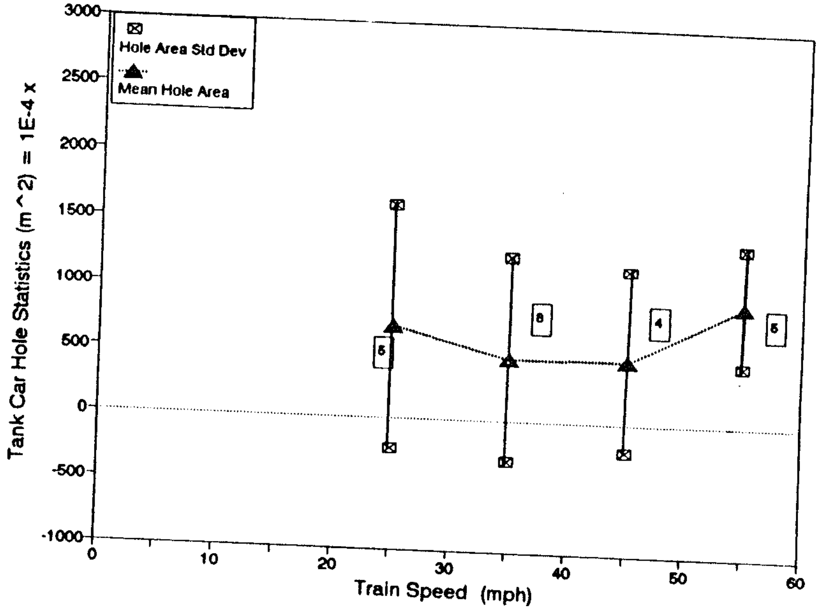


FIGURE 4.4E

Hole Size vs. Train Speed

TANK CAR TYPE: DOT 105-112/114 S, J, T



The results shown in Figure 4.4E for the protected pressure cars (105 and 112) are very interesting. First, we find that the actual areas of the holes are smaller compared to those in unprotected cars (see Figures 4.4C and 4.4D). Clearly, the effectiveness of the protective appurtenances can be seen in decreasing the damage sizes. Second, there is a reasonably clear trend of increasing hole sizes with increase in speed.

(d) Hole Size Correlations with Speed

In view of the above observations, it can be argued that we can ignore speed as a factor in determining the puncture size on a tank car (except in the case of DOT 105 S, J, T and DOT 112/114 S, J, T cars). The speed independent average hole area and hole area standard deviations are indicated in the last column of Table 4.8 for different types of tank cars.

4.4 SUMMARY OF FINDINGS

The principal findings from the analysis and results therefrom, presented in this chapter are:

1. Almost all of the punctures in tank cars caused by derailment accidents have hole sizes less than $0.3m^2$ equivalent area (i.e., equivalent diameter of hole less than about 0.6 m or about 2 feet).

2. Near circular hole shape punctures seem to occur with high probability.

3. There is noticeable difference between the hole sizes occurring on DOT 111 class tank cars and DOT 105 or DOT 112/114 cars. The difference in mean diameter of holes between DOT 111 cars and DOT 105 cars is that between 0.34m and 0.29 m, respectively. The ratio of mean puncture areas in DOT 111 cars to that in DOT 105 cars is about 1.4.

4. The provision of insulation on a tank car does not seem to have any significant effect on the tank car puncture size, shape, or the probability of occurrence of a given size hole.

5. There is no statistically discernable pattern to relate hole puncture area with the speed of the accident. This correlation is, in some cases, completely contradictory to an expectation based on engineering models (which would predict increased hole sizes with increased speed).

6. The scatter in the puncture hole area data (represented by the standard deviation) at all speeds is large compared to the mean hole area value. Therefore, no real trend of hole size dependency on speed could be developed. Hence, hole sizes assumed to be independent of speed of tank car before the accident.

7. The actual hole areas are smaller on protected cars (DOT class 105, 112/114 S, J, T) compared with non protected cars (DOT 111, 112/114).

The use of the results obtained in this chapter in determining the risks in transporting hazardous chemicals in tank cars is discussed in the next chapter.

CHAPTER 5

Risk Analysis Model: Event Probabilities

5.1 INTRODUCTION

The assessment of risks related to the transportation of hazardous chemicals in this report consists of evaluating both the probability of occurrence of various types of accidents and levels of seriousness and the consequences of these accidents. In the case of hazardous materials transport in tank cars, it is necessary to evaluate, first, the frequency (or alternately, the probability of occurrence) of accidents that could result in hazardous material releases from tank cars. Secondly, the consequence of such releases need to be determined. The consequence of concern in this study is the involuntary exposure of population in the vicinity of accidents. The focus of this chapter is the determination of the probabilities of event occurrences.

In this chapter we describe first the risk concepts as they relate to hazardous materials transport on rail. Subsequently, the different event occurrence probabilities and the method by which their magnitudes are estimated are given. Finally, the synthesis of these probabilities to estimate the probability of exposing a specified number of people is described.

5.2 THE RISK MODEL

5.2.1 Concepts

The aim of a risk analysis model is to provide an answer to the following type of question in relation to hazardous materials transportation on rail.

> "What is the annual probability of exposing a given number of people to the detrimental effects of a specified chemical due to rail accidents involving hazardous material tank cars?"

To answer this question, information on the number of tank cars of a specified class transporting the specified chemical in a year, the geographical area in which the tank cars operate, the class and type of track and historical train accident rates over these tracks, the population density in the vicinity of rail lines, etc., are required. These data are not easily available, in general, and in the public domain, in particular. Rail link specific accident rate data are essential if the objective of the risk analysis is to compare the risks of transporting the same chemical over different routes. However, in the performance of a nationwide risk assessment, the national average accident rates can be used. Even in this situation, data on the annual volume of rail traffic of the specified commodity and/or the number of movements per year of freight trains carrying the commodity should be known "a priori." In many instances, the absolute risk of transporting a specified chemical on a specific transportation corridor will be needed. Then, the volume of chemical transport (expressed, say, in number of tank cars/year moving on that transportation corridor) is needed. However, when a comparison of the relative risks from different chemicals transported in the same tank car on the same route are needed, they can be evaluated on the basis of a single tank car use for transporting the specified chemical. The analysis presented below is based on the latter approach.

The principal objective of the risk model developed in this study is to compare the relative risks (or safety) in transporting the same chemical in different types of tank cars over statistically similar routes. The term "risk" can be defined in a number of ways. The first and possibly the simplest way is to determine the expected number (or the average number) of people that are exposed annually to the harmful effects of a specified chemical and the annual probability for such an exposure. The second definition of "risk" is to identify all possible types of accidents, releases, and then determine the corresponding number of people exposed to the chemical effects and for each type or severity of hazard, the probability of occurrence of such an event. A plot of the probability of occurrence against the severity of the exposure provides a graphical view of the "risk" (this plot is called a risk profile).

The model described below uses the second definition of risk. The advantage in such a definition is that the potential for occurrence of a series of different levels of hazards can be discerned and modifications to either the operational procedures or to the hardware may be developed to minimize both the frequency of occurrence and the level of a particular type hazard. The model uses this approach to determine the relative risks arising from the transportation of a specified hazardous chemical in different classes of tank cars. The relative risks from different chemicals can also be evaluated.

5.2.2 Model Assumptions

The risk analysis model described in Section 5.2.3 makes the following assumptions:

1. The probability of a train being involved in an accident is independent of its consists.

2. The probability of a tank car being involved in an accident is independent of the size or class of tank car.

3. The accident occurrence is a relatively rare event and, therefore, it can be represented by a Poisson statistic.

4. Only main line train accidents are considered in the model.

5. The model evaluates only the conditional risk. That is, only probabilities of occurrence of different magnitude events are determined conditioned on the assumption that a train accident has occurred.

6. National risk is the product of conditional risk, the number of in service tank cars of the particular class carrying the chemical and the mean derailment/ damage rate.

7. Hazardous material releases/leaks from tank car appurtenance failures or malfunctions are <u>not</u> considered.

8. Mitigating effects of emergency response action ("active response") or the beneficial protective effects of buildings, automobiles, and other shelters for short term exposure of humans to chemical dangers ("passive protection") are <u>not</u> considered in the model.

Assumption 1 above is based on the fact that the commodity being hauled does not, in a very large number of accident cases, cause the accident. That is, train accidents occur due to mechanical failures, human errors, or other operational causes rather than due to the cargo.

The second assumption is based on the premise that train accidents are caused by circumstances and external forces that are not dependent on what types of freight cars are in the consist. If, for example, a derailment is caused by a freight car due to bearing seizure or a wheel breakage resulting in the derailment of several trailing cars the presence or absence of hazardous material tank car or its size or its tank car class in the consist behind the defective car will not significantly alter the probability of derailment of the cars behind the defective car.

The third assumption has to do with the rarity of train accidents (compared to the number of trains that are in service at any given instant of time) and damage to tank cars in the consist carrying hazardous materials. In such rare events, one can interchangeably use the annual frequency with the probability of occurrence of at least one event in a year (both of which are numerically equal to the mean frequency of occurrence of the event in a given year). This, therefore, leads to Poisson statistic. The analysis is focused on main line train accidents. This is because of the "a priori" assumption that the potential for damage to tank cars is higher in main line accidents (possibly because of higher speeds) and that anticipated size of hazardous material releases are greater than in, say, yard accidents. Large releases tend to envelope large areas and potentially expose a larger number of the population to the chemical effects. Therefore, it is necessary to evaluate the risks associated with main line accidents.

The data on leakage from fittings from tank cars is not available completely. AAR provided information on a number of incidents in which the quantity of material leak was < 100 gallons, 100-1,000 gallons, and > 1,000 gallons. Unfortunately, it is uncertain whether a part of these fitting leak incidents are also included in the tank car leak incidents or whether they form a completely independent set of incidents. In any case, since neither the size of the opening (to evaluate the rate of release of the hazardous material) nor the exact quantity released in the > 1,000 gallon category is known, it is difficult to estimate a potential hazard area. Hence, in this risk assessment study, the leaks from fittings are not included.

The risk model indicated below addresses only the conditional risks. That is, the conditional risk of exposing a specified number of persons given that an accident has occurred, is evaluated. The frequency of occurrence of main line accidents leading to damage to a hazardous material car is obtained from the national average statistics. This number will be common to all tank cars. A more exact risk analysis will take into account the car specific derailment and damage rate. This number will depend on local track conditions, speed, and volume of traffic (expressed, perhaps, in the units of train miles), etc. Not included in the risk model is the beneficial effects of response action by emergency personnel in reducing the number of people who may be exposed to the harmful chemical effects.

5.2.3 Model Details

We define the following probabilities used in the model

$P(N|Acc)$ = Conditional probability of exposing N persons to the harmful effects of a hazardous material release from a single tank car in a train accident given that a train accident has occurred and a tank car is derailed and damaged.

$P(N \geq N^{*}|Acc)$ = Conditional probability of exposing a number of persons equal to or greater than a specified number N^{*} given that a train accident has occurred (in which a tank car is derailed and damaged).

$P(R|Acc)$ = Probability of chemical release from a tank car given that the tank car is damaged. (Alternately, this is the probability that a derailed and damaged tank car sustains a puncture.)

$p(A_H)$ = Probability density that the derailed and damaged tank car sustains a puncture of area A_H and $A_H + dA_H$.

$P(N|A_H)$ = Probability of exposing N persons to the chemical effects when the tank car sustains a puncture of hole area A_H

We have the relationship

$$P(N|Acc) = P(R|Acc) \sum_{A_H = 0}^{A_H^{max}} p(A_H)\ dA_H\ P(N|A_H) \tag{5.1}$$

The expression within the summation operator is the probability of a hole area A_H occurring and exposing N persons to the chemical effects. The summation over all possible hole sizes on the tank car yields the probability of exposing N persons from any puncture. A_H^{max} represents the largest hole area possible on a tank car.

For a specified tank car, with specified safety enhancement features (shelf coupler, head shield, insulation, etc.) the term $P(R|Acc)$ is obtained from historical accident data and engineering models. In this study, this value is obtained from the data provided by AAR (see Table 4.3). The value of $p(A_H)$ is obtained from the slope of the curves presented in Figure 4.3B or by using the correlation equation 4.4 together with the results in Table 4.7.

The evaluation of the term $P(N|A_H)$, unfortunately, involves a very complex process. The number of people potentially "exposed" when a tank car with a hazardous chemical sustains a puncture depends on at least the following parameters:

1. The physical, chemical, and hazardous behavior properties of the chemical released.
2. The rate at which the chemical is released and the total quantity released.
3. The meteorological, topographical, and other environmental conditions at the time and location of release.
4. The hazard criterion; that is, the index by which the harmful effects of the chemical is specified. (This index will be different for different types of hazards–toxic effects, fires, explosions, etc. and also will depend on the definition of what constitutes a "hazard".)
5. The distribution of the density of population from the location of release.
6. Effects of active mitigative actions (emergency evacuations) or passive protections (buildings, automobiles, etc.).

We describe in the sections to follow how each of the above parameters is considered and used in the Tank Car Risk Model. The number of people potentially exposed under a given set of chemical release circumstances is given by

$$N = A_E \rho \tag{5.2a}$$

where,

N = Number of persons potentially exposed

ρ = Population density in the vicinity of the train accident. (The value of this density is assumed to be constant over the potential chemical exposure area A_E)

A_E = Chemical exposure area due to the hazardous nature of the released chemical.

The exposure area A_E depends on the nature of the chemical, the meteorological and local environmental conditions. In Chapter 6 we discuss in detail the models and methodologies for determining the hazard area for a variety of chemicals, and environmental conditions. The density of population also varies not only from place to place, but also as a function of the distance from a rail corridor at a given locality. The variation of population density is discussed in Section 5.3.

It is noticed that there could be a number of different situations in which the product of A_E and ρ could be the same or nearly the same. A large value of A_E (a major release occurring) and a low value of ρ (say, a rural area) could lead to the same number or people being exposed as in the case of a low A_E and high ρ. However, the probabilities of occurrence of each situation will be different. Hence, we have

$$P(N|A_H) = \sum_{\rho} p(\rho)\, d\rho \times P(A_E = N/\rho\, |A_H) \tag{5.3}$$

where,

$p(\rho)$ = Probability density of population density (ρ) distribution.

$P[(A_E = N/\rho)|A_H]$ = Conditional probability of realizing an exposure area A_E linked to a population density ρ, given that a hole of size A_H has occurred on the tank car.

The nature of hazard area calculations (see Section 5.3) is such that it is not very straightforward to determine the probability of occurrence of a specified hazard area resulting from a hole size A_H. This is because, the hazard area calculation involves complex and nonlinear interaction among a number of different variables. It is impossible to determine, "a priori", what exact sets of combinations of these parameters will result in a population exposure area A_E specified in equation 5.2a and 5.3. (If this were possible, then the probability of realizing the area A_E will merely be the product of the probabilities of realizing the values of each of the parameters that together lead to the hazard area A_E.)

5.2.4 Model Evaluation Methodology

In this section we discuss the methodology by which the probability of N exposures, given an accident, is determined. For the purposes of this study, we have established the following four important variables as influencing the calculation of hazard area, <u>for a specified chemical</u> and a <u>specified type of tank car</u>.

a. A_H = size (area) of hole on the tank car; the probability of A_H area hole occurring is represented by $p(A_H)\ dA_H$.

b. Different types of hazardous behavior of the chemical. These are, (i) toxic vapor dispersion, (ii) fire on a combustible or flammable pool of liquid, (iii) explosive combustion of the chemical vapors, and (iv) non-explosive fire in a vapor cloud.

   The probability that a released chemical behaves in any one of the above types is represented by P(C).

c. Two different types of weather conditions ("atmospheric stabilities") that influence the toxic vapor dispersion hazards are utilized.

   The probability of realizing the specified weather type at the time of an accident is represented by P(W).

d. A continuous distribution of population density distribution in the United States is utilized (see Section 5.3). The probability of finding a population density of between ρ and $\rho+d\rho$ at the location of a train accident is represented by $p(\rho)d\rho$.

To determine the P(N|Acc), the probability of N exposures given an accident (see equation 5.1) we follow the calculation steps indicated below.

1. The hole area region between the smallest area to the largest area in the continuous distribution of hole area probabilities (Figure 4.3B) is divided into a number of equal regions (about twenty). The mid point of each region represents a mean hole area A_H and the probability $P(A_H)$ of this hole area occurring is obtained. (This is the difference between the cumulative probabilities, indicated on the x axis of Figure 4.3B, corresponding to the boundary values of the area region chosen.)

2. A weather type is chosen. The probability of occurrence of this weather is P(W).

3. A specific chemical behavior mode is assumed. The probability of this occurrence is P(C).

4. For the chosen sets of conditions in Steps 1, 2, and 3, the hazard area is calculated (see Chapter 6).

   Let this area be A_E

5. A spill location is assumed corresponding to a population density between, say, ρ_1 and ρ_2. The probability $P(\rho_m)$ of the population density being between ρ_1 and ρ_2 is then determined. ρ_m is the mean value of population density ρ_1 and ρ_2.

6. The number of persons exposed to the hazardous chemical effects under the circumstances indicated in Steps 1 through 5 is

$$N = A_E * \rho_m \tag{5.2b}$$

The probability of this N exposures resulting from an accident involving the derailment of the specific tank car carrying the specified chemical is

$$P^*(N|Acc) = P(R|Acc) * P(A_H) * P(W) * P(C) * P(\rho_m) \tag{5.4}$$

where P^* on the left hand side of the above equation represents the probability of N exposures subject to the conditions used in steps 1 through 5 above. The value of N obtained by equation 5.2b and the probability of its realization P^* calculated in equation 5.4 are recorded into a table.

7. Steps 1 through 6 are repeated with each time changing only one parameter and retaining the values of all other parameters constant.

8. When all the calculations are completed by stepping through all possible values for all four parameters in the above procedure, a table of N vs. P^* values result. This table can then be sorted in the increasing order of N. Where there are identical values of N the corresponding P^*s can be added. The resulting sorted table gives the values of N vs. P(N|Acc) which is the result sought in equation 5.1.

The cumulative probability that in any accident (involving the release of a chemical from a <u>single tank car</u>) the number of persons exposed (N) is <u>less than</u> a given value N^* is then calculated using the equation

$$P(N \le N^*|Acc) = \sum_{N=0}^{N^*} P(N|Acc) \tag{5.5}$$

Let

$$P_{\max} = \sum_{N=0}^{N_{\max}} P(N|Acc) \tag{5.6}$$

where, N_{max} is the maximum number of persons that are calculated to be exposable in the calculations in step 6 above.

Then the probability that in a given derailment accident a number of people equal to or greater than a specified number N^* are exposed is given by

$$P(N \geq N^* | Acc) = P_{max} - P(N \leq N^* | Acc) \qquad (5.7a)$$

$$P(N \geq N^* | Acc) = \sum_{N = N^*}^{N = N^{max}} P(N | Acc) \qquad (5.7b)$$

The plot of $P(N \geq N^* | Acc)$ vs. N^* gives the "conditional risk profile." The conditional probability here is that the specified tank car is involved in a main line derailment accident and is carrying the specified chemical.

5.2.5 National Risk from a Specific Tank Car

The result from the model discussed in the previous section gives the risk from a tank car carrying a specified chemical given that a main line derailment accident has occurred and the hazardous material car has derailed and has sustained damage. As discussed before, to evaluate the national risk arising from the transport of a specified chemical in tank cars, it is necessary to have the traffic data (i.e., the number of shipments per year of the chemical in the specified tank car and the accident history of the specific tank car). These data are not easily available.

In this section, we determine the national risk due to the transport of a chemical in a particular tank car. This risk is expressed per tank car so that if the total number of tank cars of the specified type that are in service in any year (transporting the specified chemical) then the overall risk from that activity can be determined by merely multiplying the per tank car risk by the number of tank cars in service. For the purposes of this discussion the word "risk" is assumed to imply the probability of occurrence of accidents and releases.

The number of hazardous material tank cars involved in all derailment accidents in each of the years, 1985 to 1990, are indicated in Table 5.1. The data are from the FRA publication Accident and Incident Bulletin (AIB, 1985-1990). The table also indicates the number of tank cars that were damaged and the number that leaked their contents. It is seen that on the average the percent of derailed & damaged tank cars that released is about 15.7. The average ratio of number of cars releasing to that derailed (only) is about 3.8%. Furthermore, the average ratio of number of tank cars derailed to the number damaged is about 4.6.

The data on the probability of release for different classes of tank cars (discussed in section 4.2 and Table 4.3) provided by AAR are based on the assumption that the ratio of derailed to damaged cars is 1.25. This is clearly a very conservative assumption as can be seen from the results identified in Table 5.1. Hence, we interpret the AAR data as indicating the conditional probabilities of release from a tank car given that the tank car is damaged in a derailment accident (and not as AAR has implied the conditional being mere derailment).

In Table 5.1 we also provide data on the number of tank cars in service each year during 1985 - 1990. Assuming that only 70% of the tank car fleet is in motion at any instant of time we calculate the annual probability that any one tank car in motion will derail and be damaged. This probability value is designated by $P(Acc \mid T)$ and has an average value of 3.85×10^{-3}.

We now define the following probability values related to the determination of the national risk.

$P(N>N^*)$ = Annual probability of exposing a number of persons $N>N^*$ due to mainline derailment accidents involving the specified chemical and the class of tank cars in which they are transported.

$P(N>N^*|T)$ = Annual probability that a single tank car carrying the specified chemical is involved in a mainline derailment accident, suffers a release and exposes a number of persons $N>N^*$.

$P(Acc|T)$ = Annual probability that any single tank car carrying a hazardous material is derailed and damaged in a mainline accident.

TABLE 5.1

Probability of a Single Hazardous Material Tank Car Being Involved in a Derailment Accident

Year	Number of HazMat Tank Cars (see Note 1)			<--Probability of--> <--Release given --> <--a Tank Car is -->		Number of Hazmat Cars Placed in Service		Annual Probability of a specified Tank Car	
	Derailed	Damaged	Releasing	Derailed (%)	Derailed Damaged (%)	up to the year (Note 2)	in the year (Note 3)	Derailing only (Note 4)	Derailing & being damaged (Note 5)
1985	1752	554	99	5.65	17.87	174205	158688	1.58E-02	4.99E-03
1986	1411	392	71	5.03	18.11	177891	162375	1.24E-02	3.45E-03
1987	1715	412	76	4.43	18.45	184185	168669	1.45E-02	3.49E-03
1988	2689	507	65	2.42	12.82	190480	174963	2.20E-02	4.14E-03
1989	2848	527	74	2.60	14.04	196774	181258	2.24E-02	4.15E-03
1990	2480	541	71	2.86	13.12	203069	187552	1.89E-02	4.12E-03
						AVERAGE VALUE		1.77E-02	4.06E-03

Note 1: Source of data: Accident/Incident Bulletins, USDOT/FRA.

Note 2: Personal Communications, J. Rader (1992), FRA

Note 3: Based on the assumption that only 50% of cars built before 1967 are in hazardous materials service and all cars built in 1967 are currently in service.
A total of 166641 stub sill cars were in service in 1991 (Phillips, 1992)

Note 4: Assumes that at any given moment 70% of the hazmat tank cars in the fleet are in trains and in motion. Others are in yards or on customer sidings being loaded or unloaded (TMS estimates).
The number in this column is the ratio of number of cars derailed and the effective number in movement at any give time.

Note 5: This is the ratio of number of cars derailed and damaged to the total number of effective cars in service.

We have, therefore,

$$P(N>N^* \mid T) = P(Acc \mid T) \times P(N>N^* \mid Acc) \tag{5.8}$$

and,

$$P(N>N^*) = NT \times P(N>N^* \mid T) \tag{5.9}$$

where,

NT = Number of tank cars of the particular class in service in any specified year, transporting the specified chemical.

The conditional probability, $P(N>N^* \mid Acc)$, of exposing a number of people N^* or greater is that given by equation (5.7b). The determination of this value was discussed in earlier sections.

The plot of $P(N>N^* \mid T)$ against the exposure index (N) results in the national risk profile for <u>a single tank car</u> of the specified class carrying the specific chemical. The total national risk profile for that particular class of tank cars and chemical combinations can then be obtained from equation (5.9) if the number of tank cars NT in service for that chemical is known.

The use of a value of 3.85×10^{-3} for $P(Acc \mid T)$ in equation (5.8) is conservative in that the FRA data on hazardous material tank car derailment & damage do not distinguish between derailments on mainline, yard and other locations. Therefore, we anticipate that the true value for this probability for mainline derailments only will be even less than the above magnitude.

The results of application of this model to the transport of PIH and flammable chemicals are discussed in Chapter 7.

5.3 POPULATION DENSITY DISTRIBUTION

For the purposes of risk analysis rail accident locations can be broadly classified into three categories, namely, (i) rural, (ii) suburban, (iii) urban. The definition by which a specified accident location is classified into the above areas is somewhat arbitrary. In general, rural areas have low population densities, suburban has medium densities, and urban has high densities.

The US Bureau of Census publishes population densities (US DOC, 1991; US DOC 1988). These include the densities by counties and cities, organized by state. A sample of these statistics is indicated in Table 5.2. We have reviewed these statistics and based on subjective association of towns with "rural communities", "suburban - bedroom communities", and "large cities", we have developed the range of census based population densities. These are indicated in Table 5.3. Very high density areas are in downtown regions of major metropolitan cities (with population densities greater than 10,000 persons per sq. km.).

Locations of mainline rail accidents are not equally distributed over the different population regions. If we assume that the rate of mainline accidents is the same per unit length of track (which is not correct because different classes of track have different accident rates – see Nayak, et al, 1983) then we can develop the fraction of total mainline accidents that occur in, say, rural areas if the ratio of the mileage of track in "rural" areas and the total mileage of track in the US is known. Unfortunately, such data are not available readily. We have used our best engineering judgement to develop the values for these fractions. These TMS estimates are indicated in column 5 of Table 5.3.

Using the values presented in Table 5.3 for both population densities and the fraction of mainline accidents that occur in the respective regions we have developed a population density probability distribution. This distribution is shown in Figure 5.1. The abscissa in this figure is the census population density and the ordinate is the cumulative probability that given a mainline accident has occurred then the location (in the US) that it occurs in has a population density less than or equal to a specified value. It is assumed (due to the lack of any other data) that the probability distribution, in the various regions, is a straight line on the semi-log plot shown in Figure 5.1. It is also noted that slope of the distribution changes at the log mean population density values (indicated in column 4 of Table 5.3) and not at the area boundary population density values. This is because, as can be seen from Table 5.3, the population density values are not contiguous from one type of area to the other.

TABLE 5.2

Sample Data on Population Densities

MSA/ CMSA code[1]	State and place code	City	Land area[2]		Population						Population characteristics, 1980					
					1986				Net change, 1980-1986		Percent –					
			1985 (Sq mi.)	1980 (Sq mi.)	Total persons	Rank	Per square mile	1980	Number	Percent	White	Black	American Indian, Eskimo, and Aleut	Asian and Pacific Islander	His-panic[3]	65 years old and over
			1	2	3	4	5	6	7	8	9	10	11	12	13	14
...	28 0000	MISSISSIPPI	47 232.7	47 232.7	2 625 000	X	56	2 520 770	104 230	4 1	64 08	35.20	.25	.29	.98	11 5
0920	28 0110	Biloxi	19.7	19 7	47 750	482	2 424	49 311	-1 561	-3 2	78 56	17 70	.32	2 18	2 88	8 6
...	28 0265	Columbus	11.4	11 4	28 290	861	2 482	27 503	787	2 9	55.03	44 28	.08	.37	.74	11 7
...	28 0495	Greenville	11.6	11 6	40 000	602	3 448	40 613	-613	-1.5	39 84	59 43	02	.55	.93	12 3
0920	28 0515	Gulfport.................	22.4	20 0	43 410	546	1 938	39 676	3 734	9 4	73 92	25 06	.19	57	1.61	11 9
...	28 0535	Hattiesburg..............	19.5	19.2	40 740	594	2 089	40 829	-89	- 2	64 40	34 28	.07	60	1.55	11 8
3560	28 0615	Jackson	106.2	106 2	208 420	74	1 963	202 895	5 525	2 7	52 38	47 00	.07	31	.74	9 7
..	28 0805	Meridian	35.4	35.4	42 970	552	1 214	46 577	-3 607	-7.7	62 08	37 35	.09	.30	.84	14 6
6025	28 0975	Pascagoula	17.6	17.6	30 860	802	1 753	29 318	1 542	5 3	81.88	16 78	.47	51	1.37	7.4
...	28 1390	Vicksburg	13.5	13.5	26 020	911	1 927	25 434	586	2.3	47.01	52 41	.05	.38	1 41	15 6
...	29 0000	MISSOURI	68 945.1	68 945.1	5 066 000	X	73	4 916 762	149 238	3 0	88.38	10.46	.25	47	1 05	13.2
3760	29 0425	Blue Springs	14.4	13.9	33 230	747	2 308	25 936	7 294	28 1	96.73	1 46	.31	90	1.50	3.7
...	29 0695	Cape Girardeau...........	20.5	20.5	34 360	719	1 676	34 361	-1	Z	93 23	5 93	.15	46	.54	12 6
1740	29 0930	Columbia	44.2	41.9	63 140	332	1 429	62 061	1 079	1.7	88.25	8.75	.19	1 51	1.13	7.6
7040	29 1465	Florissant	12.5	10.0	59 040	367	4 723	55 721	3 319	6.0	97.63	1.78	.14	.25	.75	7 5
3760	29 2125	Independence	80.6	80.6	112 950	150	1 401	111 797	1 153	1.0	97.62	.71	.42	63	1 44	10 9
...	29 2180	Jefferson City	25.8	24.0	36 210	668	1 403	33 619	2 591	7 7	87.83	11 20	.15	38	55	13 1
3710	29 2205	Joplin...................	29.5	29.3	40 220	600	1 363	39 023	1 197	3 1	96.21	2 01	1.11	.37	.85	15 9
3760	29 2220	Kansas City	316.4	316.3	441 170	29	1 394	448 028	-6 858	-1.5	69 80	27.38	.36	.78	3.26	12 3
7040	29 2280	Kirkwood.................	8.9	8 9	27 430	881	3 082	27 739	-309	-1 1	92 63	6 65	.11	.43	.57	15 5
3760	29 2435	Lee's Summit.............	60.2	60.2	36 070	671	599	28 741	7 329	25 5	97.99	1.01	.25	.38	.85	14 8
3760	29 3615	Raytown	10.4	10.4	30 850	803	2 966	31 831	-981	-3 1	98 08	.81	.20	.43	1.20	11.3
7040	29 3630	St. Charles	12.5	12 3	41 990	571	3 359	37 379	4 611	12.3	97.38	1 72	.21	.33	63	8 9
7000	29 3865	St Joseph	44.3	44.3	74 070	274	1 672	76 691	-2 621	-3.4	95.58	3 42	.25	.20	1.85	15 9
7040	29 3875	St Louis	61.4	61 4	426 300	31	6 943	452 801	-26 501	-5 9	53.54	45 55	.14	.37	1.22	17 6
7920	29 4075	Springfield	67.2	64 9	139 360	118	2 074	133 116	6 244	4 7	96 48	2 15	.53	.55	.73	13 2
7040	29 4320	University City	5.9	5.9	42 270	567	7 164	42 690	-420	-1.0	54.98	42 98	.09	1.36	.82	15 6

[1] MSA = Metropolitan statistical area. CMSA = Consolidated MSA. All areas defined as of October 18, 9186. [2] Dry land and land temporarily or partially covered by water. [3] Persons of Hispanic origin may be of any race.

Source: USDOC (1988)

TABLE 5.3

Census Population Density by Geographical Areas

AREA CATEGORY	NUMBER OF PERSONS RESIDING PER		LOG MEAN IN NUMBER PER SQ. KM. (SEE NOTE 3)	FRACTION OF TOTAL US MAINLINE TRACK MILES IN DIFFERENT REGIONS (%) (SEE NOTE 4)
	SQUARE MILE (SEE NOTE 1)	SQUARE km (SEE NOTE 2)		
Rural	25 - 300	10 - 100	30	80
Suburban	800 - 2,000	300 - 800	500	15
Urban/City Metro	8,000 - 12,000 (max. 65,000)	3,000 - 5,000 (max. 25,000)	4,000	4
Very Congested Cities	12,000 - 65,000	5,000 - 25,000	10,000	1

Note 1: TMS estimates based on US census data indicated in "County and City Data Book", US Bureau of Census, US Department of Commerce, 1988.

Maximum density refers to Manhattan, NY

Note 2: Approximate values expressed in $\#/(km)^2$

Note 3: Approximate values of the log mean. Log mean is the square root of the product of the range extremum values.

Note 4: TMS estimates based on the assumption that 80% of mainline track mileage is in rural areas, 15% in suburban, and 4% in cities. The very high population density areas may comprise 1% of track (an extremely conservative estimate).

The population density values indicated in Table 5.3 and Figure 5.1 are the census values. The census values may not represent the true population density potentially exposed to the harmful effects of chemicals released from train accidents. It is well known that population densities vary by time of day, significantly in urban and suburban areas (Glickman, 1986). Also the population density may vary considerably from the railroad track, increasing in some cases and vice versa in other. Also a recent investigation (Glickman and Raj, 1992) in which the potentially exposed population, calculated on the basis of census population density and hazard models (see Chapter 6), and the actual casualties from recent ammonia release transportation accidents indicates that the "effective population density" may be considerably smaller than the census values. In this study, however, we have used the census population density values because the interest of the study is a comparison of relative risks in the transport of hazardous chemicals in different types of tank cars.

5.4 WEATHER OCCURRENCE PROBABILITY

One of the parameters that influence the extent of a hazard area is the meteorological condition of the atmosphere. Toxic and flammable vapor dispersion is dependent on both the wind speed and the stability of the atmosphere. Atmosphere stability condition is categorized into six categories (Slade, 1968) designated by the letters A through F. Stability A designates a very unstable atmosphere in which a vapor is quickly mixed with the atmospheric air. D Stability, also called Neutral Stability, is the more common stability class that occurs in nature. In very stable conditions very little vertical mixing occurs (early morning, late evening, or inversion conditions).

In our consequence model (see Chapter 6), we have used only D and F stability classes of atmospheres to represent most frequent condition and a condition in which mixing of hazardous vapor is low and, hence, the area of hazard is large (a conservative calculation).

The frequency of occurrence of different stability class atmospheres in a location depends on the location, the season, and other meteorological conditions (passage of fronts, etc.). Unfortunately, we were unable to obtain any type of weather data averaged over the entire US, and averaged over different seasons indicating the percent of time (annually) different stability classes occur. We have therefore estimated the probability of occurrence based on the general understanding that F type stability occurs for about 3 hours in the early morning and 3 hours late in the evening. Table 5.4 shows the (assumed) weather stability occurrence probability using the above argument.

FIGURE 5.1

Probability Distribution of Mainline Accidents in Various Population Density Areas

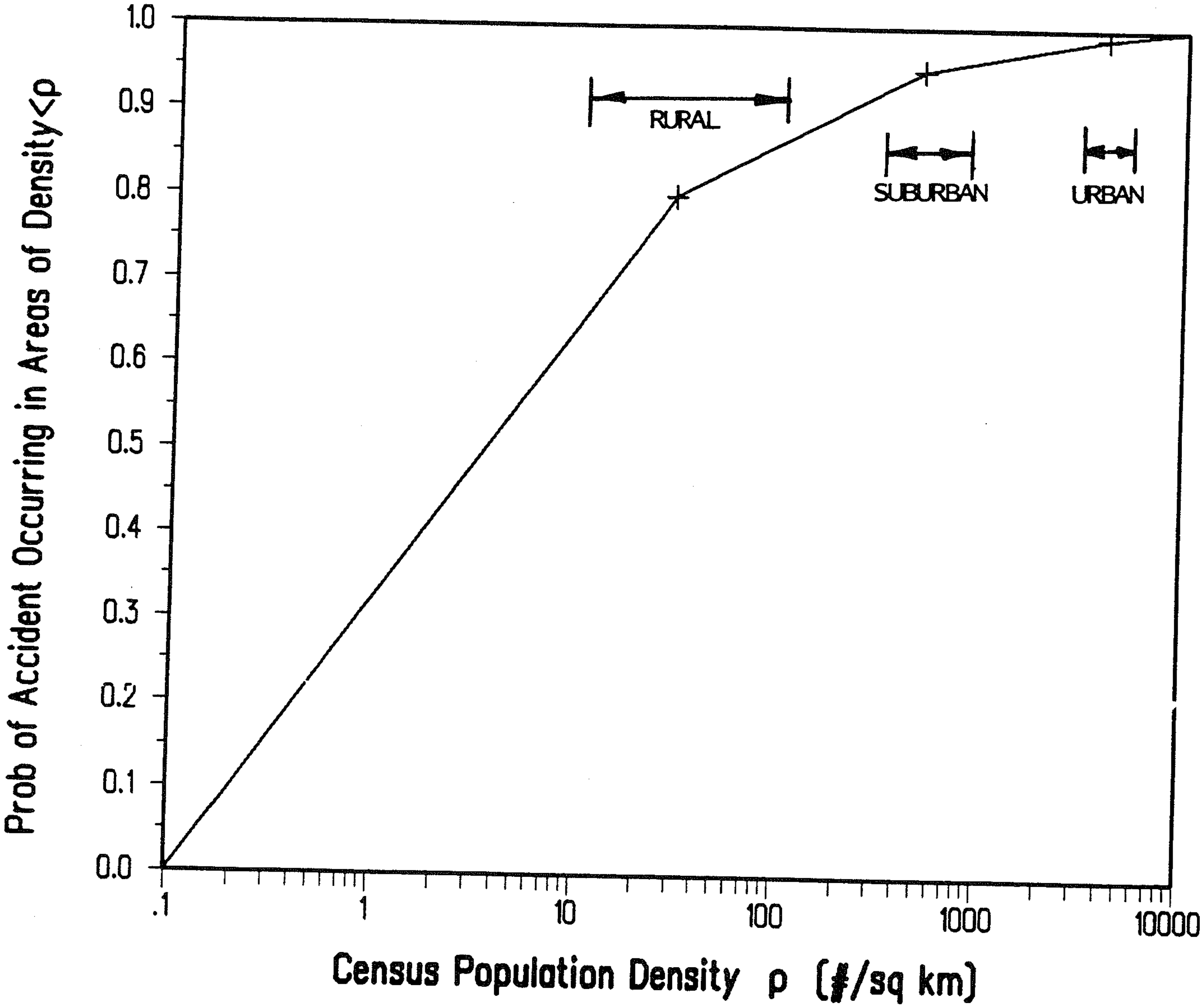


TABLE 5.4

Occurrence Probabilities of Atmospheric Stability Classes

ATMOSPHERIC STABILITY CLASS	P(W) PROBABILITY OF OCCURRENCE	MEAN WIND SPEED M/S
D - Neutral	0.75	6.0
F - Stable	0.25	2.0

5.5 DISCUSSIONS

In this chapter we discuss the evaluation of the conditional probabilities of different events related to the release of a hazardous material from a tank car. The conditional probability in this case is that a mainline derailment accident has occurred resulting in the damage to a hazardous material tank car. The events (or conditions) discussed include the release given an accident, size of the hole formed, occurrences of the event in different population density areas, and the types of weather. Also discussed is the model by which the determination is made of the probability of exposing a specified number of people.

In the next chapter we discuss several consequence models and the evaluation of the hazard area.

CHAPTER 6

Consequence Analysis

6.1 INTRODUCTION

A hazardous chemical released from a tank car following a train accident can exhibit different types of behavior depending upon the nature of the chemical, the condition of the accident, other hazardous materials released, local topography, and other external parameters. The subject matter of this chapter is the evaluation of hazard areas following the release of a chemical from a tank car and the number of people exposed to the harmful effects of the chemical. In performing these evaluations, we have made a number of assumptions and estimations. These are discussed in this chapter.

In general, a chemical released into the ambient can pose the following types of hazards to human beings, namely,

- toxicity due to vapor inhalation;
- burn injury due to thermal radiation heat flux from a pool fire;
- blast effects due to an explosion;
- burn injury due to engulfment in a propagating vapor fire; and
- contact burn injury due to corrosivity, acidity, or cryogenic temperature of the released chemical.

The focus of this chapter include the first four types of hazards. Contact burn injury is assumed to be very localized and rarely poses hazards to the general public. First we discuss the physical behavior of released chemicals and the criteria associated with each behavior for determining the hazard area. The definition of what constitutes a population "exposure" is also discussed. The basic methodology of hazard assessment models is described. Finally, the hazard area results for example scenarios and chemicals are provided.

The results of this chapter and those from Chapter 5 are combined to generate risk profiles. These latter results are discussed in Chapter 7.

6.2 TOXIC VAPOR DISPERSION

6.2.1 Dispersion Scenarios

The release of a nonflammable PIH chemical from a punctured tank car can be described by four scenarios depending on the chemical's thermodynamic state and the size of the puncture. The series of schematic diagrams in Figure 6.1 illustrate these scenarios.

Figure 6.1a shows the release of a compressed liquefied gas PIH from a relatively small hole[1]. The liquid issues from the hole in the form of a high velocity jet which flashes just outside the hole to a high velocity stream of vapor and liquid droplets. This stream entrains air from the ambient and manifests itself as a ground hugging plume because of the higher-than-air density of the vapor-liquid mixture. The mean concentration of the PIH chemical in the plume decreases as the axial distance from the hole increases. Similarly, the concentration decreases off axis.

The release of a PIH compressed liquefied gas when the puncture size is large is significantly different from the previous scenario. This is shown schematically in Figure 6.1b. The entire contents of the tank are released in an extremely short time. This leads to the formation of a very large vapor cloud containing saturated vapor, liquid droplets, and any entrained air. This large cloud tends to collapse due to its heavier-than-air density and starts moving in the wind direction *en masse*. As the cloud moves downwind it gets diluted with air, and, therefore, the vapor concentration decreases. The concentration of the PIH at ground level decreases from the center of the cloud. Also the peak concentration at the center decreases in magnitude as the cloud moves downwind. The ground level contour for a specified hazard concentration is generally circular. The sweep of the hazard concentration contour on the ground forms the hazard area.

Figure 6.1c shows the release of a liquid PIH material at ambient temperature and pressure inside the tank car through a small hole. A liquid pool forms on the ground (the shape and size of the pool being determined by the local topography). The liquid in the pool evaporates relatively slowly due to the low vapor pressure of the chemical. The toxic vapors produced are swept by the prevailing wind and dispersed downwind as a toxic vapor plume. Since the vapors of most PIH materials are heavier-than-air, the plume formed will be a ground hugging plume. When the release is through a large hole on the tank car, a larger size pool is formed very quickly; however, the vapor dispersion phenomena is similar.

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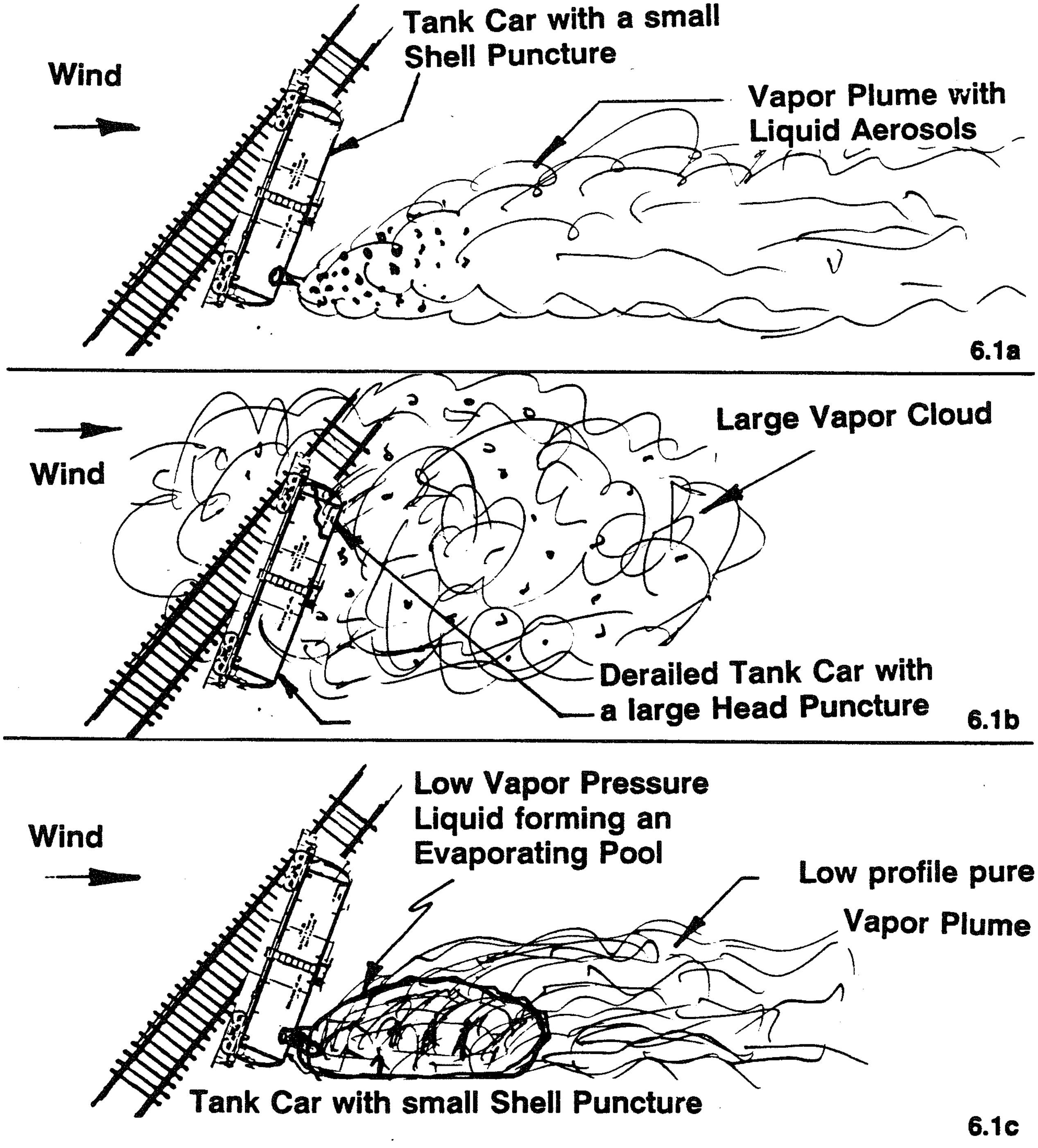
[1] *For a discussion of what size of hole is "small" or "large", see Section 4.2*

FIGURE 6.1

Contour Flow of Liquified Compressed Gas



6.2.2 Vapor Dispersion Models

A number of dispersion models exist in the literature, mathematically describing the variation of concentration within a plume or cloud as a function of spatial coordinate distances from the source as well as with time. Classical Gaussian models are applicable to releases of vapors of density close to that of the ambient air (Slade, 1968). For heavier-than-air vapors, and gas and entrained liquid droplet mixtures, heavy gas dispersion models are used. The complexity of these models range from relatively simple "top hat" models to models that solve numerically three dimensional hydrodynamic equations with turbulence included. (For a comprehensive review of the models see Raj, 1981; Raj, 1987).

In this project we have utilized the Air Force Dispersion Assessment Model ("ADAM") code for calculating the hazard area from PIH material releases. The details of this model have been published (Raj & Morris, 1987; Raj, Morris, and Reid, 1987). This model has been incorporated into a TMS proprietary chemical hazard assessment software system called "SAFEMODE". This software was used in developing the hazard area results presented in this report. The dispersion model in SAFEMODE has the following features:

- The thermodynamic state of the chemical in the tank car prior to release for specified ambient temperature and transportation condition is calculated.
- The rate of release of the chemical from the tank car for a specified hole size is calculated. Also calculated is the thermodynamic state of the chemical and outside the tank car (flashed vapor mass, liquid fraction, temperature, etc.).
- In the case of release of a compressed liquefied gas, the length of high velocity two phase jet, the air entrainment into the jet, the evaporation and/or chemical reaction of liquid aerosols with ambient moisture, etc. are determined. Also, the physical dimensions of the jet and the PIH concentration distributions are calculated.
- In the dispersion regime (where the plume velocity is close to that of the wind speed) the concentration distribution across the plume and the width of the hazard zone at ground level to a specified concentration, are also calculated. The software also determines the maximum downwind distance beyond which the concentration is below the hazard concentration.

- Similar calculations are also performed for a very rapid (instantaneous) release of the material from the tank car. In this case, a large cloud moving in the wind direction results. The program calculates the radius of the ground level hazard zone (to the specified concentration) at every downwind location of the center of the cloud. The total hazard area "swept" by the moving cloud and the maximum downwind distance of hazard area also calculated.

- In the case of release of liquids at ambient temperature, the pool size formed on the ground is determined as well as the evaporation rate from the pool. This vapor evaporation rate is used in the dispersion model to calculate the downwind extent of the hazard and the total ground level area of the hazard.

Detailed mathematical formulas and equations for this model are not presented because (i) they have been published in prior government reports (see Raj and Morris, 1987; Raj and Mullett, 1991), (ii) they are to numerous and complex, and (iii) the solution of these equations can be obtained only with the aid of a computer. Closed form solutions are, unfortunately, not obtainable.

The results of application of the above model to selected PIH material release scenarios are discussed in Section 6.2.4.

6.2.3 Toxic Vapor Exposure (Concentration) Limit

One of the key parameters that define the area of hazard resulting from the dispersion of a PIH vapor in the atmosphere is the "limit exposure concentration," also termed the "hazard concentration." Different concentration values pose different types of harmful health effects on human beings, ranging from slight discomfort to fatality. A number of toxic chemical concentration standards include (i) Threshold Limit Value (TLV); (ii) Permissible Exposure Limits (PEL); (iii) Immediately Dangerous to Life and Health (IDLH); (iv) Emergency Response Planning Guideline Concentrations (ERPGs); (v) LC_{50}; (vi) Short Term Exposure Limit (STEL); etc. The precise definition of these standards, the source of the standards, and their applicability to determining the hazards posed to a population from short duration chemical releases are discussed in greater detail in Appendix B.

One of the principal difficulties in performing a risk analysis of this nature is specifying "a priori" what the measure of consequence should be. That is, for example, in the case of toxic hazardous material effects, should we consider (and count) only potential serious injuries or only potential fatalities, or some other criterion? The term "Exposure of Population" has to be clearly defined and understood. We have used the IDLH concentration value (NIOSH, 1990) as the limit concentration. In generating the consequence results presented in Chapter 7 of this report, the following definition of exposure is used:

> "A person is counted as being exposed to the detrimental effects of a toxic vapor cloud if he/she is exposed continuously to airborne chemical vapors at a concentration equal to or in excess of exposure-time-modified-IDLH concentration value."

The IDLH concentration value is defined as that concentration of the airborne hazardous material to which if a person is subject for 30 minutes or less will not result in any irreversible health effects or suffer symptoms leading to an impairment of his/her ability to take protective action. It can be argued that if a person is exposed to a chemical vapor for less than 30 minutes, a higher level of concentration can be tolerated. Human toxicological data are not available for most hazardous materials that provide the IDLH equivalent concentration vs. time of exposure. In keeping with the trend in environmental risk assessment approaches (Policastro, 1991) we use the following toxic exposure concentration limit criteria:

$$C_{TL} = \begin{cases} 2 * C_{IDLH} & \text{for } t_{exp} < 15 \text{ min} \\ (30/t_{exp}) * C_{IDLH} & \text{for } 15 \leq t_{exp} \leq 60 \text{ min} \\ 0.5 * C_{IDLH} & \text{for } t_{exp} > 60 \text{ min} \end{cases} \tag{6.1}$$

where

C_{TL} = Concentration (toxic limit) for exposure (kg/m^3 or ppm)

C_{IDLH} = IDLH concentration for the chemical

t_{exp} = duration over which a person is exposed to a vapor cloud (with concentration greater than $0.5 * C_{IDLH}$)

Table 6.1 shows the IDLH values for a selected number of PIH and flammable material for which we have both the physical and chemical property data.

TABLE 6.1

IDLH Concentrations and Maximum Volume in Tank Cars for Selected PIH and Flammable Chemicals

Chemical Name	IDLH (ppm) (See Note 1)	Max Volume (m^3) (See Note 2)
POISON BY INHALATION (PIH) MATERIALS		
Allylamine	N/A	89.4
Ammonia, Anhydrous	500	121.0
Bromine	10	N/A
Cyanogen Chloride, Inhibited	N/A	N/A
Chlorine	30	58.0
Cyclohexyl Isocyanate	N/A	N/A
Ethylene Chlorohydrin	10	N/A
Ethylene Dibromide	400	36.0
Ethylene Oxide	800	92.8
Ethyleneimine, Inhibited	100	N/A
Cryogenic Liquid Fluorine	25	N/A
Hexachlorocylopentadiene	N/A	N/A
Hydrogen Chloride, Anhydrous	100	89.0
Hydrogen Sulfide, Liquefied	300	N/A
Hydrogen Fluoride, Anhydrous	30	N/A
Methyl Iodide	800	N/A
Methyl Bromide	2000	36.0
Nitric Acid, Fuming	100	62.9
Nitrogen Tetroxide	50	N/A
Phosgene	2	N/A
Phenyl Isocyanate	N/A	N/A
Phenyl Mercaptan	N/A	N/A
Phosphorus Oxychloride	N/A	N/A
Sulfuryl Chloride	N/A	N/A
Sulfuric Acid, Fuming	20	43.1
Sulfur Dioxide	100	62.6
Sulfur Trioxide	N/A	43.1

Chemical Name	IDLH (ppm) (See Note 1)	Max Volume (m^3) (See Note 2)
Silicon Tetrafluoride	N/A	N/A
Trichloroacetyl Chloride	N/A	N/A
Thionyl Chloride	N/A	N/A
FLAMMABLE LIQUID MATERIALS		
Butyl Alcohol	8000	N/A
Butyl Acetate	10000	N/A
Butryaldehyde	N/A	N/A
Chloroprene	400	74.9
Crotanaldehyde, Stabilized	400	N/A
Gasoline	N/A	112.4
Isopropanol	12000	N/A
Methyl Ethyl Ketone	3000	N/A
Xylene	1000	88.1
FLAMMABLE GAS MATERIALS		
Liquefied Petroleum Gas	19000	127.4
Vinyl Chloride	N/A	96.7

Note 1: IDLH values from NIOSH (1992)

Note 2: This represents the maximum volume carried in any authorized tank car consistent with outage requirements and maximum allowable rail loading (Woodall, 1992)

6.2.4 Thermodynamic Properties of Chemicals

In order to calculate the hazard area resulting from the release of a PIH material it is necessary to know the chemical and thermodynamic properties of the material. As indicated in Chapter 3, HM-181 contains 163 PIH materials. Unfortunately, physical, chemical, and thermodynamic property values necessary to execute hazard models are not available for all hazardous materials. As a part of this project, we initiated a thermodynamic property data gathering effort. We were able to obtain information only for a limited number of hazardous materials (31 PIH and 11 flammable materials). The principal source of these data was the publication of Penn State University (Daubert and Danner, 1989).

The dispersion model in SAFEMODE utilizes both temperature dependent and temperature independent thermodynamic properties of a hazardous material. The temperature dependent values are stored in the form of coefficients of a constituent equation. Table 6.2 shows a sample of the types of data gathered for each hazardous material. The table also indicates the formula for calculating the different temperature dependent property values. The program codes in SAFEMODE were modified to include these formulas.

6.2.5 Calculation of Vapor Toxic Hazard Areas

The magnitude of the hazard area depends on the chemical properties, the rate of release and the total quantity of release, atmospheric conditions, and topographical features (primarily on a parameter called the "aerodynamic roughness factor"). The hazard area calculation procedure is complex, having to solve a number of cloud/plume property parameters and the thermodynamic state of the HazMat vapor-liquid aerosol-air mixture. On an IBM AT 386 machine, each spill scenario calculation takes between 2 to 3 minutes.

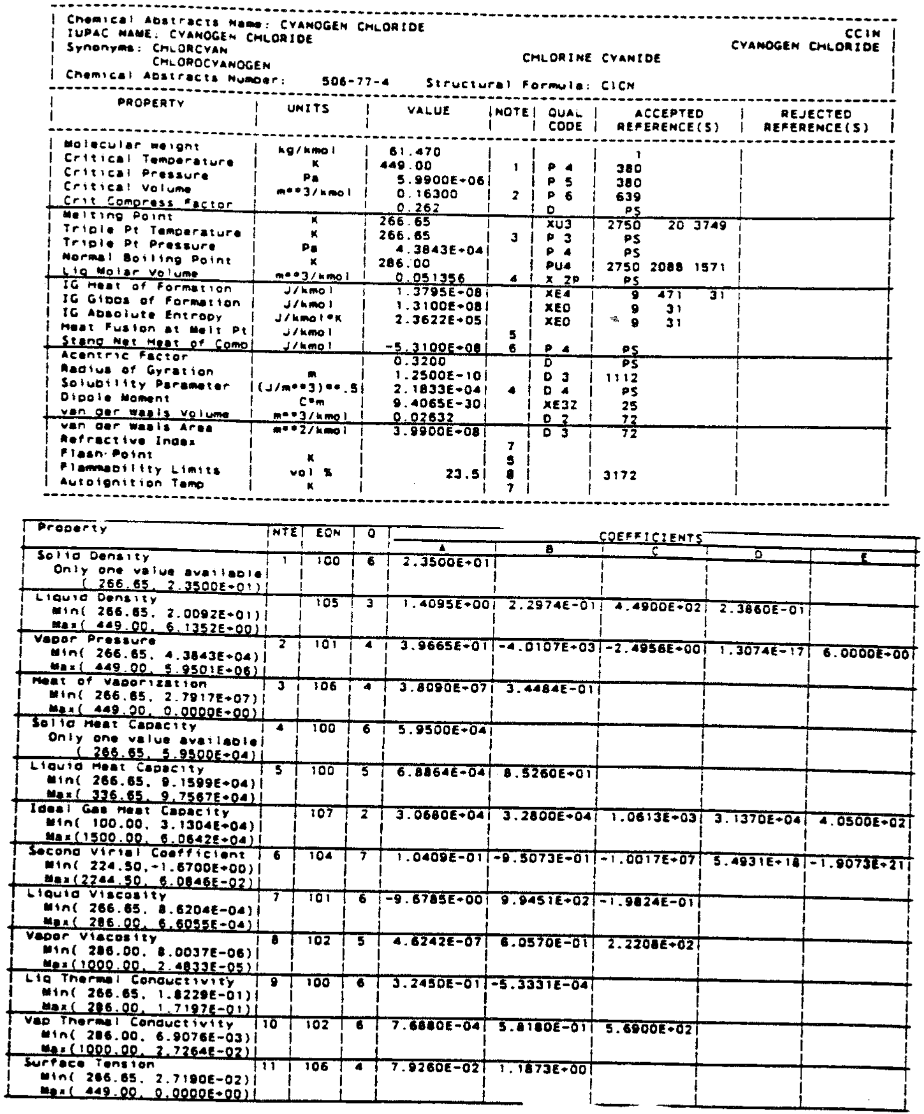
We have used the SAFEMODE software to precalculate the hazard areas for several PIH chemicals of interest to this study. The results are generated for two atmospheric conditions (namely, neutral stability and stable atmosphere[2]) and for different hole sizes on tank cars. The hazard concentration corresponding to the IDLH value for the particular chemical is used. Also, for several PIH materials we have gathered data on the maximum amount carried in the corresponding authorized tank car (Woodall, 1992). Table 6.1 shows these maximum volumes transported in tank cars.

---

[2] *Stability of the atmosphere is defined by the rate of change of atmospheric temperature with height above the ground (this is also termed the "lapse rate"). A lapse rate of 9.8°C/km of temperature decrease with height is defined as the neutral stability. In a stable atmospheric condition, the temperature increases with height. A pollutant released into a neutral atmosphere is mixed rapidly by the atmospheric turbulence. In stable atmosphere, the stable density stratifications in the atmosphere suppresses atmospheric turbulence; hence, the pollutant mixing is slow resulting in the persistence of high concentrations at ground level for a long distance.*

TABLE 6.2

Thermodynamic Chemical Property Data – A Sample Chemical



Chemical Abstracts Name: CYANOGEN CHLORIDE
IUPAC NAME: CYANOGEN CHLORIDE
Synonyms: CHLORCYAN
CHLOROCYANOGEN
CHLORINE CYANIDE
CCIN
CYANOGEN CHLORIDE
Chemical Abstracts Number: 506-77-4
Structural Formula: ClCN

PROPERTY	UNITS	VALUE	NOTE	QUAL CODE	ACCEPTED REFERENCE(S)	REJECTED REFERENCE(S)
Molecular weight	kg/kmol	61.470			1	
Critical Temperature	K	449.00	1	P 4	380	
Critical Pressure	Pa	5.9900E+06		P 5	380	
Critical Volume	m**3/kmol	0.16300	2	P 6	639	
Crit Compress Factor		0.262		D	PS	
Melting Point	K	266.65		XU3	2750 20 3749	
Triple Pt Temperature	K	266.65	3	P 3	PS	
Triple Pt Pressure	Pa	4.3843E+04		P 4	PS	
Normal Boiling Point	K	286.00		PU4	2750 2088 1571	
Liq Molar Volume	m**3/kmol	0.051356	4	X 2P	PS	
IG Heat of Formation	J/kmol	1.3795E+08		XE4	9 471 31	
IG Gibbs of Formation	J/kmol	1.3100E+08		XE0	9 31	
IG Absolute Entropy	J/kmol*K	2.3622E+05		XE0	9 31	
Heat Fusion at Melt Pt	J/kmol		5			
Stand Net Heat of Comb	J/kmol	-5.3100E+08	6	P 4	PS	
Acentric Factor		0.3200		D	PS	
Radius of Gyration	m	1.2500E-10		D 3	1112	
Solubility Parameter	(J/m**3)**.5	2.1833E+04	4	D 4	PS	
Dipole Moment	C*m	9.4065E-30		XE32	25	
van der Waals Volume	m**3/kmol	0.02632		D 2	72	
van der Waals Area	m**2/kmol	3.9900E+08		D 3	72	
Refractive Index			7			
Flash Point	K		5			
Flammability Limits	vol %	23.5	8		3172	
Autoignition Temp	K		7			

Property	NTE	EQN	Q	COEFFICIENTS A	B	C	D	E
Solid Density Only one value available (266.65, 2.3500E+01)	1	100	6	2.3500E+01				
Liquid Density Min(266.65, 2.0092E+01) Max(449.00, 6.1352E+00)		105	3	1.4095E+00	2.2974E-01	4.4900E+02	2.3860E-01	
Vapor Pressure Min(266.65, 4.3843E+04) Max(449.00, 5.9501E+06)	2	101	4	3.9665E+01	-4.0107E+03	-2.4956E+00	1.3074E-17	6.0000E+00
Heat of Vaporization Min(266.65, 2.7917E+07) Max(449.00, 0.0000E+00)	3	106	4	3.8090E+07	3.4484E-01			
Solid Heat Capacity Only one value available (266.65, 5.9500E+04)	4	100	6	5.9500E+04				
Liquid Heat Capacity Min(266.65, 9.1599E+04) Max(336.65, 9.7567E+04)	5	100	5	6.8864E+04	8.5260E+01			
Ideal Gas Heat Capacity Min(100.00, 3.1304E+04) Max(1500.00, 6.0642E+04)		107	2	3.0680E+04	3.2800E+04	1.0613E+03	3.1370E+04	4.0500E+02
Second Virial Coefficient Min(224.50,-1.6700E+00) Max(2244.50, 6.0846E-02)	6	104	7	1.0409E-01	-9.5073E+01	-1.0017E+07	5.4931E+18	-1.9073E+21
Liquid Viscosity Min(266.65, 8.6204E-04) Max(286.00, 6.6055E-04)	7	101	6	-9.6785E+00	9.9451E+02	-1.9824E-01		
Vapor Viscosity Min(286.00, 8.0037E-06) Max(1000.00, 2.4833E-05)	8	102	5	4.6242E-07	6.0570E-01	2.2208E+02		
Liq Thermal Conductivity Min(266.65, 1.8229E-01) Max(286.00, 1.7197E-01)	9	100	6	3.2450E-01	-5.3331E-04			
Vap Thermal Conductivity Min(286.00, 6.9076E-03) Max(1000.00, 2.7264E-02)	10	102	6	7.6880E-04	5.8180E-01	5.6900E+02		
Surface Tension Min(266.65, 2.7190E-02) Max(449.00, 0.0000E+00)	11	106	4	7.9260E-02	1.1873E+00			

Number	Equation
100	$Y = A + BT + CT^2 + DT^3 + ET^4$
101	$Y = \exp\left[A + \frac{B}{T} + C \ln T + DT^E\right]$
102	$Y = \frac{AT^B}{1 + \frac{C}{T} + \frac{D}{T^2}}$
103*	$Y = A + B \exp\left[\frac{-C}{T^D}\right]$
104	$Y = A + \frac{B}{T} + \frac{C}{T^3} + \frac{D}{T^8} + \frac{E}{T^9}$
105	$Y = A/B^{[1+(1-T/C)^D]}$
106	$Y = A(1 - T_r)^{(B + CT_r + DT_r^2 + ET_r^3)}$
107**	$Y = A + B\,[(C/T)/\sinh(C/T)]^2 + D\,[(E/T)/\cosh(E/T)]^2$

(Source: Daubert & Danner, 1989)

The program SAFEMODE can calculate the ground level toxic areas (for specified hazard concentration) for the cases of (i) a "continuous" release of a hazardous material at a constant rate, *ad infinitum* and, (ii) an "instantaneous" release of a given mass of the hazardous material. The model cannot handle the case in which a finite volume of the hazardous material is released at a decreasing rate; yet in the case of release from a tank car, the hazardous material is released over a finite period and, in general, a rate which decreases with time. In order to account for this real phenomena and yet utilize the dispersion model in SAFEMODE we used the following approach:

1. A particular hole size on the tank car (within the limits of sizes indicated in Chapter 4) is chosen. The hole on the tank car is assumed to be located such that the maximum hydrostatic head of liquid and the ullage pressure is felt at the hole (this is a conservative assumption).

2. The maximum leak rate is calculated and knowing the total volume in the tank car (see Table 6.1) the duration of release time, at the maximum release rate, is calculated. We assume that this is also the "exposure time" for exposure to a continuous toxic plume.

3. Using this time, and the criteria indicated in equation 6.1, the hazard limit concentration is determined.

4. This limit concentration is used in SAFEMODE calculations for the release of the hazardous material in a continuous model at the maximum rate of release consistent with the hole diameter chosen in step 1 above.

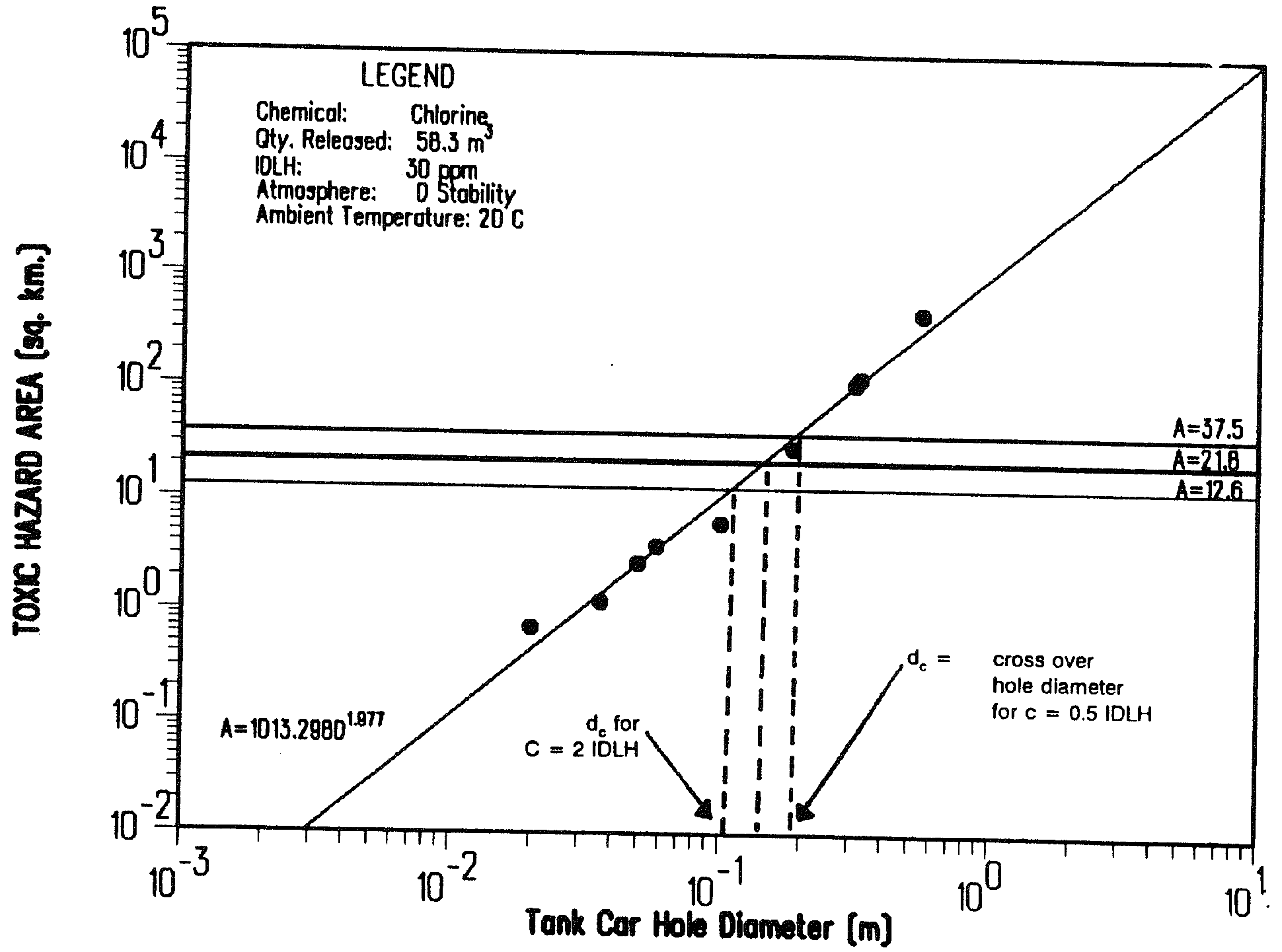
5. The calculated hazard area is plotted against the hole diameter. Steps 1 through 5 are repeated for several hole sizes.

6. The hazard areas are also calculated assuming that the release is instantaneous. Three values of the hazard concentrations are used namely, 2 * IDLH, IDLH and 0.5 * IDLH.

Figure 6.2 shows the results from the above calculation for one hazardous material, namely chlorine. The atmospheric temperature and stability conditions as well as the IDLH value and the total quantity released are indicated in the legend. The ordinate is the calculated hazard area and the abscissa is the hole size on the tank car.

FIGURE 6.2

Variation of Toxic Hazard Area with Hole Diameter



The sloping line indicates the correlation line for the results obtained from SAFEMODE's "continuous dispersion" model. The hazard area calculated for an instantaneous release does not depend on the hole size but depends on the atmospheric stability, the total mass of chemical released, and the limit concentration for toxicity. Hence, for a specified volume of hazardous material released in a given atmosphere, the plot of hazard area from instantaneous release vs. hole diameter (as in Figure 6.2) results in a horizontal line. the intercept of this line on the y axis is determined by the tolerable toxic concentration. A dispersion model cross over hole diameter d_c is defined such that for all hole diameters greater than d_c the hazard area computed by the continuous release model is greater than that from an instantaneous release (a physically impossible scenario). The cross over diameter d_c is determined for each hazardous material and each weather condition. This cross over diameter is the hole diameter corresponding to the point of intersection of the horizontal line from the instantaneous model and the sloping line from the continuous dispersion model. This is indicated in Figure 6.2. The hazard areas used in risk assessment are as follows: for all tank car hole diameters less than d_c, the continuous model correlation line is used to determine the hazard area and for diameters larger than d_c the instantaneous dispersion hazard area is used.

The toxic hazard area resulting from the release of other PIH liquids (which are not compressed liquefied gases) is also determined using the SAFEMODE program. It is anticipated that in the case of these liquids, the vapor pressure will be low at ambient temperature. Hence, the evaporation rate from a liquid pool will be relatively low. On the other hand, any leak from a noticeable hole on the tank car will result in the formation of a large pool of liquid on the ground (assuming that the ground is flat and relatively impervious). For the purposes of a conservative calculation, it can be assumed that any leak results in the formation of the same large diameter pool from which vapors emanate and are dispersed by the wind.

In SAFEMODE, the maximum pool size is calculated to be consistent with the volume of liquid spilled and a pool depth of 1cm. The downwind hazard area is then calculated using the continuous plume dispersion model. Therefore, it is noted that, in the case of release of liquids which are not compressed liquefied gas, the hazard areas are not dependent on the hole size of the tank car.

The toxic hazard area results for selected PIH materials are indicated in Table 6.3

TABLE 6.3

Toxic Hazard Area Results for Selected PIH Chemicals

CHEMICAL	MAXIMUM VOLUME IN TANK CAR (M^3) (NOTE 1)	MAXIMUM TOXIC HAZARD AREA (SQ. KM.) (NOTE 2) ATM D	ATM F
Ammonia, anhydrous	121.0	6.19	3.32
Chlorine	58.0	21.8	80.3
Ethylene Dibromide	36.0	0.037	0.077
Ethylene Oxide	92.8	0.24	0.67
Hydrogen Chloride, anhydrous	89.0	21.7	80.6
Nitric Acid, Fuming	62.9	0.022	0.022
Sulfuric Acid, Fuming	43.1	0.015	0.015
Sulfur Dioxide	62.6	7.11	26.6
Sulfur Trioxide	43.1	0.397	0.884

Note 1: Source of data (Woodall, 1992)

Note 2: The hazard areas correspond to an instantaneous release of the tank car contents and a hazard limit concentration equal to the IDLH value.

In the case of non liquefied gas liquids with low evaporation rate, hazard area is calculated using continuous vapor release models.

6.3 POOL FIRE THERMAL RADIATION HAZARD

6.3.1 Fire Hazard Description

When a flammable or combustible liquid is released and gets ignited, a pool fire is formed. The characteristic of this fire is that the liquid pool burns sustaining a tall column (or plume) of fire. This fire plume radiates thermal energy. Some fires are more radiative than others because of higher luminosity and higher temperature within the fire. In general, higher hydrocarbon liquid pool (gasoline, diesels, fuel oil, etc.) burn with black soot shrouding the fire core. This results in lesser magnitude of thermal radiation.

The effect of thermal radiation on a human being can range from a "hot" feeling to a severe burn to fatality depending on the magnitude of the heat flux as well as the duration of exposure. The intensity of radiation decreases as the distance from the fire increases. The area bounded by the contour of a specified hazard heat flux on the ground will constitute the hazard area.

6.3.2 Hazard Thermal Flux Criteria

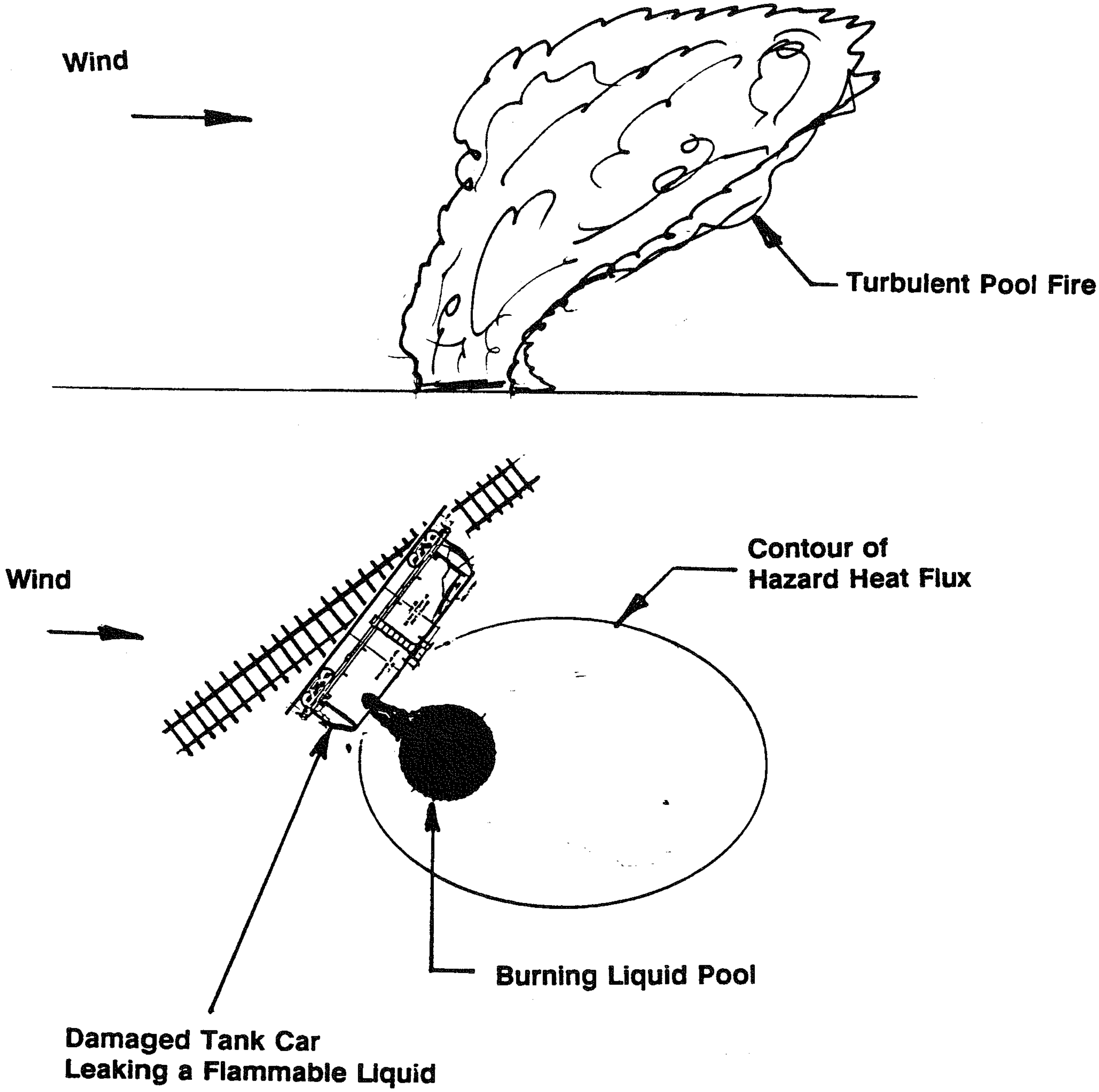
US DOT has set the tolerable levels for incident radiant thermal flux on off-site targets from liquefied natural gas facilities (49 CFR 193.2057) as a part of the site requirements. The minimum level set is 5 kW/m^2 (1600 BTU/hr ft^2) when the "outdoor areas are occupied by 20 or more persons during normal use, such as beaches, playgrounds, outdoor theaters, other recreational areas, and areas of public assembly." We have used this criterion (5kW/m^2) as the heat flux level for harmful exposure for calculating hazards from pool fires.

6.3.3 Fire Model

The potential area of thermal radiation hazard due to a liquid pool fire is calculated using the pool fire model in SAFEMODE. This model, for a specified combustible or flammable liquid, pool diameter, and wind speed, calculates the physical dimension of the fire plume, the tilt, if any, of the plume due to wind and the radial distance (on the ground) from the fire base center to the specified hazard heat flux, all around the fire. The total hazard area within the contour of constant heat flux is then calculated. Figure 6.3 shows schematically the turbulent pool fire and the expected shape of a hazard area on the ground when the fire is tilted by a strong wind.

FIGURE 6.3

Schematic Representation of a Flammable Liquid Pool Fire and the Resulting Hazard Area



The area of hazard is dependent on several thermodynamic properties of the burning liquid. When exact property values were either unknown or unavailable, default values were used. This was particularly the case for the parameter that indicates the heat emission rate from the fire (called the "Emissive Power"). The pool fire diameter is assumed to be equal to the maximum diameter formed by the spill of the tank car contents to a depth of 2.5 cm.[3]

The pool fire hazard area has been calculated for a number of flammable liquids consistent with the maximum volume of the liquids transported in authorized tank cars. The hazard area results from this analysis are indicated in Table 6.4 for selected flammable chemicals. It can be seen that, in general, pool fire hazard areas are small compared to the toxic vapor hazard areas for PIH materials. The pool fire hazard area extends in all directions from the fire center in contrast to toxic vapor hazard area which is mostly in the downwind direction.

6.4 VAPOR CLOUD FIRE HAZARDS

When a flammable liquid does not get ignited immediately after release, the liquid pool formed will evaporate and form a flammable vapor plume. If this vapor plume is ignited somewhere downwind, a turbulent (travelling) fire can result, engulfing the vapor plume and burning all of the vapor-air mixture whose vapor concentration is higher than the lower flammable limit. This phenomena is called the "vapor cloud fire."

All objects and person lying within the vapor cloud prior to ignition are considered "exposed." The ground level area of hazard will be, therefore, enclosed by the contour representing the lower flammability concentration corresponding to the flammable material.

Using the heavy gas dispersion model described earlier, we have evaluated the vapor cloud for the hazard area. These values for selected flammable materials are indicated in Table 6.4.

---

[3] *The diameter of the pool for a fire is based on an initial pool depth of 2.5cm to sustain a fire. For most hydrocarbon fuels, the burning rate is about 4 mm/min. Also, in general, pool depths of less than 0.5cm (especially in rough soils where the mean grain size of the particles on the ground are of the order of 0.5cm) a large fire cannot be sustained due to ground heat transfer limitations. The total burning duration for the pool depth to change from 2.5cm to 0.5cm is about 5 minutes, consistent with the burning time of large fires in accidents. It is because of these two factors (heat transfer limitation for less than 1 cm depth and observed fire durations) that we have chosen an initial depth of 2.5cm. This depth should be compared to 1cm pool depth used in toxic dispersion calculations.*

TABLE 6.4

Hazard Area Results for Selected Flammable Chemicals

CHEMICAL NAME	MAXIMUM VOLUME IN A TANK CAR (NOTE 1) (m^3)	HAZARD AREAS (SQ. KM.) FROM			
		POOL FIRES (NOTE 2)	EXPLOSIONS (NOTE 3)	VAPOR FIRES (NOTE 4)	
				ATM D	ATM F
Ethylene oxide	92.8	0.141	0.456	0.183	0.427
Gasoline	112.4	0.033	0.653	0.0058	0.011
Liquefied Petroleum Gas	127.4	0.252	0.589	0.118	0.129
Vinyl Chloride	96.7	0.042	0.376	0.088	0.098
Xylene	88.1	0.140	0.589	-	-

Note 1: Source of data (Woodall, 1992)

Note 2: Based on the assumption of fire diameter equal to that of a pool of 2.5cm initial depth, calm (wind) condition and 5 KW/m^2 hazard criterion.

Note 3: Assuming 10% of the mass of released hydrocarbon detonates and the hazard criterion is the over pressure for threshold lung punctures.

Note 4: Calculated vapor dispersion area for the hazard concentration equal to the lower flammability value.

Note 5: Atm D represents a neutral stability atmosphere (also termed Atmospheric Stability Class D). Atm F represents a stable atmosphere (Atmospheric Stability Class F).

6.5 EXPLOSION HAZARDS

6.5.1 Description of Explosion Phenomenon

A mixture of flammable vapor and air may explode under certain circumstances such as confinement, ignition by energetic charge, etc. Very, very few flammable chemicals exhibit explosive burning of unconfined vapor-air clouds. The word "explosion" is used here to mean the detonation type of burning of the cloud resulting in the formation of a blast wave which may adversely impact people and structures due to the over pressure pulse.

Even when a vapor cloud "detonates," only a small fraction of the mass of the chemical in the cloud is known to participate in the creation and maintenance of the blast wave; this fraction ranges between 1 and 10 percent. This is because in a vapor cloud, only those portions of the cloud which have chemical vapor in the "detonation concentration range" participate in the explosion (Zabetakis, 1967).

We do not contend that any one of the flammable chemicals will or will not explode. We have considered in this risk analysis study this possibility only as a remotely probable phenomenon under some circumstances.

6.5.2 Explosion Model

The vapor cloud explosion model we have used is based on the calculation of the TNT equivalent mass of the flammable chemical released. Once the TNT equivalent mass is known, then the over pressure field (i.e., the variation of over pressure magnitude with distance from the cloud center) is determined from the published TNT blast wave correlations.

In performing the vapor cloud explosion model calculations, we have assumed the following:

1. The entire contents of the tank car are released, very quickly;
2. Only 10% of the mass of the chemical released participates in the explosion, if explosion does occur; and
3. The pressure field is symmetrical surrounding the tank car (i.e., effects of abstractions in reflecting shock waves are ignored).

6.5.3 Explosion Hazard Exposure Criteria

The effects of a vapor cloud explosion are primarily due to the over pressure and impulse. The higher the over pressure (or the impulse) the higher the level of damage. Structural damage can range from minor glass breakage to entire buildings collapsing. Human injuries can range from eardrum rupture (at low over pressures) to lung collapse, to fatality by being knocked onto hard objects. Because of the variability in human physiology, response, and sometimes due to geographic factors (that may collimate or diffuse the over pressure waves) there are no unique over pressure values at which each of the above hazards occur; instead, there is a probability distribution of over pressure vs. damage for a given damage type.

In our calculation to determine population exposure, we have used the threshold lung damage over pressure as the criterion for determining the hazard area.

6.5.4 Explosion Hazard Results

The results obtained by the application of this model to a selected number of flammable chemicals are indicate din Table 6.4. Again, we caution that the presentation of an explosion area in Table 6.4 does not imply that the chemical vapor cloud will detonate in the open.

6.6 MULTI HAZARD BEHAVIOR OF CHEMICALS

6.6.1 Multiple Hazard Types

Some PIH chemicals display multiple hazard behavior properties (ethylene oxide is a good example). While the primary hazard from Division 2.3 an Division 6.1 hazardous materials are due to the poisonous nature of the vapors which pose inhalation toxicity hazards, some of the chemicals are also flammable, combustible, or pose a contact burn injury type of hazard (class 8 material).

The type of behavior of a multi hazard chemical, after its release from a tank car, will depend on a number of parameters, including the accident scenario, local conditions, (rural or urban setting) and environmental/meteorological conditions. Consider, as an example, the release of ethylene oxide. The following scenarios may be realized:

(i) Release of chemical from the tank car with no ignition, either at the source or at any downwind location of the plume – a toxic vapor hazard results;

(ii) Release through a relatively small hole occurs with immediate ignition – A pool fire results;

(iii) A very quick ("instantaneous") release of the entire tank car contents occurs with immediate ignition – very likely a large cloud fire will occur;

(iv) Instantaneously released vapor cloud is not ignited immediately, but meets an ignition source at a downwind location when the cloud is spread out – this results in a vapor fire; and

(v) A vapor cloud that is not ignited seeps into semi-confined (open buildings) or areas that provide a high degree of confinement (sewers, leaky buildings) and ignition occurs – possible explosive burning of the cloud.

6.6.2 Considerations of Multi-Hazards in Risk Analysis

It is clear that conditions prevailing immediately after the accidental release have a significant effect on the type of hazardous behavior of the chemical. Of course, the chemical property also influences which one of the behavior types predominates (a chemical with very low ignition energy will ignite under circumstances that another chemical with high ignition energy would not ignite). It is difficult, "a priori" to determine which of the multi-hazard behavior types will occur in one accident. The only way to consider these behavior models of a multi-hazard is to assign a probability for each type of behavior.

Based on (i) review of the thermodynamic property data, (ii) a knowledge of the transportation and potential accident scenarios involving the chemicals, and (iii) intuitive engineering judgement, we have developed a table of conditional probabilities. Table 6.5 shows, for selected chemicals, the conditional probability (fraction) of realizing particular scenarios of behavior of the released hazardous material. The table indicates the name of the chemical, its hazard class or division and the conditional probability values for (i) toxic vapor dispersion, (ii) pool fire, (iii) vapor fire, and (iv) explosion type of hazard occurrence. The sum of the conditional probability fractions adds to unity for each chemical. Also note that for those chemicals which exhibit only one type of behavior (for example, chlorine has only toxic vapor behavior) the probability for that type of behavior is 1 and the remaining probabilities are 0.

TABLE 6.5

Conditional Probabilities of Multi-Hazard Behavior of Selected Chemicals

CHEMICAL NAME	CHRIS CODE	HAZARD TYPE AND CHEMICAL PHASE	HAZARD CLASS OR DIVISION NO.	PROBABILITY OF DIFFERENT BEHAVIORS			
				TOXIC VAPOR	POOL FIRE	EXPLO-SION	VAPOR FIRE
Allyl Alcohol	ALA	Poison Liquid	6.1	0.30	0.65	0.00	0.05
Allylamine	ALY	Poison Liquid	6.1	0.90	0.10	0.00	0.00
Ammonia, Anhydrous (I)	AMA	Poison Gas	2.3	0.95	0.00	0.00	0.00
Ammonia, Anhydrous (D)	AMA	Non-Flammable Gas	2.2	0.95	0.00	0.00	0.00
Butyl Alcohol	BAN	Flammable Liquid	3	0.00	1.00	0.00	0.00
Butyl Acetate	BCN	Flammable Liquid	3	0.00	1.00	0.00	0.00
Butyraldehyde	BLD	Flammable Liquid	3	0.00	1.00	0.00	0.00
Bromine	BRX	Poison Liquid	6.1	1.00	0.00	0.00	0.00
Cyanogen Chloride, Inhibited	CCL	Poison Gas	2.3	1.00	0.00	0.00	0.00
Chlorine	CLX	Poison Gas	2.3	1.00	0.00	0.00	0.00
Chloroprene	CRP	Flammable Liquid	3	0.00	1.00	0.00	0.00
Crotanaldehyde, Stabilized	CTA	Flammable Liquid	3	0.40	0.60	0.00	0.00
Cyclohexyl Isocyanate	CXN	Poison Liquid	6.1	1.00	0.00	0.00	0.00
Ethylene Chlorohydrin	ECH	Poison Liquid	6.1	0.30	0.70	0.00	0.00
Ethylene Dibromide	EDB	Poison Liquid	6.1	1.00	0.00	0.00	0.00
Ethylene Oxide	EOX	Poison Gas	2.3	0.50	0.10	0.20	0.20
Ethyleneimine, Inhibited	ETI	Poison Liquid	6.1	0.30	0.70	0.00	0.00
Cryogenic Liquid Fluorine	FXX	Poison Gas	2.3	1.00	0.00	0.00	0.00
Gasoline	GAT	Flammable Liquid	3	0.00	0.90	0.05	0.05
Hexachlorocylopentadiene	HCC	Poison Liquid	6.1	1.00	0.00	0.00	0.00
Hydrogen Chloride, Anhydrous	HDC	Poison Gas	2.3	1.00	0.00	0.00	0.00
Hydrogen Sulfide, Liquefied	HDS	Poison Gas	2.3	0.80	0.05	0.05	0.10

CHEMICAL NAME	CHRIS CODE	HAZARD TYPE AND CHEMICAL PHASE	HAZARD CLASS OR DIVISION NO.	PROBABILITY OF DIFFERENT BEHAVIORS			
				TOXIC VAPOR	POOL FIRE	EXPLO-SION	VAPOR FIRE
Hydrogen Fluoride, Anhydrous	HFX	Corrosive	8	1.00	0.00	0.00	0.00
Isopropanol	IPA	Flammable Liquid	3	0.00	1.00	0.00	0.00
Liquefied Petroleum Gas	LPG	Flammable Gas	2.1	0.00	0.05	0.30	0.65
Methyl Ethyl Ketone	MEK	Flammable Liquid	3	0.00	1.00	0.00	0.00
Methyl Iodide	MII	Poison Liquid	6.1	1.00	0.00	0.00	0.00
Methyl Bromide	MTB	Poison Gas	2.3	1.00	0.00	0.00	0.00
Nitric Acid, Fuming	NAC	Corrosive	8	1.00	0.00	0.00	0.00
Nitrogen Tetroxide	NOX	Poison Gas	2.3	1.00	0.00	0.00	0.00
Phosgene	PHG	Poison Gas	2.3	1.00	0.00	0.00	0.00
Phenyl Isocyanate	PHI	Poison Liquid	6.1	1.00	0.00	0.00	0.00
Phenyl Mercaptan	PHM	Poison Liquid	6.1	0.80	0.20	0.00	0.00
Phosphorus Oxychloride	PPO	Corrosive	8	1.00	0.00	0.00	0.00
Sulfuryl Chloride	SCL	Corrosive	8	1.00	0.00	0.00	0.00
Sulfuric Acid, Fuming	SFA	Corrosive	8	1.00	0.00	0.00	0.00
Sulfur Dioxide	SFD	Poison Gas	2.3	1.00	0.00	0.00	0.00
Sulfur Trioxide	SFT	Corrosive	8	1.00	0.00	0.00	0.00
Silicon Tetrafluoride	SIF	Poison Gas	2.3	1.00	0.00	0.00	0.00
Trichloroacetyl Chloride	TCC	Corrosive	8	1.00	0.00	0.00	0.00
Thionyl Chloride	TCH	Corrosive	8	1.00	0.00	0.00	0.00
Vinyl Chloride	VCM	Flammable Gas	2.1	0.00	0.70	0.10	0.20
Xylene	XLM	Flammable Liquid	3	0.00	0.50	0.50	0.00

6.7 DISCUSSIONS

In this chapter we have indicated the various chemical behavior scenarios and important details of the models used to determine the potential hazard areas. The hazard areas are determined by defining an exposure index for the particular type of hazard. In general, the exposure indices are "threshold human effect" indices. As such, our risk analysis methodology is very conservative in determining the consequences due to hazardous material releases. It is emphasized that "exposure" of the population does not mean serious injuries or fatalities. Table 6.6 summarizes the population exposure criteria (values) used for different types of hazards.

We note that the models used may not be very accurate if used for, say, siting purposes. However, it is our contention that these models are adequate for the purposes of risk analysis, especially when relative risks are being evaluated. In the determination of hazard areas a number of assumptions have been made both in regard to release scenarios, occurrence of different topographical, meteorological, and other conditions. Also, inaccuracies are inherent in mathematical representation of physical phenomena. The hazard area results developed have to be, therefore, viewed with the above assumptions in mind.

In the next chapter, we describe how the accident probability values discussed in Chapter 5 and the hazard area results presented in this chapter are combined to produce the risk results.

TABLE 6.6

Exposure Criteria Values Used for Hazard Area Calculations

HAZARD TYPE	EXPOSURE CRITERION
Toxic Vapor (Inhalation)	0.5 * IDLH; IDLH; or 2 * IDLH
Pool Fire (Thermal Radiation)	Maximum exposure heat flux = 5 kW/m^2
Vapor Fire	Lower flammability limit concentration
Explosion (of Vapor Cloud)	Threshold lung damage (6 psi over pressure)

CHAPTER 7

Risk Analysis Results

In this chapter the probability results discussed in Chapter 5 and the consequence results indicated in Chapter 6 are synthesized into the development of a risk profile. The presentation of the risk values using qualitative categories indicated in the MIL Standard for risk assessments is also discussed.

7.1 RISK CATEGORIES: MIL STANDARD 882-B

A US Military Standard called "System Safety Program Requirements" (MIL-STD-882B) has been developed to assess the potential risks from an existing system and for evaluating the acceptability of a new system. While this MIL-STD does not provide any detailed guidance as to how to evaluate the probabilities of failures in a system or the consequence of these failures, the standard provides guidance criteria for acceptability of a system. System accidents are ranked by the severity and the chance of its occurrence. This standard identifies four categories of severity, namely, catastrophic (I), critical (II), marginal (III), and negligible (IV). Broad definitions are provided as a guide to classifying a particular hazard into one of these four categories. Table 7.1 indicates these definitions. Similarly, the frequency of occurrence of detrimental events is classified into five (5) categories namely, frequent (A), probable (B), occasional (C), remote (D), and improbable (E). These categories are defined in Table 7.2. Figure 7.1 illustrates the "Risk Matrix" in which each cell represents a particular category of hazard and its frequency of occurrence. The figure also illustrates the regions of various levels of acceptability of the system from a risk perspective.

The MIL-Standard leaves it very much to the discretion of the researcher how the system performance is quantified. Therefore, in converting the quantitative estimates of both the hazard and the probability of occurrence of events to the MIL-STD categories, considerable judgement needs to be used.

The risk model presented in the next section uses the MIL-STD categories to communicate the results. However, considerable leeway is taken in translating certain quantitative results into qualitative risk categories.

TABLE 7.1

Undesired Event Severity Categories

CATEGORY	SEVERITY	CHARACTERISTICS
I	Catastrophic	Death to person or employee, loss of system
II	Critical	Severe injury to public or employee, or major system damage.
III	Marginal	Minor injury not requiring hospitalization or the hazard present does not by itself threaten the safety of the public. Also minor system damage.
IV	Negligible	Less than minor injury. Does not impair any of the critical systems.

TABLE 7.2

Undesired Event Probability Categories

CATEGORY	LEVEL	SPECIFIC EVENT
A	Frequent	Not an unusual event, could occur several times in annual operations.
B	Probable	Event could occur several times in the lifetime of the system.
C	Occasional	Expected to occur at least once in the lifetime of the system.
D	Remote	Event is unlikely to occur during the lifetime of the system.
E	Improbable	Event is so unlikely that it is not expected to occur in the lifetime of the system.

FIGURE 7.1

Risk Assessment Matrix

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FREQUENCY OF OCCURRENCE	UNDESIRED EVENT CATEGORIES			
	I CATASTROPHIC	II CRITICAL	III MARGINAL	IV NEGLIGIBLE
(A) FREQUENT	IA	IIA	IIIA	IVA
(B) PROBABLE	IB	IIB	IIIB	IVB
(C) OCCASIONAL	IC	IIC	IIIC	IVC
(D) REMOTE	ID	IID	IIID	IVD
(E) IMPROBABLE	IE	IIE	IIIE	IVE

RISK INDEX

IA, IB, IC, IIA, IIB, IIIA	■	UNACCEPTABLE
ID, IIC, IID, IIIB, IIIC	▤	UNACCEPTABLE (MANAGEMENT DECISION REQUIRED)
IE, IIE, IIID, IIIE, IVA, IVB	☐	ACCEPTABLE WITH REVIEW BY MANAGEMENT
IVC, IVD, IVE	▥	ACCEPTABLE WITHOUT REVIEW

7.2 EQUIVALENCY BETWEEN MIL STANDARD RISK MEASURES AND QUANTITATIVE VALUES

The procedures for determining the quantitative estimates of risk have been discussed in Chapters 5 and 6. In the context of a rail transport accident involving hazardous materials, "risk" is defined by the probability (generally on an annualized basis) of exceeding a specified number of people exposure given an accident. However, the quantitative estimates, in general, do not provide a "feel" for the riskiness of the venture unless a comparison is made with the risks from another phenomenon or activity which is familiar to the public. Therefore, absolute numbers seldom provide a good measure of the risk (for a non-technical audience); only the relative risks do..

In order to express the risk results developed in this project we have devised a table of equivalencies between the quantitative estimates of probability and consequence (population exposure) with the respective qualitative categories in MIL Standard. These equivalencies are indicated in Table 7.3a and Table 7.3b. The reasons for choosing these equivalency values are discussed below. It should be clearly understood that the values in the equivalency table are <u>entirely subjective</u>.

7.2.1 Probability Categories

The events of interest to this study are the derailment accidents involving hazardous material tank cars. The geographic area of interest is the entire United States. It can be argued that the public would consider accidents of this kind occurring (not necessarily leading hazardous material releases) as being too numerous and therefore "frequent" if, on the average, one such accident occurred per day anywhere in the US. Since we are dealing here in orders of magnitude, this can be translated to equating "frequent" incidents to those occurring at a rate of 500 or more events per year. Events occurring once a week can be considered as "probable" (we, intuitively define the "probable" events to occur with a frequency which is about an order of magnitude less than the "frequent"). Similarly, once in 3 to 4 months is assigned to the "occasional" category, and those that occur once in 3 or 4 years to the "remote" category. All others are assigned to the "improbable" category. Table 7.3a also shows the range of frequency ratios with the "frequent" for each of the different categories.

TABLE 7.3a

Relationship Between Numerical Risk Values and MIL Standard 882B Categories Probability Categories

MIL STANDARD PROBABILITY CATEGORIES	NUMBER OF EVENTS ASSUMED TO OCCUR PER YEAR (NOTE 1)	MEAN FREQUENCY OF EVENTS #/YEAR (NOTE 2)	EVENTS OCCUR APPROXIMATELY ONCE IN	RATIO OF EVENT FREQUENCY TO THAT OF "FREQUENT"	
				RANGE	MEAN (NOTE 2)
Frequent	>500	500	a day	1	1
Probable	10 - 500	70	a week	2x10^{-2} to 1	1.4x10^{-1}
Occasional	1 - 10	3	a season	2x10^{-3} to 2x10^{-2}	6.3x10^{-3}
Remote	0.1 - 1	0.3	3 years	2x10^{-4} to 2x10^{-3}	6.3x10^{-4}
Improbable	0.01 - 0.1	0.03	30 years	2x10^{-5} to 2x10^{-4}	6.3x10^{-5}

TABLE 7.3b

Relationship Between Numerical Risk Values and MIL Standard 882B Categories Severity Categories

MIL STANDARD CATEGORIES	NUMBER OF PERSONS EXPOSED		RATIO OF EXPOSURES TO CATASTROPHIC	
	RANGE (NOTE 1)	MEAN (NOTE 2)	RANGE	MEAN (NOTE 2)
Catastrophic	>1000	1000	1	1
Critical	30 - 1000	170	0.33 to 1	170x10^{-3}
Marginal	1 - 30	6	10^{-3} to 3.3x10^{-1}	5.5x10^{-3}
Negligible	≤1	<1	<10^{-3}	<10^{-3}

Note 1: TMS' definitions

Note 2: Represents the logarithmic mean of the extremum values of the range.

MIL Standard risk categories apply to the absolute risk arising from a system. In evaluating the system, risks all possible failure modes need to be considered. It is recalled that a major emphasis in this study has been the development of risk values conditional on the occurrence of a derailment accident and tank car damage. In order to compare similar quantities between the MIL Standard risk categories and numerical values developed in this study, it has become necessary to evaluate (and use) the frequency of hazardous material tank car derailments and damage. The method by which this probability was evaluated was discussed in Chapter 5, Section 5.2.5. However, a true comparison between the probability categories of the MIL Standard and the numerical values determined for the probabilities of exposing a specified number of people can be made only if the magnitude of the number of tank cars in service during each year and carrying the specific hazardous material is known.

7.2.2 Severity (Consequence) Categories

We refer the reader to Chapter 6 for the definition used in this study for determining the consequence of a hazardous material release. A population "exposure" criterion was used which does not imply fatality or serious and irreversible injury to the exposed public. With this definition, therefore, it is somewhat difficult to equate the results from our calculations with the severity categories of MIL Standard. Our definitions presented in Table 7.3b are based on judgement and guided by "what the public perception" may be of events leading to an exposure of different numbers of people.

We term an event as "catastrophic" if there is a potential for more than 1000 persons being "exposed" to the hazards of the hazardous material. The number 1000 is based on the following argument. Let us say there is a potential event in which a mean number of 1000 persons are likely to be exposed to a threshold level of concentration (which is our definition of "exposure"). It can be assumed that if indeed this event occurs, because of the nature of very conservative assumptions we have made, only about one-half to one-third of the potentially exposable population is indeed exposed and hence may require treatment in hospitals. This would represent that anywhere from 300 to 500 persons may need to be treated at the same time. Such an event can be classified as a catastrophe.

We have termed the potential exposure of 300 to 1000 persons as a critical event (the log mean of this range is 170). Again using the same argument as in the previous paragraph, anywhere from 60 to 100 people may require attention at a hospital. Such an event could be construed to be a critical event. Similarly, an event with a mean exposure number of 6 persons can be termed marginal, and that with less than 1 person exposure termed negligible.

7.3 RISK ANALYSIS RESULTS

Consequence models discussed in Chapter 6 were exercised for a sample of the chemicals indicated in Table 7.4. The toxic hazard areas were correlated with the puncture size on tank cars and atmospheric stability conditions. The volume of chemical released from each tank car was assumed to be equal to the maximum volume carried in that particular class of tank car consistent with the outage requirements and maximum allowable load on rails. In the case of flammable material releases, the fire thermal radiation hazard area and the potential explosion areas were determined assuming that all of the chemical in the tank car is released very quickly ("instantaneously"). The hazard areas for the corrosive and acid materials were determined assuming that the liquid pool formed on the ground was 1 cm in depth and the diameter was consistent with this depth and maximum liquid volume released. The hazard distance is assumed to extend two pool diameters from the edge of the pool. These hazard area results are combined with the population density data (see section 5.3) to obtain the potential number of people exposed.

TABLE 7.4

Chemicals for Which Hazard Areas Have Been Correlated with Conditions of Release from a Tank Car

CHEMICAL NAME
Ammonia, Anhydrous
Chlorine
Ethylene Oxide
Ethylene Dibromide
Gasoline
Hydrogen Chloride, Anhydrous
Liquefied Petroleum Gas
Nitric Acid
Sulfuric Acid
Sulfur Dioxide
Sulfur Trioxide
Vinyl Chloride
Xylene

The conditional probability of exposure for the assumed circumstances is calculated. The probability results are then converted to the cumulative probabilities for experiencing events which expose a number of people equal to or greater than a specified number. These conditional probabilities are then multiplied by the probability P(Acc | T) of one tank car of the specified class and subclass experiencing a derailment and damage in a main line accident (see section 5.2.5). This provides a national risk probability of population exposure due to one tank car of the specified class being in service carrying the specific hazardous material.

The numerical values of the probabilities and exposures are then converted into the MIL Standard risk classes using the methodology described in section 7.2. These results are presented in Figure 7.2a through Figure 7.2e for a sample of chemicals. These chemicals include, respectively, ethylene oxide, anhydrous ammonia, chlorine, LPG and gasoline. In each figure, the Y-axis is the annual probability of exposing, to the effects of the particular chemical, nation wide, a population number equal to or greater than a specified value. The probability refers to that arising from the service of a single tank car of the specified class (or subclass) carrying the indicated chemical. The probability in each figure spans a range of 5 orders of magnitude (10^{-8} /year to 10^{-3} /year). On the X-axis the exposure in terms of the MIL Standard indices is indicated. To get the national risk values, the Y-axis values in each of the figures should be multiplied by the respective number of tank cars (of the specified class carrying the chemical) in nation wide service in a year.

In each figure we compare the single car annual risks for two different classes of cars, namely, DOT 111A tank car and DOT 105J500W. The 111A car is assumed to be "as built" with no protective improvements; the 105 car, however, is assumed to be equipped with shelf couplers, full height head shield, and thermal protection. We note that for purposes of illustration of the risk differences between an unprotected tank car and a fully protected tank car, we have ignored the HM-181 requirements (and for that matter the car pressure rating requirements) for the transport of the identified chemical in the particular car. For example, anhydrous ammonia is never carried or allowed to be carried in DOT 111A cars. Therefore, the results should be interpreted only as a representation of the risks if the cars had the strengths of the cars indicated in the figures and should not be interpreted as the cars being allowed for service with the identified chemical.

7.4 DISCUSSIONS ON THE RESULTS

Figure 7.2a shows the single car national risk profile for transporting ethylene oxide in a DOT 111A100W tank car and in a DOT 105J500W tank car. First, we notice that as the magnitude of exposure increases, the annual probability of exposure of that magnitude decreases. The range of decrease of the probability is between 3 to 4 orders of magnitude over the range of exposures indicated. The second observation we make is that transport of ethylene oxide in a DOT 111A car is about an order of magnitude more risky (for the same exposure level) than transport in a DOT 105T car. However, the single car risk (in the probability scale) for both tank cars is in the "improbable" range for most of the exposure scale, indicating that the service in either car may be acceptable (see Figure 7.1 for a graphic illustration of the acceptability regions on the risk matrix).

Figure 7.2b shows similar plots for anhydrous ammonia, and Figure 7.2c for chlorine. These three chemicals form the example chemicals for PIH materials. It is noticed that the higher the IDLH values, the steeper is the decrease in the probability with an increase in exposure. For example, in the case of ethylene oxide (whose IDLH value is 800 ppm) the risk value decreases by about an order of magnitude for an exposure level change from "negligible" to "critical". In the case of chlorine (IDLH = 30 ppm) there is virtually no change in the risk probability for the same range of exposure level change as above. This is because, in the case of chemicals with lower toxic hazard concentration levels, even small leaks can potentially expose a large number of people (because of the larger hazard area) compared with the same size leak of a hazardous material with a higher level toxic concentration.

The risk profiles of flammable materials such as LPG and gasoline are in marked contrast to that of PIH materials. Figure 7.2d shows the profile for LPG and Figure 7.2e for gasoline. We observe that, in general, the risk probabilities are lower. Also, the rate of decrease of these probabilities is much higher than in the case of PIH materials. Finally, while in the case of the hypothetical transport of LPG and gasoline in DOT 111A cars catastrophic exposure is indicated to be possible, it should be noted that this arises due to significant assumptions on the very rare behavior mode of the vapors of these chemicals. It is very clear from the results presented in Figure 7.2d and Figure 7.2e that in the case of flammable materials those that are pressurized (LPG) present a higher degree of risk than those that are non-pressurized (gasoline).

The overall findings and conclusions from this study are indicated in Chapter 8.

FIGURE 7.2a

Single Tank Car National Risk Comparison for Different Tank Car Classes ETHYLENE OXIDE

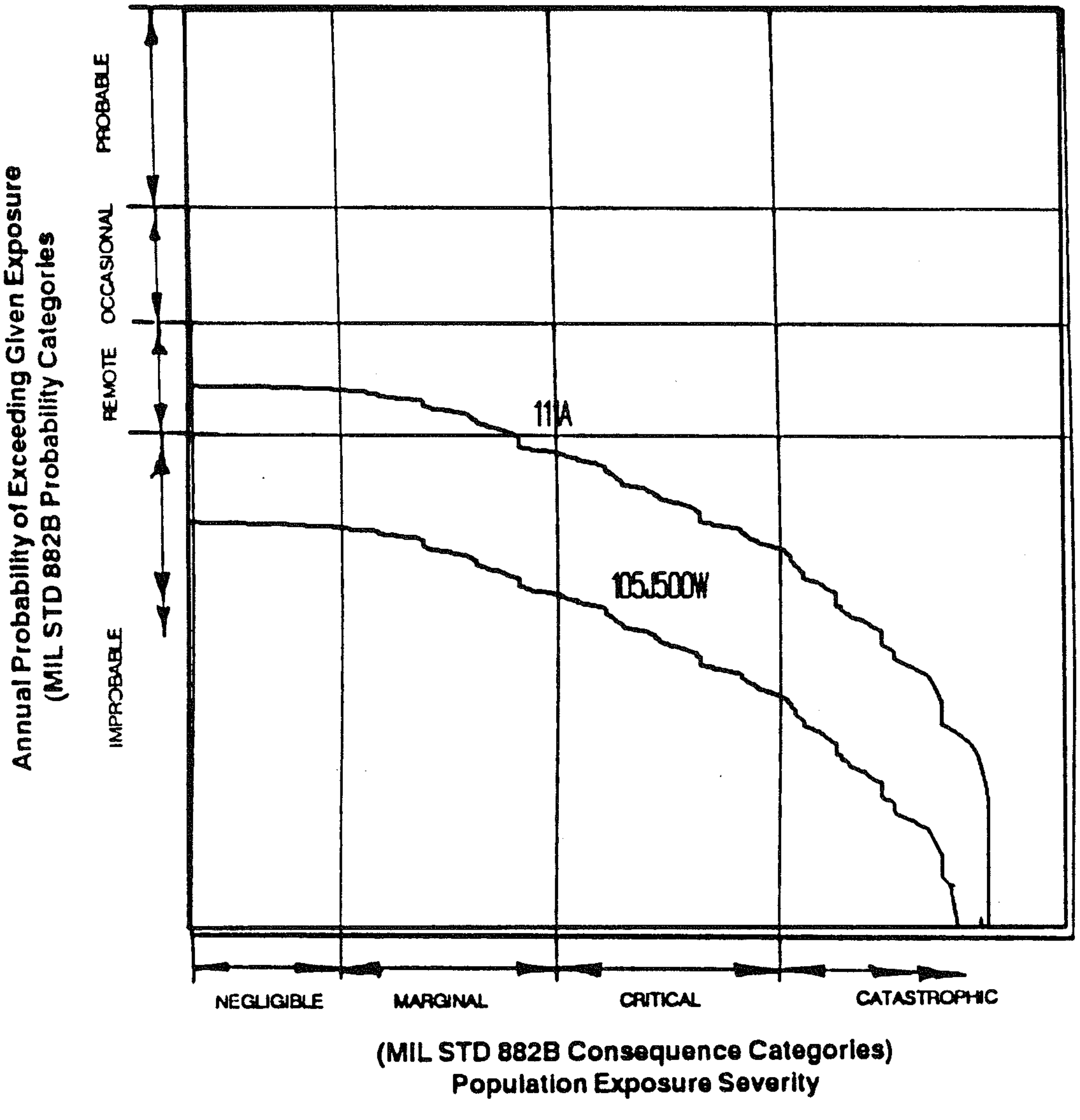


FIGURE 7.2b

Single Tank Car National Risk Comparison for Different Tank Car Classes
AMMONIA, ANHYDROUS

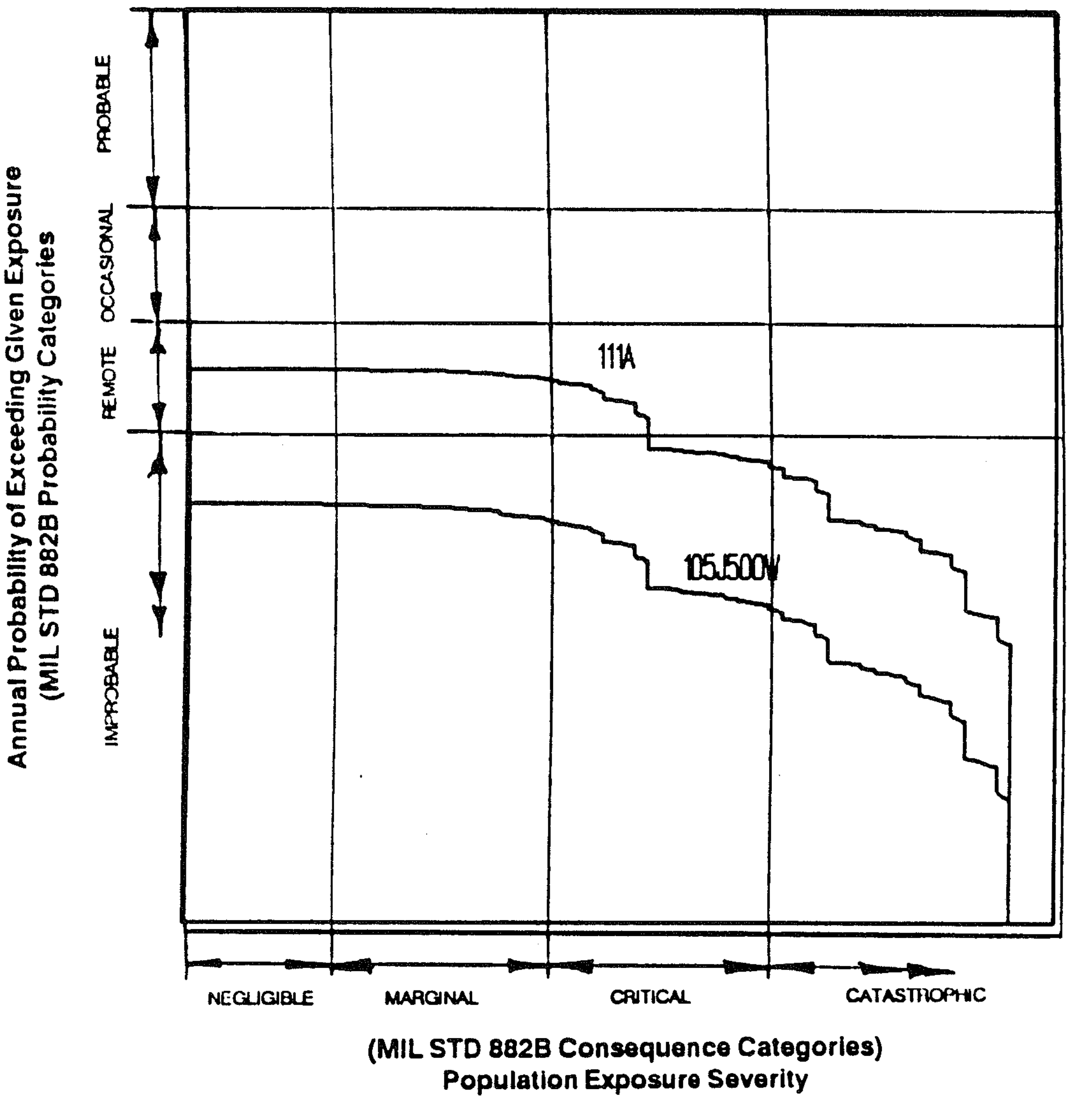


FIGURE 7.2c

Single Tank Car National Risk Comparison for Different Tank Car Classes CHLORINE

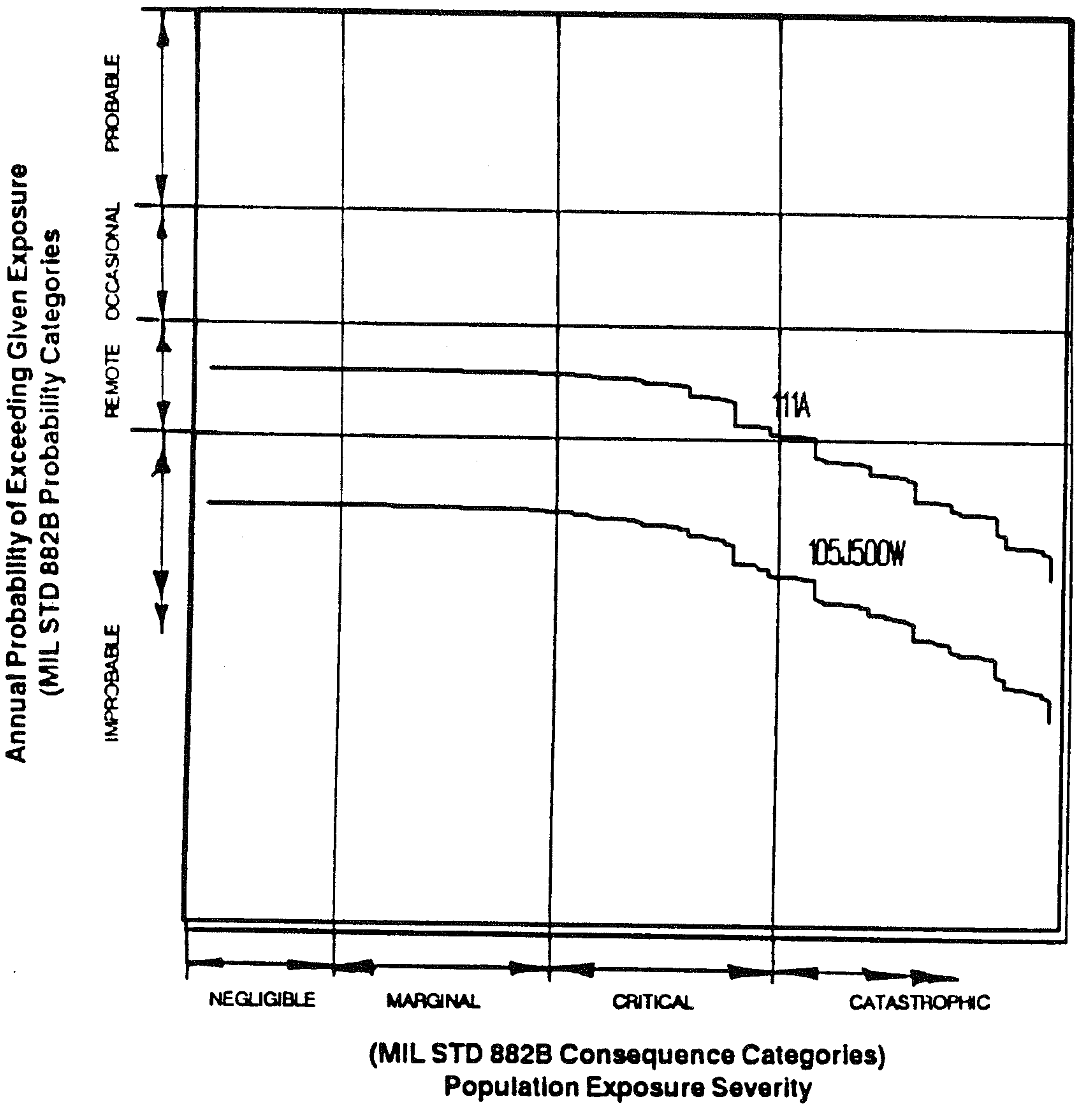


FIGURE 7.2d

Single Tank Car National Risk Comparison for Different Tank Car Classes
L.P.G.

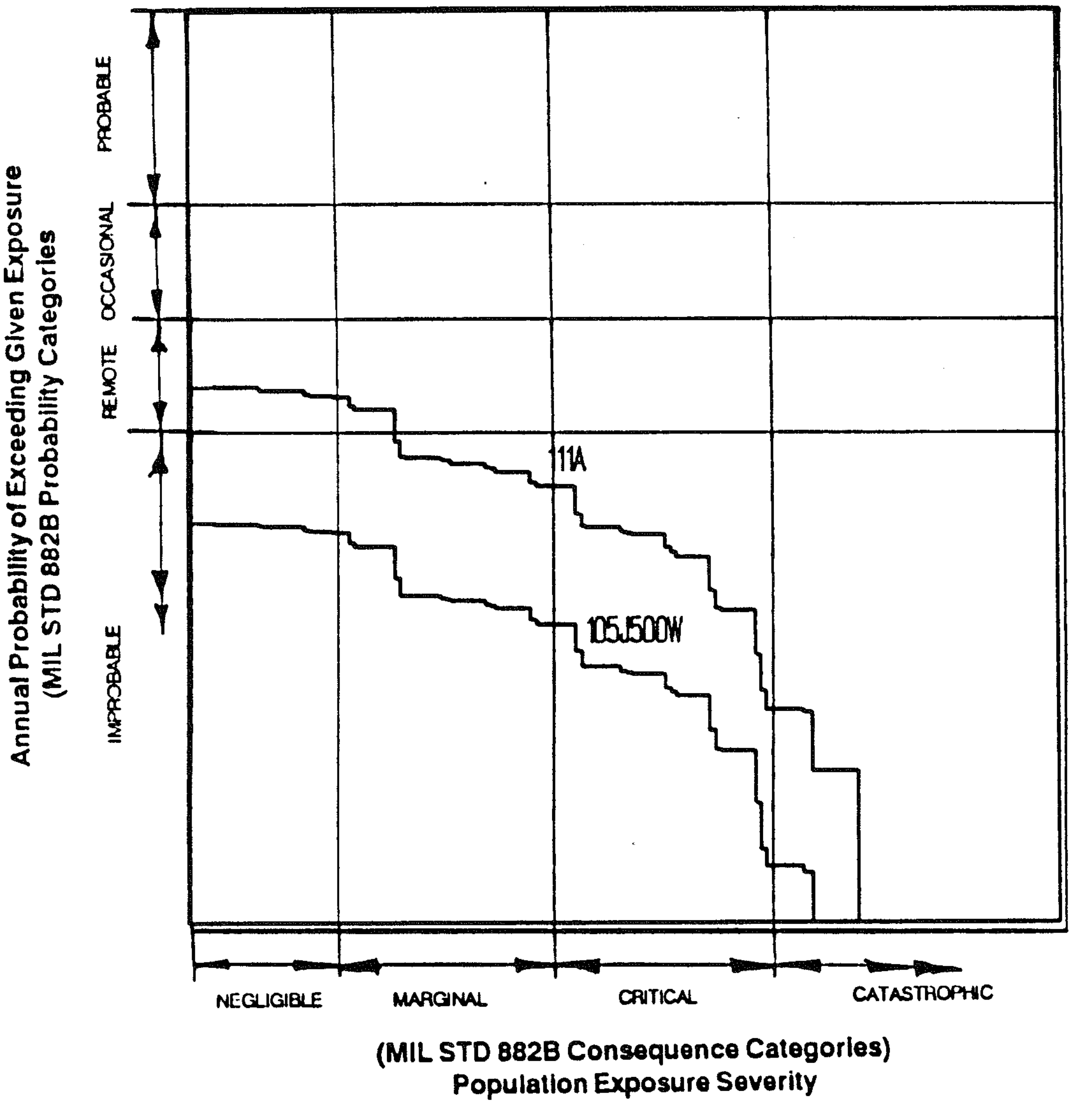
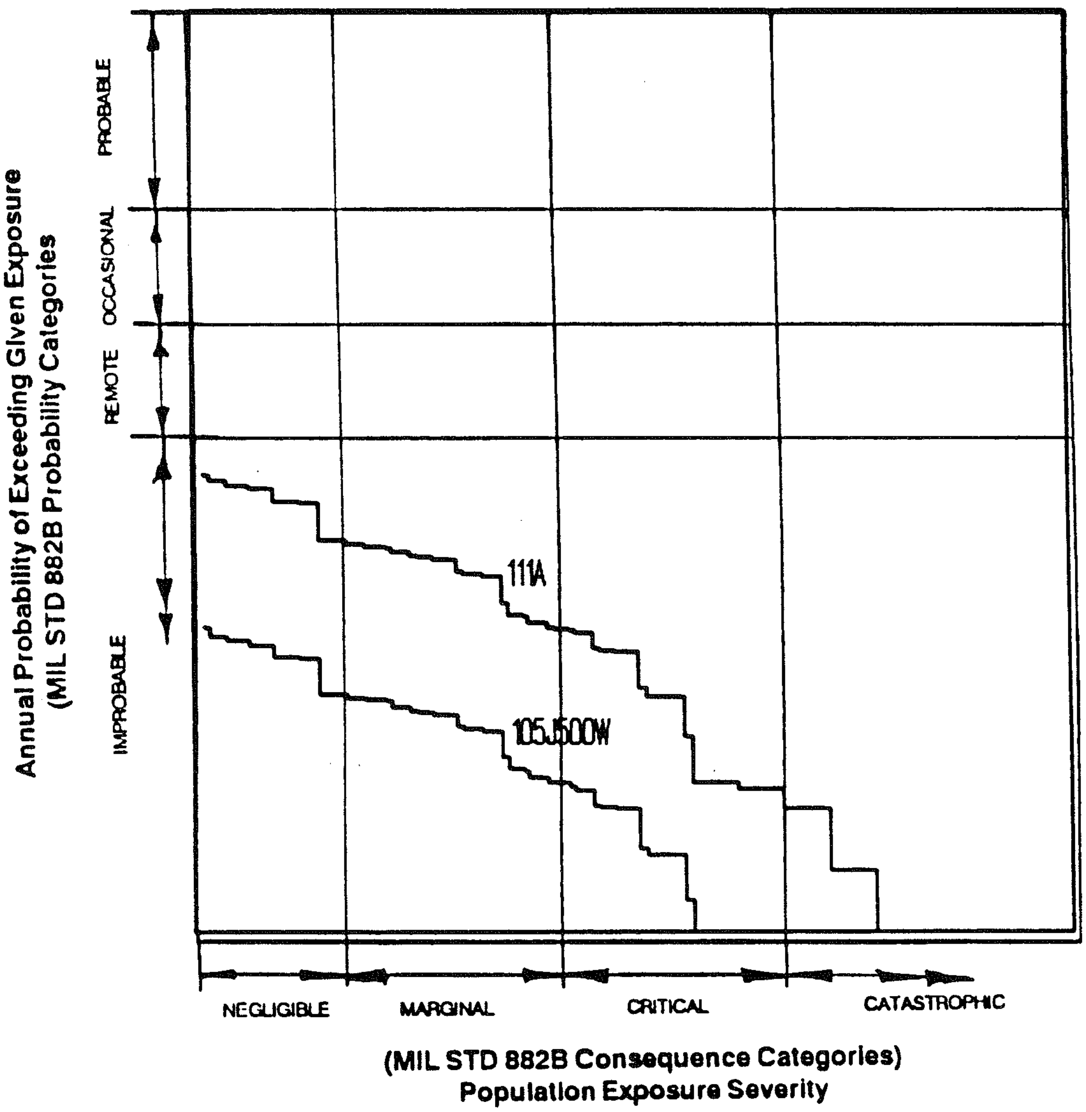


FIGURE 7.2e

Single Tank Car National Risk Comparison for Different Tank Car Classes GASOLINE



7.5 COMPUTERIZED CODE

From the tank car damage data provided by RPI/AAR, the probabilities of tank car puncture (by different classes of tank cars with and without safety devices), the event probability determination methodology discussed in Chapter 5, the chemical hazard area calculation procedures indicated in Chapter 6 and the risk calculation methodology described in the earlier sections of this chapter have been coded into a computer program called "FRA Risk Assessment Program". Using this code a selection can be made of the tank car and the chemical transported in it. The code checks for the permissibility of the tank car - lading combination and indicates to the user the Regulatory restriction, if any. However, the code can be made to proceed with the calculations for any combination of tank car and lading. The program then plots the risk profile and identifies the risk regions per the MIL Standard indices. Only a selected number of hazardous materials are at present in the repertory of this program. These chemicals were identified in Table 7.4.

The results presented in Figures 7.2a through Figure 7.2e were calculated using the above computer code.

CHAPTER 8

Findings & Conclusions

In this study we have reviewed the HM-181 Regulations concerning the transportation of hazardous materials in rail tank cars. Of particular interest to this study were the poison by inhalation materials and flammable materials. The compatibility of the currently authorized tank car - lading combinations in terms of vapor pressure of the at a regulation identified reference temperature and the safety valve setting for excess pressure discharge were examined and the safety factors in these combinations were evaluated.

The principal effort in this study was devoted to the development of a methodology for assessing the potential risk to the public arising from the transport in rail cars of PIH and flammable materials. The purpose of such a risk assessment development was to use the model to compare the relative risks of transporting the same in different classes of tank cars and to assess the extent of reduction of risk if a higher strength tank car is used instead of the one that is now authorized.

As a part of this risk methodology development effort, we gathered data on historical tank car accidents, analyzed and correlated the tank car damages (puncture) sizes with different strength tank cars and established the probabilities of occurrence of different size holes in tank car accidents. Several materials of interest were chosen. The potential areas of hazard for different size leaks from tank cars were calculated under different weather and local topographic conditions and different modes of behavior of the chemicals. These hazard areas were correlated with sizes of leaks. Sample population densities by different "locality classifications" were obtained. All of these data and the model results were integrated in the development of a risk assessment methodology. This risk calculation procedure yields the relationship between the annual probability of mainline derailment accidents (involving the release of a specified chemical from a specified class of tank car) and the potential number of people exposed to the hazardous chemical effects, nation wide.

8.1 FINDINGS

The following are the findings from this study:

Valve Settings

1. There are 180 PIH materials authorized for transport in rail tank cars. Of these, 75 are gases at normal ambient temperature and pressure and remainder are liquids. Thermodynamic properties of relevance to this study were found for only eighteen (18) of the bulk shipment gases (i.e, those transported in tank cars as liquefied gases).

2. Of the above 18 materials, 16 have the ratio of valve set-to-discharge pressure to vapor pressure greater than one. The greater this value compared to unity the higher is the level of safety from over pressure discharge of the PIH chemical vapors into the atmosphere.

   Sulfuryl fluoride has unity value and anhydrous ammonia has a value very close to 1 (ranges from 1.06 to 1.08).

3. For liquid PIH materials the ratio of valve set-to-discharge pressure to the vapor pressure is far higher than 1.

4. The valve set-to-discharge pressure to vapor pressure ratio for most of the flammable materials is far in excess of unity providing a large margin of safety for over pressure discharge.

Tank Car Puncture Susceptibility in Accidents

5. Tank cars in mainline derailment accidents can sustain punctures which vary in size from a very small hole (of equivalent diameter 1.5 cm) to a very large hole (equivalent diameter 0.56 m). The statistical mean size of holes range from about 0.35 m equivalent diameter for DOT 111A cars to 0.29 m equivalent diameter for DOT 105J500W cars.

6. There appears no correlation between the train speed and the size of the puncture in the data examined. The standard deviation in hole area is larger than the mean hole area for almost all of the tank cars investigated, indication a large data scatter.

Accident Probabilities & Exposure Areas

7. The rail accident data for the years 1985 - 1990 indicate that on the average <u>any</u> hazardous material tank car in service has a probability of 1.77×10^{-2} per year of being involved in a derailment accident and a 4.06×10^{-3} per year probability of being in the derailment accident and being damaged. The average probability of leak from a derailed and damaged tank car in a mainline accident is 15.74 %.

8. The probability of release of a hazardous material from a tank car decreases as safety control measures such as head shields, shelf couplers, thermal insulation jackets and increased shell thickness are provided. The improvement (i.e., the reduction in the release probability), in some cases, can be by a factor of 10.

9. Hazard areas for population exposure to the harmful effects of the material depend very much on the type of hazard, the environmental conditions and the volume of chemical released (or the rate of release). In general, the toxic vapor hazard areas are significantly larger than those due to the pool fire thermal hazards or vapor fire hazards. In the case where the flammable vapors detonate in the open after forming a flammable vapor cloud (an extremely rare occurrence) the hazard area can be relatively large.

9. It is uncertain what fraction of the population within the area of hazard, calculated with the threshold levels of effect as criteria, is actually affected by the detrimental effects of the chemical. The exposure risk values calculated are very sensitive to the value used for this fraction.

Risk Results

10. In general, the low consequence risk (expressed in annual probabilities of causing a level of exposure equal to or greater than the "negligible" category) values for most PIH and flammable materials are within an order of magnitude of each other for transport in similar class of tank cars. However, the reduction in risk with increase in exposure level is significant with flammable materials compared to those from PIH materials due to the relatively smaller hazard area in the former materials.

11. The reduction in the single tank car risk between the transport of a chemical in an unprotected tank car (such as 111A) and the well protected tank car (such as the 105J500W) is at least one order of magnitude for the same level of population exposure.

    The reduction in the most severe category of exposure risk is more pronounced in the case of flammable materials than in the case of PIH materials when the chemical is transported in a higher strength tank car.

12. The overall national risk will depend on the number of tank cars in service in any given year transporting the specified hazardous material.

8.2 CONCLUSIONS

The following conclusions can be drawn from the results of this study.

1. The adequacy of the safety provided by the currently authorized valve set-to-discharge pressure setting on anhydrous ammonia tank cars needs to be further investigated. The ratio of this valve set-to-discharge pressure to the vapor pressure of ammonia is very close to unity.

2. The risk assessment model (and the associated computer program) developed in this study can be used very beneficially to evaluate the relative risks of transporting the same chemical in different classes of tank cars or to compare the relative risks posed by different chemicals. For example, gasoline is acceptable for shipment in either a DOT 111A or a DOT 105J tank car, using the system developed. For ethylene oxide, the DOT 105J is acceptable; the 111A is acceptable only with review. The 111A may be a candidate for an orderly transition to a car of greater integrity. Note: Present regulations provide that DOT 105J100W is acceptable for ethylene oxide service.

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List of Acronyms

AAR	Association of the American Railroads
ACGIH	American College of General Industrial Hygiene
ADAM	U.S. Air Force Dispersion Assessment Model
AIB	Accident/Incident Bulletin (published by FRA)
ANPRM	Advanced Notice of Proposed Rule Making
CFR	Code of Federal Regulations
EPA	Environmental Protection Agency
FRA	Federal Railroad Administration
HMR	Hazardous Materials Regulations
IDLH	Immediately Dangerous to Life and Health (toxic vapor concentration)
NA	North American
NIOSH	National Institute of Occupational Safety & Health
NPRM	Notice of Proposed Rule Making
NTSB	National Transportation Safety Board
OSHA	Occupational Safety & Health Administration
PEL	Personnel Exposure Limit
PIH	Poison by Inhalation Materials
RPI	Railway Progress Institute
RSPA	Research & Special Programs Administration
SI	Standard International Units of Measurements
STCC	Standard Transportation Commodity Code
STEL	Short Term Exposure Limit (concentration)
TLV	Threshold Limit Value (concentration)
TMS	Technology & Management Systems, Inc.
UN	United Nations
US DOT	Department of Transportation of the United States

Nomenclature

SYMBOL	DESCRIPTION	UNITS
A_H	Area of the hole on tank car	m^2
A_E	Area of hazard presented by the chemical	km^2
C_{IDLH}	Toxic hazard concentration (IDLH value)	ppm
d_{eq}	Equivalent diameter of the puncture	m
N	Number of tank cars involved in accidents, damages, etc.	
NT	Number of tank cars of the particular class and type in service per year transporting a specific chemical	
p	A symbol which in general represents the probability density of distribution of a certain parameter	
P_{valve}	Relief valve set-to-discharge pressure	psia
P_{vapor}	Chemical vapor pressure at the lading temperature or at 41 °C (insulated tank cars) or at 46 °C (non-insulated tank cars)	psia
$p(A_H)$	Probability density of hole area distribution. That is, $p(A_H)\ dA_H$ represents the probability of realizing a hole of area between A_H and $A_H + dA_H$.	m^2
P	A symbol generally representing the total Probability	
$P(N\|Acc)$	Conditional probability of exposing N persons to chemical effects given that a derailment accident has occurred leading to a damaged tank car (other conditional probabilities are defined in section 5.2.3)	
r_v	Valve safety ratio (see equation 3.1)	
ρ	Population density	(#/sq km)
σ	Standard deviation of the tank car hole area	(m^2)

APPENDIX A

APPENDIX A

Overview of DOT Tank Cars

GENERAL

Railroad tank cars are usually identified by the tank car *type*, *class*, and *specification*. The tank car type indicates the approving or regulating authority such as the DOT (Department of Transportation), AAR (Association of American Railroads), or the ICC (Interstate Commerce Commission). The class of a tank car is a general designation and usually encompasses several specifications. For example, DOT-105A is a *class* of tank car while DOT-105A100ALW is a tank car *specification*.

Tank cars currently in use by the railroad industry are of the DOT, AAR, and ICC types. AAR type tank cars are used, for the most part, for the transportation of non-regulated commodities. ICC type tank cars were constructed prior to 1967 and the Department of Transportation Act at which time the Interstate Commerce Commission Regulations became the DOT Hazardous Materials Regulations (HMR). Starting in 1968 most ICC type cars were re-designated with DOT specifications. Currently, the majority of hazardous materials are transported in DOT type tank cars. For this reason, this discussion is devoted exclusively to DOT type cars.

In general, DOT tank cars can be classified as either "common" or "rare". Common tank cars consist of both pressure or non-pressure, insulated or non-insulated cars and are used for shipping a variety of hazardous and non-hazardous materials. Common cars include DOT class 103, 104, 105, 111, 112, and 114 cars. Rare cars include DOT class 113 cryogenic tanks. Multi-unit tanks were designed to be removed from the car chassis for loading and unloading purposes. Cryogenic cars were designed to transport highly refrigerated liquids such as liquid ethylene and liquid hydrogen (-104°C and -253°C, respectively).

Some of the original DOT tank cars still in use today are the DOT-103 and 104 non-pressure cars. DOT-103 cars are identified by the expansion dome mounted high on the tank shell. This expansion dome provides outage space for the commodity. These cars are constructed of either carbon steel, aluminum alloy, or steel alloy and may or may not be insulated. DOT-104 cars are constructed from carbon steel and are similar to 103 class cars except that the expansion dome is somewhat larger (minimum of 2% outage for 104 cars vs nominal of 1% outage for most 103 cars). DOT-111 class cars are essentially DOT-103 or

104 cars without the expansion dome. Outage space for these cars must be provided within tank shell. A car unique in the 111 class is the 111A100W4 insulated car used to transport Ethylene oxide, a multi hazard material (Ethylene oxide is both a PIH and flammable gas material). The DOT-111A100W4 car is identical in both use and appearance to the DOT-105A100W car, an insulated pressure car. Depending on the regulations governing tank car construction (49 CFR Part 179), DOT-103, 104, and 111 cars may or may not have bottom outlets, wash-outs, and insulation. Non-pressure type cars have tank test pressures of either 60 or 100 psig. Tank car types with no designated test pressure, e.g., 103, 104, are tested to 60 psig.

The DOT-112A and 114A class of cars are carbon steel pressure cars designed to carry flammable liquids and liquified gases and were originally designed as non-insulated cars. Current regulations, however, allow for the use of insulation on these cars for transporting materials meeting the criterion of PIH. DOT class 112 and 114 cars are essentially identical except that bottom outlets and wash-outs are optional on 114 cars and prohibited on 112 cars. DOT-112 and 114 cars are used to carry such commodities as anhydrous ammonia (D) and allyl alcohol.

The DOT-105 class of tank cars are insulated pressure cars constructed of carbon steel or aluminum alloy. These cars are used to transport such commodities as PIH and flammable liquids and liquified gases (Chlorine, Ethylene Oxide, Anhydrous ammonia, etc.).

Table A.0 lists the principal characteristics of DOT class 103, 104, 111, 105, 112, and 114 tank cars.

TANK CAR PROTECTION

Puncture protection devices used on tank cars include shelf couplers (or a coupler vertical restraint systems) and head shields. In the event of an accident, shelf couplers reduce the chance of the tank car "riding over" the coupler of the forward car and puncturing the tank head. Head shields, as the name implies, are steel plates mounted parallel to the tank head and prevent or reduce the damage to the head in the event of an accident. Today, shelf couplers are standard on all DOT tank cars. The installation of head shields may be required by the regulations for cars transporting certain materials.

Thermal protection systems, or protection systems, applied to the tank shell, are used to reduce the heat transferred to the commodity in the event that the tank car is exposed to a fire. Both "sprayed on" and "jacketed" thermal protection systems are used. Sprayed on thermal protection, once applied, hardens and forms a shell which does not require a jacket. Both systems, unlike insulation, are non-flammable and are required to meet performance standards set in the regulations. Insulation, on the other hand, which may be similar to standard residential insulation and may be flammable, is used mainly to control the lading temperature along the shipping route.

In general, except for certain tank car classes (103, 104, 106, 110), the extent of protection installed on a car is indicated by the letters "S", "J", or "T" in the car specification. The letter "A" usually signifies an "as built" car without protection (other than shelf couplers).

DOT TANK CAR SPECIFICATIONS

DOT tank car specifications consist of a class designation followed by identifying letters and numbers. The second number, where present, indicates tank test pressure in psig. In all classes except 103, 104 and 113, the two number series are separated by an "A" which has no significance and usually denotes a car without any protection (other than shelf couplers). Suffix W denotes a fusion welded tank; suffix F denotes a forge welded tank and suffix X denotes a fusion welded tank seam with forge welded head seams. The absence of a suffix indicates seamless construction. For example, the tank car specification:

```
DOT  105  A  100  AL  W
 |    |   |   |   |   |
 |    |   |   |   |   └———————— Welded Construction
 |    |   |   |   └———————— Material when other than steel
 |    |   |   └———————— Tank test pressure
 |    |   └———————— No special significance, except when replaced with S, J, or T
 |    └———————— Class designation
 └———————— Authorizing Agency
```

indicates a DOT class 105 car with a tank test pressure of 100 psig. The tank is constructed of aluminum (AL) and is fusion welded (W).

For DOT 112, 114, 105 and some 111 class tank cars, the "A" in the specification may be replaced by the letter "S", "J", or "T" signifying the extent of protection installed on the car. The significance of each letter is:

S:	Denotes a tank car equipped with head shields. This car does *not* have thermal protection;
J:	Denotes a car equipped with thermal protection system and protective steel jacket. All cars with a "J" designation are required to have head protection as defined by the letter "S";
T:	Denotes a car equipped with spray-on thermal protection without steel jacket. This car is also required to have head shields.

For products requiring thermal protection, either the "J" or "T" type car may be used. Also, when the regulations authorize the use of a particular tank car, the same class tank car having a higher tank test pressure may be used. Tank cars of the same class and pressure having increase protection may also be used. However, if authorized cars are required to have protective equipment installed, the higher test pressure cars must be similarly equipped.

Overview of DOT Tank Cars

This discussion provides an overview of U.S. DOT tank car tanks used to transport hazardous materials. A brief history of tank cars is provided as well as a discussion of the nomenclature and numbering system used for tank car identification. Various tank car protective device systems are identified as are the specific characteristics of a number of DOT tank car types.

TABLE A.0

Principal Characteristics of Various DOT Tank Car Classes

CAR CLASS	PRESSURE CAR	TANK TEST PRESSURES	INSULATION	BOTTOM OUTLETS	BOTTOM WASHOUTS	CLASS OF MATERIALS CARRIED (4)
103	No	60	Optional	(1)	(1)	FL, CL, CM, OX, NH
104	No	60-100	Optional	Optional	Optional	FL, CL, CM, OX, NH
111	No	60-100	Optional (2)	(1)	(1)	FL, CL, CM, OX, NH, (3)
105	Yes	100-600	Required	Prohibited	Prohibited	FL, FG, NG, PIH
112	Yes	200-500	Optional	Prohibited	Prohibited	FL, FG, NG, PIH
114	Yes	340-400	Optional	Optional	Optional	FL, FG, NG, PIH

(1) Either prohibited or optional, depending on specification.

(2) Required on 111A60W1, 111A60W2, 111A100W3, 111A100W4 cars.

(3) Ethylene oxide and methyl bromide allowed in DOT-111A100W4 cars.

(4) NG = Non flammable gas
FL = Flammable liquid
FG = Flammable gas
CL = Combustible liquid
CM = Corrosive material
OX = Oxidizer
NH = Non hazardous material
PIH = Poisonous gas or liquid

TABLE A.1

AAR 1990 Top 125 Hazardous Commodities Movements by Tank Car Origination

This table contains a listing of the American Association of Railroads 1990 Top 125 Hazardous Commodities Movements by Tank Car Origination. The data listed was obtained from the Bureau of Explosives Annual Report of Hazardous Materials Transported by Rail for the year 1990 (Report BOE 90-1, June 15, 1991).

Table A.1

1990 Top 125 Hazardous Commodities Movements by Rank

RANK	STC Code	COMMODITY	DOT HAZARD CLASS	TOTAL ORIGINS
1	49 457 70	Molten Sulfur	OC	82917
2	49 300 40	Sulfuric Acid	CM	63677
3	49 042 10	Anhydrous Ammonia	NG	56345
4	49 352 43	Sodium Hydroxide	CM	55302
5	49 041 20	Chlorine	NG	53130
6	49 057 52	Liquified Petroleum Gas	FG	50696
7	49 352 40	Sodium Hydroxide	CM	34265
8	49 302 47	Phosphoric Acid	CM	29044
9	49 057 92	Vinyl Chloride	FG	28983
10	49 057 81	Propane (LPG)	FG	28282
11	49 092 30	Methyl Alchohol	FL	27733
12	49 057 06	Butane (LPG)	FG	21770
13	49 151 68	Fuel Oil	CL	20683
14	49 072 65	Styrene Monomer, Inhibited	FL	17858
15	49 045 09	Carbon Dioxide, Ref. Liq.	NG	15893
16	49 057 47	Isobutane (LPG)	FG	14491
17	49 302 28	Hydrochloric Acid	CM	14436
18	49 057 82	Propylene (LPG)	FG	12810
19	94 101 65	Crude Oil, Petroleum	FL	12809
20	49 091 51	Denatured Alchohol	FL	11300
21	49 151 11	Fuel Oil	CL	10240
22	49 081 78	Gasoline	FL	9733
23	49 601 32	Hazardous Substance, n.o.s.	OE	9427
24	49 057 04	Butane (LPG)	FG	9015
25	49 151 13	Fuel Oil	CL	8529
26	49 151 12	Fuel Oil	CL	7714
27	49 066 10	Ethylene Oxide	FL	7583
28	49 212 20	Phenol	PB	7400
29	49 081 10	Benzene	FL	7388
30	49 057 02	Butane	FG	7327
31	49 356 45	Hexamethylenediamine Solution	CM	6796
32	49 152 59	Petroleum Naphtha	CL	6654
33	49 300 42	Sulfuric Acid, Spent	CM	6578
34	49 072 70	Vinyl Acetate	FL	5835
35	49 102 59	Petroleum Naphtha	FL	5662
36	49 081 32	Cyclohexane	FL	5248
37	49 066 20	Propylene Oxide	FL	4972
38	49 072 50	Methyl Methacrylate Monomer	FL	4860
39	49 151 85	Combustible Liquid, n.o.s.	CL	4849
40	49 093 51	Xylene	FL	4666
41	49 352 30	Potassium Hydroxide	CM	4284
42	49 057 50	Isobutane (LPG)	FG	4177
43	49 093 05	Toluene	FL	3999
44	49 313 03	Acetic Acid, Glacial	CM	3965
45	49 064 20	Acrylonitrile	FL	3937
46	49 092 15	Fuel, Aviation, Turbine	FL	3922
47	49 300 30	Oleum	CM	3865
48	49 072 10	Acetaldehyde	FL	3859

Table A.1 continued

RANK	STC Code	COMMODITY	DOT HAZARD CLASS	TOTAL ORIGINS
49	49 081 05	Acetone	FL	3812
50	49 161 41	Phosphorus, White	FS	3757
51	49 082 24	Methyl Tert-Butyl Ether	FL	3474
52	49 131 68	Formaldehyde Solution	CL	3333
53	49 057 07	Butene (LPG)	FG	3276
54	49 091 66	Ethylene Dichloride	FL	3176
55	49 042 90	Sulfur Dioxide	NG	3169
56	49 091 41	Denatured Alcohol	FL	3089
57	49 215 75	Toluene Diisocyanate	PB	3086
58	49 092 05	Isopropanol	FL	2739
59	49 057 48	Isobutylene (LPG)	FG	2658
60	49 122 15	Butyl Acetate	CL	2626
61	49 300 24	Hydrogen Fluoride	CM	2477
62	49 101 85	Flammable Liquid, n.o.s.	FL	2466
63	49 183 35	Hydrogen Peroxide Solution	OM	2417
64	49 151 67	Fuel, Aviation,Turbine	CL	2307
65	49 151 17	Fuel Oil, #2	CL	2302
66	49 152 45	Oil, n.o.s.	CL	2179
67	49 302 21	Corrosive Liquid, n.o.s	CM	2126
68	49 323 42	Ferric Chloride Solution.	CM	2086
69	49 314 05	Acrylic Acid	CM	2053
70	49 093 50	Xylene	FL	1967
71	49 131 58	Octyl Alcohol	CL	1916
72	49 313 04	Acetic Anhydride	CM	1912
73	49 105 35	Fuel Oil Additives	FL	1887
74	49 210 25	Hydrocyanic Acid, Liquid	PA	1877
75	49 092 37	Methyl Alcohol	FL	1865
76	49 302 48	Phosphoric Acid	CM	1727
77	49 151 10	Fuel Oil	CL	1669
78	49 091 17	Butyl Alcohol	FL	1653
79	49 411 61	Maleic Anhydride	OA	1637
80	49 092 43	Methyl Ethyl Ketone	FL	1517
81	48 105 60	Waste Flammable Liquid, n.o.s.	HW	1514
82	49 072 15	Ethyl Acrylate, Inhibited	FL	1498
83	49 101 02	Alcoholic Berverage	FL	1458
84	49 091 60	Ethyl Acetate	FL	1432
85	49 365 40	Corrosive Liquid, n.o.s.	CM	1429
86	49 352 68	Sodium Hydrosulfide Solution	CM	1419
87	49 081 83	Hexane	FL	1404
88	49 057 61	Methyl Chloride	FG	1369
89	49 411 76	1,1,1-Trichloroethylene	OA	1346
90	49 091 59	Ethyl Alcohol	FL	1324
91	49 091 46	Ethyl Alcohol	FL	1303
92	49 102 45	Oil, n.o.s.	FL	1303
93	49 187 74	Ammonium Nitrate Solution	OM	1265
94	49 104 90	Aromatic Concentrates	FL	1245
95	49 131 94	Glycol Ethers	CL	1230
96	49 151 47	Compounds, Cleaning	CL	1205

Table A.1 continued

RANK	STC Code	COMMODITY	DOT HAZARD CLASS	TOTAL ORIGINS
97	40 300 26	Hydrofurosilicic Acid	CM	1137
98	49 081 25	Carbon Disulfide	FL	1097
99	49 103 20	Pulp Mill Liquid	FL	1092
100	49 045 03	Argon, Ref. Liq.	NG	1089
101	49 081 19	Butylraldehyde	FL	1044
102	49 045 52	Chlorodifluoromethane	NG	1027
103	49 164 56	Sodium, Metal	FS	1019
104	49 352 48	Sodium Solution (waste)	CM	1017
105	49 214 10	Aniline Oil	PB	999
106	49 403 20	Carbon Tetrachloride	OA	946
107	49 072 41	Styrene/Ethylbenzene Mixture	FL	926
108	49 403 60	Naphthalene	OA	915
109	49 081 62	Ethyl Chloride	FL	905
110	49 091 28	Butyl Acetate	FL	902
111	49 072 23	Chloroprene, Inhibited	FL	873
112	49 352 60	Sodium Aluminate Solution	CM	862
113	49 042 71	Hydrogen Chloride, Ref. Liq	NG	862
114	49 055 10	Dimethylamine, Anhydrous	FG	848
115	49 104 44	Rosin Solution	FL	832
116	49 131 44	Formaldehyde Solution	CL	827
117	49 411 32	Dichloromethane	OA	823
118	49 091 29	Butyl Alcohol	FL	809
119	49 403 56	Toluenediamine	OD	798
120	49 072 80	Vinylidene Chloride	FL	795
121	49 074 20	Epichlorohydrin	FL	779
122	49 082 55	Pentane	FL	761
123	49 631 20	Haz Sub (w/dinitrotoluene)	OE	749
124	49 365 39	Petroleum Refinery Waste	CM	749
125	49 323 29	Ferrous Chloride Solution	CM	748

TABLE A.2

Partial Listing of HM-181 PIH Chemical Data Base

This table contains a partial listing of the PIH data base as compiled from HM-181 and the December 1991 corrections document. Listed are approximately 163 chemical names and corresponding hazard classes, and HM-181 bulk packaging authorization sections. Also provided is a listing of authorized tank cars by reference as well as chemical vapor pressures at 41 °C and 46 °C, if available.

CHEM_NAME	CLASS	BULK_PACK	BULK_SPROV[1]	CARNUMB[2]	PRESS_REF[3]	VAPOR_41C[4]	VAPOR_46C[4]
3,5 Dichloro-2,4,6 trifluoropyridine	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Acrolein, inhibited	6.1	244	9,12,14,42,72,77	44,45	A	< 15	< 15
Acetone cyanohydrin, stabilized	6.1	244	9,14,74,76,77	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	A	< 15	< 15
Allyl alcohol	6.1	244	9,14,74,77	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	A	< 15	< 15
Allyl chloroformate	8	244	9,14,72	44,45	A	< 15	< 15
Allyl isothiocyanate, stab.	6.1	244	9,14,74	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	A	< 15	< 15
Allylamine	6.1	244	9,14,74	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	A	< 15	< 15
Ammonia, anhydrous (D)	2.2	314		33,34,35,36,42,43,44,45,68,69, 71,72,74,75,77,79,80,89,90,91, 92,93,94	G	213.0	237.0
Ammonia, anhydrous, (I)	2.3	314		33,34,35,36,42,43,44,45,68,69, 71,72,74,75,77,79,80,89,90,91, 92,93,94	G	213.0	237.0
Arsenic trichloride	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Arsine	2.3	NONE		none authorized			
Boron tribromide	8	244	9,14,74	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	A	< 15	< 15
Boron trichloride	2.3	314	9,14	33,34,35,36,42,43,44,45,41,42, 43,44,45,68,69,71,77,79,80,89, 90,93,94	G	22.0	29.0
Boron trifluoride	2.3	314	9,14	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94			
Bromine	6.1	249	9,12,64	33,34,35,36,42,43,44,45	A	< 15	< 15
Bromine chloride	2.3	314	9,12,14	42,43,44,45,68,69,71,77,79,80, 89,90,93,94			
Bromine pentafluoride	5.1	244	9,14,72	44,45	A	< 15	< 15
Bromine trifluoride	5.1	244	9,14,74	41,42,43,44,45,68,69,71,77,79,	A	< 15	< 15

Table A.2: Partial listing of HM-18' 'H Chemical Data Base

CHEM_NAME	CLASS	BULK_PACK	BULK_SPROV	CARNUMB	PRESS_REF	VAPOR_41C	VAPOR_46C
				80,89,90,93,94			
Bromoacetone	6.1	244		none authorized			
Carbon dioxide / Ethylene oxide mixture, > 25% EO	2.3	314	9,14	42,43,44,45,68,69,71,77,79,80, 89,90,93,94			
Carbon monoxide & hydrogen mixture	2.3	NONE		none authorized			
Carbon monoxide gas	2.3	NONE		none authorized			
Carbon monoxide, refrigerated liquid	2.3	NONE		none authorized			
Carbonyl fluoride	2.3	NONE		none authorized			
Carbonyl sulfide	2.3	314	9,14	43,44,45,68,69,71,77,79,80,89, 90,93,94	G	249.0	286.0
Chlorine	2.3	314	9,14	33,36,44,45	G	154.2	176.0
Chlorine pentafluoride	2.3	314	7,9,14	none authorized			
Chlorine trifluoride	2.3	314	7,9,14	none authorized			
Chloroacetaldehyde	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Chloroacetone, stabilized	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Chloroacetonitrile	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Chloroacetyl chloride	8	244	8,9,14,74,77	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Chloropicrin	6.1	244	7,9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Chloropicrin / methyl bromide mixtures	2.3	314	9,14	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	G	36.0	42.0
Chloropicrin / methyl chloride mixtures	2.3	245		none authorized	G	110.0	129.0
Chloropicrin mixtures, n.o.s.	6.1	243		42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Chloropivaloyl chloride	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15

Table A.2 continued

CHEM_NAME	CLASS	BULK_PACK	BULK_SPROV	CARNUMB	PRESS_REF	VAPOR_41C	VAPOR_46C
Chlorosulfonic acid (with or without Sulfur trioxide)	8	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Coal gas	2.3	314		41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94			
Compressed or liquified gases, poisonous, flammable, n.o.s. (1000 ppm < LC50 < 3000 ppm)	2.3	314	14	42,43,44,45,68,69,71,77,79,80, 89,90,93,94			
Compressed or liquified gases, poisonous, flammable, n.o.s. (200 ppm < LC50 < 1000 ppm)	2.3	314	9,14	42,43,44,45,68,69,71,77,79,80, 89,90,93,94			
Compressed or liquified gases, poisonous, flammable, n.o.s. (LC50 < 200)	2.3	NONE		none authorized			
Compressed or liquified gases, poisonous, flammable, n.o.s. (3000 ppm < LC50 < 5000 ppm)	2.3	314		42,43,44,45,68,69,71,77,79,80, 89,90,93,94			
Compressed or liquified gases, poisonous, n.o.s. (1000 ppm < LC50 < 3000 ppm)	2.3	314	14	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94			
Compressed or liquified gases, poisonous, n.o.s. (200 ppm < LC50 < 1000 ppm)	2.3	314	9,14	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94			
Compressed or liquified gases, poisonous, n.o.s. (200 ppm < LC50)	2.3	NONE		none authorized			
Compressed or liquified gases, poisonous, n.o.s. (3000 ppm < LC50 < 5000 ppm)	2.3	314		41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94			
Crotonaldehyde, stabilized	3	244	9,14,74,77	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Cyanogen bromide	6.1	244	9,14,72	44,45	A	< 15	< 15
Cyanogen chloride, inhibited	2.3	NONE		none authorized			
Cyanogen, liquefied	2.3	NONE		none authorized			

Table A.2 continued

CHEM_NAME	CLASS	BULK_PACK	BULK_SPROV	CARNUMB	PRESS_REF	VAPOR_41C	VAPOR_46C
Cyclohexyl isocyanate	6.1	244	9,14,74,77	41,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Diborane	2.3	NONE		none authorized			
Diborane mixture	2.3	NONE		none authorized			
Dichlorodifluoromethane/ Ethylene oxide mixture	2.3	314		42,43,44,45,68,69,71,77,79,80, 89,90,93,94			
Dichlorosilane	2.3	314	9,14	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	G	30.0	35.0
Diketene, inhibited	3	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Dimethyl sulfate	6.1	244	9,14,74,77	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Dimethylhydrazine, symmetrical	3	244	9,14,74,77	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	A	< 15	< 15
Dimethylhydrazine, unsymmetrical	6.1	244	9,14,58,79	33,34,35,36,42,43,44,45	A	< 15	< 15
Dinitrogen tetroxide	2.3	314	12,14,45,46,61,66,67,77	35,36,44,45	G	20.0	29.0
Ethyl chloroformate	6.1	244	9,14,32,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Ethyl chlorothioformate	8	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Ethyl isocyanate	3	244	9,14,72	44,45	A	< 15	< 15
Ethyl phosphonothioic dichloride, anhydrous	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Ethyl phosphonous dichloride, anhydrous, pyrophoric liquid	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Ethyl phosphorodichlroridate	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Ethyldichloroarsine	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Ethylene chlorohydrin	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Ethylene dibromide	6.1	244	9,14,74,77	41,42,43,44,45,68,69,71,77,79,	A	< 15	< 15

Table A.2 continued

CHEM_NAME	CLASS	BULK_PACK	BULK_SPROV	CARNUMB	PRESS_REF	VAPOR_41C	VAPOR_46C
				80,89,90,93,94			
Ethylene oxide	2.3	323		29,33,34,35,36,38,40,42,43,44, 45,104	G	28.0	35.0
Ethyleneimine, inhibited	6.1	244	9,72,77	44,45	A	< 15	< 15
Fluorine, compressed gas	2.3	NONE		none authorized			
Germane (germanium hydride)	2.3	NONE		none authorized			
Hexachlorocylopentadiene	6.1	244	9,14,74,77	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Hexaethyl tetraphosphate & compressed gas mixture	2.3	NONE		none authorized			
Hexafluoroacetone	2.3	314	9,14	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	G	132.0	160.0
Hydrogen bromide, anhydrous	2.3	314	14	none authorized			
Hydrogen chloride, anhydrous	2.3	NONE		none authorized			
Hydrogen chloride, refrigerated liquid	2.3	314	6,43	36,45			
Hydrogen cyanide, anhydrous, stabilized	6.1	244	12,61,65,77	35,36,44,45	G	10.44	15.1
Hydrogen cyanide, anhydrous, stabilized (absorbed)	6.1	NONE		none authorized			
Hydrogen selenide, anhydrous	2.3	NONE		none authorized			
Hydrogen sulfide, liquefied	2.3	314	9,14	none authorized			
Insecticide gas, toxic, n.o.s.	2.3	NONE		none authorized			
Iron pentacarbonyl	6.1	244	9,14,72,77	44,45	A	< 15	< 15
Isobutyl chloroformate	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Isobutyl isocyanate	3	244	9,14,72	44,45	A	< 15	< 15
Isopropyl chloroformate	6.1	244	9,14,74,77	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Methoxymethyl isocyanate	3	244	9,14,72	44,45	A	< 15	< 15
Methyl bromide	2.3	314	14	29,31,33,34,35,36,38,40,42,43, 44,45,104	G	35.0	44.0
Methyl bromide and Ethylene	6.1	244	9,14,74	41,42,43,44,45,68,69,71,77,79,	A	< 15	< 15

Table A.2 continued

CHEM_NAME	CLASS	BULK_PACK	BULK_SPROV	CARNUMB	PRESS_REF	VAPOR_41C	VAPOR_46C
dibromide, liquid				80,89,90,93,94			
Methyl chloroformate	6.1	244	9,14,72	44,45	A	< 15	< 15
Methyl chloromethyl ether	6.1	244	9,14,72	44,45	A	< 15	< 15
Methyl chlorosilane	2.3	314	9,14	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	G	38.0	41.0
Methyl dichloroarsine	6.1	NONE	9,14	none authorized			
Methyl hydrazine	6.1	244	9,14,72,77	44,45	A	< 15	< 15
Methyl iodide	6.1	244	9,14,74	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	A	< 15	< 15
Methyl isocyanate	6.1	244	9,14,72	44,45	A	< 15	< 15
Methyl isothiocyanate	3	244	9,14,72	44,45	A	< 15	< 15
Methyl mercaptan	2.3	314	7,9,14	33,34,35,36,42,43,44,45	G	39.0	47.0
Methyl orthosilicate	3	244	9,14,74	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	A	< 15	< 15
Methyl phosphonic dichloride	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Methyl phosphonous dichloride	6.1	244	9,14,16,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Methylamine, anhydrous	2.3	314	14	33,34,35,36,42,43,44,45,68,69, 71,77,79,80,89,90,93,94	G	71.0	87.0
n-Butyl chloroformate	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94			
n-Butyl isocyanate	6.1	244	9,14,30,72,77	44,45			
n-Propyl chloroformate	6.1	244	9,14,74,77	42,43,44,45,68,69,71,77,79,80, 89,90,93,94			
n-Propyl isocyonate	3	244	9,14,72	44,45			
Nickel carbonyl	6.1	NONE		none authorized			
Nitric acid, fuming	8	244	9,74	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	A	< 15	< 15
Nitric oxide / Nitrogen tetroxide mixture	2.3	NONE		none authorized			
Nitric oxide [NO]	2.3	NONE	12,37,77	none authorized			
Nitrogen trifluoride	2.3	NONE		none authorized			

Table A.2 continued

CHEM_NAME	CLASS	BULK_PACK	BULK_SPROV	CARNUMB	PRESS_REF	VAPOR_41C	VAPOR_46C
Nitrogen trioxide	2.3	NONE		none authorized			
Nitrosyl chloride	2.3	314	14	33,34,35,36,42,43,44,45	G	64.0	77.0
Organic phosphate, Organic phosphate compound, or Organic phosphorus compound; mixed with compressed gas	2.3	NONE		none authorized			
Oxygen difluoride	2.3	NONE		none authorized			
Parathion and compressed gas mixture	2.3	245		none authorized			
Pentaborane	4.2	NONE		none authorized			
Perchloromethyl mercaptan	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94			
Perchloryl fluoride	2.3	314	12,14	43,44,45,69,69,71,77,79,80, 89,90,93,94	G	226.0	252.0
Phenyl carbylamine chloride	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Phenyl isocyanate	6.1	244	9,14,74,77	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	A	< 15	< 15
Phenyl mercaptan	6.1	244	9,14,74,77	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	A	< 15	< 15
Phosgene	2.3	314		none authorized			
Phosphine	2.3	NONE		none authorized			
Phosphorus oxychloride	8	244	9,14,74,77	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Phosphorus pentafluoride	2.3	NONE		none authorized			
Phosphorus trichloride	8	244	9,14,15,74,77	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Phosphorus trifluoride	2.3	NONE		none authorized			
Poisonous liquid, corrosive, n.o.s., PIH, HAZ 1A	6.1	244	9,14,72	44,45			
Poisonous liquid, corrosive, n.o.s., PIH, HAZ 1B	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Poisonous liquid, flammable,	6.1	244	9,14,72	44,45			

Table A.2 continued

CHEM_NAME	CLASS	BULK_PACK	BULK_SPROV	CARNUMB	PRESS_REF	VAPOR_41C	VAPOR_46C
n.o.s., PIH, HAZ 1A							
Poisonous liquid, flammable, n.o.s., PIH, HAZ 1B	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Poisonous liquid, n.o.s., PIH, HAZ 1A	6.1	244	9,14,72	44,45			
Poisonous liquid, n.o.s., PIH, HAZ 1B	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
sec-butyl chloroformate	6.1	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94			
Selenium hexafluoride	2.3	NONE		none authorized			
Silicon tetrafluoride	2.3	NONE		none authorized			
Stibine	2.3	NONE		none authorized			
Sulfur chloride (mono)	8	243	10,77	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Sulfur dioxide	2.3	314	14	31,33,34,35,36,40,42,43,44,45	G	76.0	93.0
Sulfur tetrafluoride	2.3	245		none authorized			
Sulfur trioxide, inhibited	8	244	9,12,14,49,74,77	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94			
Sulfuric acid, fuming, or Oleum	8	244	9,14,74,77,84	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	A	< 15	< 15
Sulfuryl chloride	8	244	6,9,10,14,74,77	42,43,44,45,68,69,71,77,79,80, 89,90,93,94			
Sulfuryl fluoride	2.3	314		35,36,44,45	G	357.0	390.0
Tellurium hexafluoride	2.3	NONE		none authorized			
tert-Butyl isocyanate	3	244	9,14,72	44,45			
tert-Octyl mercaptan	6.1	244	9,14,74	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94			
Tetraethyl dithiopyrophosphate	6.1	242	9,75	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	A	< 15	< 15
Tetraethyl dithiopyrophosphate/compressed gas mixture	2.3	NONE		none authorized			
Tetraethyl pyrophosphate/ compressed gas mixture	2.3	NONE		none authorized			

Table A.2 continued

CHEM_NAME	CLASS	BULK_PACK	BULK_SPROV	CARNUMB	PRESS_REF	VAPOR_41C	VAPOR_46C
Tetramethoxy silane	3	244	9,74	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	A	< 15	< 15
Tetranitromethane	5.1	NONE	9,14,74	none authorized			
Thionyl chloride	8	244	6,9,14,74,77	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Thiophosgene	6.1	244	9,14,74	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	A	< 15	< 15
Titanium tetrachloride	8	244	7,9,14,41,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Trichloroacetyl chloride	8	244	9,14,72	44,45	A	< 15	< 15
Trimethoxysilane	6.1	244	9,14,74	41,42,43,44,45,68,69,71,77,79, 80,89,90,93,94	A	< 15	< 15
Trimethylacetyl chloride	8	244	9,14,74	42,43,44,45,68,69,71,77,79,80, 89,90,93,94	A	< 15	< 15
Tungsten hexafluoride	2.3	NONE		none authorized			

(1) Only single unit tank car provisions listed

(2) Refer to Table A.6 for corresponding tank car specifications

(3) Denotes reference units for vapor pressures (A = absolute, G = gage).

(4) For most liquids, a vapor pressure of < 15 psia has been assumed (neglecting gas padding pressure, the pressure in the tank is assumed atmospheric).

Table A.2 continued

TABLE A.3

Remainder of HM-181 PIH Chemical Data Base

This table contains a listing of those fields of the PIH data base not presented in Table A.2. The listing contains the 163 chemical names presented in Table A.2 as well as corresponding UN or NA identification numbers, Required Labels, and PIH code from HM-181 Table 172.101 Column 7. Also provided are the minimum safety valve set pressure/chemical vapor pressure rations for each chemical.

CHEM_NAME	ID_NO	REQ_LABELS	PIH_CODE	REQ_RATIO	1 MIN_RATIO	TOP125_90	TOP125RNK
3,5 Dichloro-2,4,6 trifluoropyridine	UN2810	6.1	2	1.0	16.0	N	
Acrolein, inhibited	UN1092	6.1/3	1	1.0	11.0	N	
Acetone cyanohydrin, stabilized	UN1541	6.1	2	1.0	11.0	N	
Allyl alcohol	UN1098	6.1/3	2	1.0	16.0	N	
Allyl chloroformate	UN1722	8/6.1	1	1.0	26.0	N	
Allyl isothiocyanate, stab.	UN1545	6.1	2	1.0	16.0	N	
Allylamine	UN2334	6.1/3	2	1.0	16.0	N	
Ammonia, anhydrous (D)	UN1005	2.2		1.0	1.06	Y	3
Ammonia, anhydrous, (I)	UN1005	2.3	4	1.0	1.06	Y	3
Arsenic trichloride	UN1560	6.1	2	1.0	16.0	N	
Arsine	UN2188	2.3/2.1	1			N	
Boron tribromide	UN2692	8/6.1	1	1.0	16.0	N	
Boron trichloride	UN1741	2.3/8	1	1.0	10.23	N	
Boron trifluoride	UN1008	2.3	2			N	
Bromine	UN1744	6.1/8	1	1.0	16.0	N	
Bromine chloride	UN2901	2.3	2	1.0		N	
Bromine pentafluoride	UN1745	5.1/6.1/8	1	1.0	26.0	N	
Bromine trifluoride	UN1746	5.1/6.1/8	2	1.0	16.0	N	
Bromoacetone	UN1569	6.1/3	2			N	
Carbon dioxide / Ethylene oxide mixture, > 25% EO	UN1041	2.3/2.1	6			N	
Carbon monoxide & hydrogen mixture	UN2600	2.3/2.1				N	
Carbon monoxide gas	UN1016	2.3/2.1	4			N	
Carbon monoxide, refrigerated liquid	NA9202	2.3/2.1	4			N	
Carbonyl fluoride	UN2417	2.3	2			N	
Carbonyl sulfide	UN2204	2.3/2.1	2	1.0	1.02	N	
Chlorine	UN1017	2.3	2	1.0	1.46	Y	5
Chlorine pentafluoride	UN2548	2.3/5.1/8	1			N	
Chlorine trifluoride	UN1749	2.3/5.1/8	1			N	

Table A.3: Remainder of HM-181 ~'H Chemical Data Base

CHEM_NAME	ID_NO	REQ_LABELS	PIH_CODE	REQ_RATIO	MIN_RATIO	TOP125_90	TOP125RNK
Chloroacetaldehyde	UN2232	6.1	2	1.0	16.0	N	
Chloroacetone, stabilized	UN1695	6.1	2	1.0	16.0	N	
Chloroacetonitrile	UN2668	6.1	2	1.0	16.0	N	
Chloroacetyl chloride	UN1752	8/6.1	2	1.0	16.0	N	
Chloropicrin	UN1580	6.1	2	1.0	16.0	N	
Chloropicrin / methyl bromide mixtures	UN1581	2.3	2	1.0	7.08	N	
Chloropicrin / methyl chloride mixtures	UN1582	2.3	2	1.0	1.98	N	
Chloropicrin mixtures, n.o.s.	UN1583	6.1	5	1.0	16.0	N	
Chloropivaloyl chloride	UN9263	6.1/8	2	1.0	16.0	N	
Chlorosulfonic acid (with or without Sulfur trioxide)	UN1754	8/6.1	2	1.0	18.0	N	
Coal gas	UN1023	2.3	3			N	
Compressed or liquified gases, poisonous, flammable, n.o.s. (1000	UN1953	2.3/2.1	3			N	
Compressed or liquified gases, poisonous, flammable, n.o.s. (200	UN1953	2.3/2.1	2			N	
Compressed or liquified gases, poisonous, flammable, n.o.s. (LC50	UN1953	2.3/2.1	1			N	
Compressed or liquified gases, poisonous, flammable, n.o.s. (3000	UN1953	2.3/2.1	4			N	
Compressed or liquified gases, poisonous, n.o.s. (1000 ppm < LC50	UN1955	2.3	3			N	
Compressed or liquified gases, poisonous, n.o.s. (200 ppm < LC50	UN1955	2.3	2			N	
Compressed or liquified gases,	UN1955	2.3	1			N	

Table A.3 continued

CHEM_NAME	ID_NO	REQ_LABELS	PIH_CODE	REQ_RATIO	MIN_RATIO	TOP125_90	TOP125RNK
poisonous, n.o.s. (200 ppm < LC50)							
Compressed or liquified gases, poisonous, n.o.s. (3000 ppm < LC50	UN1955	2.3	4			N	
Crotonaldehyde, stabilized	UN1143	3/6.1	2	1.0	18.0	N	
Cyanogen bromide	UN1889	6.1/8	1	1.0	26.0	N	
Cyanogen chloride, inhibited	UN1589	2.3/2.1	1			N	
Cyanogen, liquefied	UN1026	2.3/2.1	2			N	
Cyclohexyl isocyanate	UN2488	6.1	2	1.0	18.0	N	
Diborane	UN1911	2.3/2.1	1			N	
Diborane mixture	UN1911	2.3/2.1	1			N	
Dichlorodifluoromethane/Ethylene oxide mixture	UN3070	2.3	4				
Dichlorosilane	UN2189	2.3/2.1	2	1.0	7.50	N	
Diketene, inhibited	UN2521	3/6.1	2	1.0	16.0	N	
Dimethyl sulfate	UN1595	6.1/8	2	1.0	18.0	N	
Dimethylhydrazine, symmetrical	UN2382	3/6.1/8	2	1.0	16.0	N	
Dimethylhydrazine, unsymmetrical	UN1163	6.1/3/8	2	1.0	16.0	N	
Dinitrogen tetroxide	UN1067	2.3/5.1	1	1.0	18.8	N	
Ethyl chloroformate	UN1182	6.1/3/8	2	1.0	16.0	N	
Ethyl chlorothioformate	UN2826	8/6.1	2	1.0	16.0	N	
Ethyl isocyanate	UN2481	3/6.1	1	1.0	26.0	N	
Ethyl phosphonothioic dichloride, anhydrous	NA2922	6.1/8	2	1.0	18.0	N	
Ethyl phosphonous dichloride, anhydrous, pyrophoric liquid	NA2845	6.1/4.2	2	1.0	18.0	N	
Ethyl phosphorodichlroridate	NA2927	6.1/8	2	1.0	18.0	N	
Ethyldichloroarsine	UN1892	6.1	2	1.0	16.0	N	
Ethylene chlorohydrin	UN1135	6.1	2	1.0	16.0	N	
Ethylene dibromide	UN1605	6.1	2	1.0	16.0	N	
Ethylene oxide	UN1040	2.3/2.1	3	1.0	2.68	Y	27

Table A.3 ntinued

CHEM_NAME	ID_NO	REQ_LABELS	PIH_CODE	REQ_RATIO	MIN_RATIO	TOP125_90	TOP125RNK
Ethyleneimine, inhibited	UN1185	6.1/3	1	1.0	26.0	N	
Fluorine, compressed gas	UN1045	2.3/5.1	1			N	
Germane (germanium hydride)	UN2192	2.3/2.1	1			N	
Hexachlorocyclopentadiene	UN2646	6.1/8	2	1.0	16.0	N	
Hexaethyl tetraphosphate & compressed gas mixture	UN1612	2.3	3			N	
Hexafluoroacetone	UN2420	2.3/2.1	2	1.0	1.70	N	
Hydrogen bromide, anhydrous	UN1048	2.3/8	3			N	
Hydrogen chloride, anhydrous	UN1050	2.3/8	3			Y	113
Hydrogen chloride, refrigerated liquid	UN2186	2.3/8	3			N	
Hydrogen cyanide, anhydrous, stabilized	UN1051	6.1/3	1	1.0	35.9	N	
Hydrogen cyanide, anhydrous, stabilized (absorbed)	UN1614	6.1/3	5			N	
Hydrogen selenide, anhydrous	UN2202	2.3/2.1	1			N	
Hydrogen sulfide, liquefied	UN1053	2.3/2.1	2			N	
Insecticide gas, toxic, n.o.s.	UN1967	2.3	3			N	
Iron pentacarbonyl	UN1994	6.1/3	1	1.0	26.0	N	
Isobutyl chloroformate	NA2742	6.1/3	2	1.0	16.0	N	
Isobutyl isocyanate	UN2486	3/6.1	3	1.0	26.0	N	
Isopropyl chloroformate	UN2407	3/8/6.1	2	1.0	16.0	N	
Methoxymethyl isocyanate	UN2605	3/6.1	1	1.0	26.0	N	
Methyl bromide	UN1062	2.3	3	1.0	2.14	N	
Methyl bromide and Ethylene dibromide, liquid	UN1647	6.1	2	1.0	16.0	N	
Methyl chloroformate	UN1238	6.1/3/8	1	1.0	26.0	N	
Methyl chloromethyl ether	UN1239	6.1/3	1	1.0	26.0	N	
Methyl chlorosilane	UN2534	2.3/3	2	1.0	5.92	N	
Methyl dichloroarsine	NA1556	6.1				N	
Methyl hydrazine	UN1244	6.1/3/8	1	1.0	26.0	N	
Methyl iodide	UN2644	6.1	2	1.0	16.0	N	
Methyl isocyanate	UN2480	6.1/3	1	1.0	26.0	N	

Table A.3 continued

CHEM_NAME	ID_NO	REQ_LABELS	PIH_CODE	REQ_RATIO	MIN_RATIO	TOP125_90	TOP125RNK
Methyl isothiocyanate	UN2477	3/6.1	1	1.0	26.0	N	
Methyl mercaptan	UN1064	2.3/2.1	2	1.0	5.77	N	
Methyl orthosilicate	UN2606	3/6.1	2	1.0	16.0	N	
Methyl phosphonic dichloride	NA9206	6.1/8	2	1.0	16.0	N	
Methyl phosphonous dichloride	NA2845	6.1/4.2	2	1.0	16.0	N	
Methylamine, anhydrous	UN1061	2.3/2.1	3	1.0	3.17	N	
n-Butyl chloroformate	UN2743	6.1/8/3	2			N	
n-Butyl isocyanate	UN2485	6.1/3	1			N	
n-Propyl chloroformate	UN2740	6.1/3/8	2			N	
n-Propyl isocyonate	UN2482	3/6.1	1			N	
Nickel carbonyl	UN1259	6.1/3	1			N	
Nitric acid, fuming	UN2032	8/5.1/6.1	2	1.0	16.0	N	
Nitric oxide / Nitrogen tetroxide mixture	UN1975	2.3/5.1	1			N	
Nitric oxide [NO]	UN1660	2.3/5.1	1			N	
Nitrogen trifluoride	UN2451	2.3/5.1	3			N	
Nitrogen trioxide	UN2421	2.3/5.1	1			N	
Nitrosyl chloride	UN1069	2.3/8	3	1.0	3.52	N	
Organic phosphate, Organic phosphate compound, or Organic phospho	UN1955	2.3	3			N	
Oxygen difluoride	UN2190	2.3/5.1	1			N	
Parathion and compressed gas mixture	NA1967	2.3	3			N	
Pentaborane	UN1380	4.2/6.1	1			N	
Perchloromethyl mercaptan	UN1670	6.1	2			N	
Perchloryl fluoride	UN3083	2.3/5.1	3	1.0		N	
Phenyl carbylamine chloride	UN1672	6.1	1	1.0	16.0	N	
Phenyl isocyanate	UN2487	6.1	2	1.0	16.0	N	
Phenyl mercaptan	UN2337	6.1/3	2	1.0	16.0	N	
Phosgene	UN1076	2.3/8	1			N	
Phosphine	UN2199	2.3/2.1	1			N	
Phosphorus oxychloride	UN1810	8/6.1	2	1.0	16.0	N	

Table A.3 continued

CHEM_NAME	ID_NO	REQ_LABELS	PIH_CODE	REQ_RATIO	MIN_RATIO	TOP125_90	TOP125RNK
Phosphorus pentafluoride	UN2198	2.3	1			N	
Phosphorus trichloride	UN1809	8/6.1	2	1.0	16.0	N	
Phosphorus trifluoride	NA9273	2.3	1			N	
Poisonous liquid, corrosive, n.o.s., PIH, HAZ 1A	UN2927	6.1/8	1			N	
Poisonous liquid, corrosive, n.o.s., PIH, HAZ 1B	UN2927	6.1/8	2	1.0	18.0	N	
Poisonous liquid, flammable, n.o.s., PIH, HAZ 1A	UN2929	6.1/8	1			N	
Poisonous liquid, flammable, n.o.s., PIH, HAZ 1B	UN2929	6.1/8	2	1.0	18.0	N	
Poisonous liquid, n.o.s., PIH, HAZ 1A	UN2810	6.1	1			N	
Poisonous liquid, n.o.s., PIH, HAZ 1B	UN2810	6.1	2	1.0	18.0	N	
sec-butyl chloroformate	NA2742	6.1/3/8	2	1.0		N	
Selenium hexafluoride	UN2194	2.3	1			N	
Silicon tetrafluoride	UN1859	2.3	4			N	
Stibine	UN2676	2.3/2.1	1			N	
Sulfur chloride (mono)	UN1828	8/6.1	5	1.0	18.0	N	
Sulfur dioxide	UN1079	2.3	3	1.0	1.97	Y	55
Sulfur tetrafluoride	UN2418	2.3	1			N	
Sulfur trioxide, inhibited	UN1829	8/6.1	1			N	
Sulfuric acid, fuming, or Oleum	UN1831	8/6.1	2	1.0	16.0	Y	2
Sulfuryl chloride	UN1834	3/6.1	1			N	
Sulfuryl fluoride	UN2191	2.3	4	1.0	1.05	N	
Tellurium hexafluoride	UN2195	2.3	1			N	
tert-Butyl isocyanate	UN2484	3/6.1	1			N	
tert-Octyl mercaptan	UN3023	6.1/3	2			N	
Tetraethyl dithiopyrophosphate	UN1704	6.1	2	1.0	16.0	N	
Tetraethyl dithiopyrophosphate/compressed	UN1703	2.3	6			N	

Table A.3 continued

CHEM_NAME	ID_NO	REQ_LABELS	PIH_CODE	REQ_RATIO	MIN_RATIO	TOP125_90	TOP125RNK
gas mixture							
Tetraethyl pyrophosphate/compressed gas mixture	UN1705	2.3	6			N	
Tetramethoxy silane	UN1992	3/6.1	2	1.0	18.0	N	
Tetranitromethane	UN1510	5.1/6.1	1			N	
Thionyl chloride	UN1836	8/6.1	2	1.0	16.0	N	
Thiophosgene	UN2474	6.1	2	1.0	18.0	N	
Titanium tetrachloride	UN1838	8/6.1	2	1.0	18.0	N	
Trichloroacetyl chloride	UN2442	8/6.1	2	1.0	26.0	N	
Trimethoxysilane	NA9269	6.1/3	2	1.0	16.0	N	
Trimethylacetyl chloride	UN2438	8/3/6.1	2	1.0	16.0	N	
Tungsten hexafluoride	UN2196	2.3	3	1.0		N	

(1) Calculated in units of psia for liquids and units of psig for gases

Table A.3 tinued

CHEM_NAME	ID_NO	CLASS	BULK_PACK	CARNUMB	VAPOR_41C	VAPOR_46C	TOP125_90	TOP125RNK
				52,53,54,56,57,58,60,61,62,64, 97,103				
Dimethyl sulfate	UN1595	6.1	255	18,50,53,60,99,103	< 15	< 15	N	
Dimethylhydrazine, symmetrical	UN2382	3	145	13,23,29,31,52,55,60,63	< 15	< 15	N	
Dimethylhydrazine, unsymmetrical	UN1163	6.1	145	23,26,29,31,52,55,60,63	< 15	< 15	N	
Dinitrogen tetraoxide	UN1067	2.3	336		20.0	29.0	N	
Ethyl chloroformate	UN1182	6.1	288	53,55	< 15	< 15	N	
Ethyl chlorothioformate	UN2826	8	245	11,17,18,20,23,24,25,26,27,28, 31,49,52,53,54,56,57,60,61,62, 97,103	< 15	< 15	N	
Ethyl isocyanate	UN2481	3	119	11,14,16,17,18,20,23,24,25,26, 27,28,29,30,31,46,47,48,49,50, 52,53,54,56,58,59,60,61,62,64, 97,103	< 15	< 15	N	
Ethyl phosphonothioic dichloride, anhydrous	NA2922	6.1	245	18,20,23,24,25,26,29,31,52,53, 61,103	< 15	< 15	N	
Ethyl phosphonous dichloride, anhydrous, pyrophoric liquid	NA2845	6.1	134		< 15	< 15	N	
Ethyl phosphorodichlroridate	NA2927	6.1	245	18,20,23,24,25,26,29,31,52,53, 61,62,103	< 15	< 15	N	
Ethyldichloroarsine	UN1892	6.1	139	11,13,18,20,26,27,29,31,49,54, 57,60,61,62,97,99,100,102,103	< 15	< 15	N	
Ethylene chlorohydrin	UN1135	6.1	346	13,18,20,26,27,29,31,49,52,53, 55,60,61,97,99,100,101,102,103	< 15	< 15	N	
Ethylene dibromide	UN1605	6.1	346	13,18,20,26,27,29,31,49,52,53, 55,60,61,97,99,100,101,102,103	< 15	< 15	N	
Ethylene oxide	UN1040	2.3	124	29,31,55	28.0	35.0	Y	27
Ethyleneimine, inhibited	UN1185	6.1	139	27,29,30,31,50,52,53,55,58,60, 61,103	< 15	< 15	N	
Fluorine, compressed gas	UN1045	2.3	N/A				N	
Germane (germanium hydride)	UN2192	2.3	328				N	
Hexachlorocylopentadiene	UN2646	6.1	245	11,17,18,20,23,24,25,26,27,29, 31,49,52,53,54,56,57,60,61,62, 97,103	< 15	< 15	N	

Table A.4 continued

CHEM_NAME	ID_NO	CLASS	BULK_PACK	CARNUMB	VAPOR_41C	VAPOR_46C	TOP125_90	TOP125RNK
Hexaethyl tetraphosphate & compressed gas mixture	UN1612	2.3	N/A				N	
Hexafluoroacetone	UN2420	2.3	314		132.0	160.0	N	
Hydrogen bromide, anhydrous	UN1048	2.3	314				N	
Hydrogen chloride, anhydrous	UN1050	2.3	N/A				Y	113
Hydrogen chloride, refrigerated liquid	UN2186	2.3	314				N	
Hydrogen cyanide, anhydrous, stabilized	UN1051	6.1	332		10.44	15.1	N	
Hydrogen cyanide, anhydrous, stabilized (absorbed)	UN1614	6.1	N/A				N	
Hydrogen selenide, anhydrous	UN2202	2.3	328				N	
Hydrogen sulfide, liquefied	UN1053	2.3	314				N	
Insecticide gas, toxic, n.o.s.	UN1967	2.3	329				N	
Iron pentacarbonyl	UN1994	6.1	346	13,18,20,26,27,29,31,49,52,53, 55,60,61,97,99,100,101,102,103	< 15	< 15	N	
Isobutyl chloroformate	NA2742	6.1	288	53,55	< 15	< 15	N	
Isobutyl isocyanate	UN2486	3	119	11,14,16,17,18,20,23,24,25,26, 27,28,29,30,31,46,47,48,49,50, 52,53,54,56,57,58,60,61,62,64, 97,103	< 15	< 15	N	
Isopropyl chloroformate	UN2407	6.1	288	53,55,64	< 15	< 15	N	
Methoxymethyl isocyanate	UN2605	3	119	11,14,16,17,18,20,23,24,25,26, 27,28,29,30,31,46,47,48,49,50, 52,53,54,56,57,58,60,61,62,64, 97,103	< 15	< 15	N	
Methyl bromide	UN1062	2.3	353	29,55,101	35.0	44.0	N	
Methyl bromide and Ethylene dibromide, liquid	UN1647	6.1	353	29,55,101	< 15	< 15	N	
Methyl chloroformate	UN1238	6.1	288	53,55	< 15	< 15	N	
Methyl chloromethyl ether	UN1239	6.1	143		< 15	< 15	N	
Methyl chlorosilane	UN2534	2.3	314		38.0	41.0	N	
Methyl dichloroarsine	NA1556	6.1	328				N	
Methyl hydrazine	UN1244	6.1	145	23,26,29,31,52,55,60,63	< 15	< 15	N	
Methyl iodide	UN2644	6.1	346	13,18,20,26,29,31,49,52,53,55,	< 15	< 15	N	

Table A.4 continued

CHEM_NAME	ID_NO	CLASS	BULK_PACK	CARNUMB	VAPOR_41C	VAPOR_46C	TOP125_90	TOP125RNK
oxide mixture, > 25% EO								
Carbon monoxide & hydrogen mixture	UN2600	2.3	N/A				N	
Carbon monoxide gas	UN1016	2.3	N/A				N	
Carbon monoxide, refrigerated liquid	NA9202	2.3	N/A				N	
Carbonyl fluoride	UN2417	2.3	N/A				N	
Carbonyl sulfide	UN2204	2.3	328		249.0	286.0	N	
Chlorine	UN1017	2.3	314		154.2	176.0	Y	5
Chlorine pentafluoride	UN2548	2.3	246				N	
Chlorine trifluoride	UN1749	2.3	246				N	
Chloroacetaldehyde	UN2232	6.1	346	13,18,20,26,27,29,31,49,52,53, 55,60,61,97,99,100,101,102,103	< 15	< 15	N	
Chloroacetone, stabilized	UN1695	6.1	346	13,18,20,26,27,29,31,49,52,53, 55,60,61,97,99,100,101,102,103	< 15	< 15	N	
Chloroacetonitrile	UN2668	6.1	346	13,18,20,26,27,29,31,49,52,53, 55,60,61,97,99,100,101,102,103	< 15	< 15	N	
Chloroacetyl chloride	UN1752	8	253	17,18,53,61,103	< 15	< 15	N	
Chloropicrin	UN1580	6.1	357		< 15	< 15	N	
Chloropicrin / methyl bromide mixtures	UN1581	2.3	329		36.0	42.0	N	
Chloropicrin / methyl chloride mixtures	UN1582	2.3	329		110.0	129.0	N	
Chloropicrin mixtures, n.o.s.	UN1583	6.1	357		< 15	< 15	N	
Chloropivaloyl chloride	NA9263	6.1	346	13,18,20,26,27,29,31,49,52,53, 55,60,61,97,99,100,102,103	< 15	< 15	N	
Chlorosulfonic acid (with or without Sulfur trioxide)	UN1754	8	254	18,23,25,53,61,99,103	< 15	< 15	N	
Coal gas	UN1023	2.3	314				N	
Compressed or liquified gas, poisonous, flammable, n.o.s. (1000 ppm < LC50 < 3000 ppm)	UN1953	2.3	328				N	
Compressed or liquified gas, poisonous, flammable, n.o.s. (200 ppm < LC50 < 1000 ppm)	UN1953	2.3	328				N	

Table A.4 continued

CHEM_NAME	ID_NO	CLASS	BULK_PACK	CARNUMB	VAPOR_41C	VAPOR_46C	TOP125_90	TOP125RNK
Compressed or liquified gas, poisonous, flammable, n.o.s. (200 ppm < LC50)	UN1953	2.3	328				N	
Compressed or liquified gas, poisonous, flammable, n.o.s. (3000 ppm < LC50 < 5000 ppm)	UN1953	2.3	328				N	
Compressed or liquified gas, poisonous, n.o.s. (1000 ppm < LC50 < 3000 ppm)	UN1955	2.3	328				N	
Compressed or liquified gas, poisonous, n.o.s. (200 ppm < LC50 < 1000 ppm)	UN1955	2.3	328				N	
Compressed or liquified gas, poisonous, n.o.s. (200 ppm < LC50)	UN1955	2.3	328				N	
Compressed or liquified gas, poisonous, n.o.s. (3000 ppm < LC50 < 5000 ppm)	UN1955	2.3	328				N	
Crotonaldehyde, stabilized	UN1143	3	119	11,14,16,17,18,20,23,24,25,26,27,28,29,30,31,46,47,48,49,50,53,54,56,57,58,60,61,62,64,97,103	< 15	< 15	N	
Cyanogen bromide	UN1889	6.1	379		< 15	< 15	N	
Cyanogen chloride, inhibited	UN1589	2.3	328				N	
Cyanogen, liquefied	UN1026	2.3	328				N	
Cyclohexyl isocyanate	UN2488	6.1	346	13,18,20,26,27,29,30,31,48,49,50,52,53,55,58,60,61,97,99,100,102,103	< 15	< 15	N	
Diborane	UN1911	2.3	N/A				N	
Diborane mixture	UN1911	2.3	N/A				N	
Dichlorodifluoromethane/Ethylene oxide mixture	UN3070	2.3	314				N	
Dichlorosilane	UN2189	2.3	314		30.0	35.0	N	
Diketene, inhibited	UN2521	3	119	11,14,16,17,18,20,23,24,25,26,27,28,29,30,31,46,47,48,49,50,	< 15	< 15	N	

TABLE A.4

49 CFR PIH Chemical Data Base

This table contains a listing of PIH chemical names and corresponding UN or NA identification numbers, hazard class, and bulk packaging sections as compiled from 49 CFR prior to the introduction of HM-181. Also provided are chemical vapor pressures at 41 °C and 46 °C.

CHEM_NAME	ID_NO	CLASS[1]	BULK_PACK[1]	CARNUMB[1]	VAPOR_41C	VAPOR_46C	TOP125_90	TOP125RNK
3,5 Dichloro-2,4,6 trifluoropyridine	UN2810	6.1	346	13,18,20,26,27,29,31,49,52,53, 55,60,61,97,99,100,101,102,103	< 15	< 15	N	
Acrolein, inhibited	UN1092	6.1	122		< 15	< 15	N	
Actone cyanohydrin, stabilized	UN1541	6.1	346	13,18,20,26,29,31,49,52,53,60, 61,99,100,102,103	< 15	< 15	N	
Allyl alcohol	UN1098	6.1	119	11,14,16,17,18,20,23,24,25,26, 27,28,29,30,31,46,47,48,49,50, 52,53,54,56,57,58,60,61,62,64, 97,103	< 15	< 15	N	
Allyl chloroformate	UN1722	8	288	53,55	< 15	< 15	N	
Allyl isothiocyanate, stab.	UN1545	6.1	346	13,14,18,20,26,27,29,30,31,48, 49,50,52,53,55,58,60,61,97,99, 100,101,102,103	< 15	< 15	N	
Allylamine	UN2334	6.1	119	11,14,16,17,18,20,23,24,25,26, 27,28,29,30,31,46,47,48,49,50, 52,53,54,56,57,58,60,61,62,64, 97,103	< 15	< 15	N	
Ammonia, anhydrous (D)	UN1005	2.2	314	33,34,35,36,42,43,44,45,68,69, 71,72,74,75,77,79,80,89,90,91, 92,93,94	213.0	237.0	Y	3
Ammonia, anhydrous, (I)	UN1005	2.3	314	33,34,35,36,42,43,44,45,68,69, 71,72,74,75,77,79,80,89,90,91, 92,93,94	213.0	237.0	Y	3
Arsenic trichloride	UN1560	6.1	346	13,18,20,26,27,29,31,49,52,53, 55,60,61,97,99,100,101,102,103	< 15	< 15	N	
Arsine	UN2188	2.3	N/A				N	
Boron tribromide	UN2692	8	251		< 15	< 15	N	
Boron trichloride	UN1741	2.3	251		22.0	29.0	N	
Boron trifluoride	UN1008	2.3	302				N	
Bromine	UN1744	6.1	252		< 15	< 15	N	
Bromine chloride	UN2901	2.3	328		< 20	< 20	N	
Bromine pentafluoride	UN1745	5.1	246		< 15	< 15	N	
Bromine trifluoride	UN1746	5.1	246		< 15	< 15	N	
Bromoacetone	UN1569	6.1	329				N	
Carbon dioxide / Ethylene oxide mixture, > 25% EO	UN1041	2.3	314	32,33,34,77,79,93,94			N	

Table A.4: 49 CFR (pre-1990) PIH Chemical Data Base

CHEM_NAME	ID_NO	CLASS	BULK_PACK	CARNUMB	VAPOR_41C	VAPOR_46C	TOP125_90	TOP125RNK
				60,61,97,99,100,101,102,103				
Methyl isocyanate	UN2480	6.1	119	11,14,16,17,18,20,23,24,25,26,27,28,29,30,31,46,47,48,49,50,52,53,54,56,57,58,60,61,62,64,97,103	< 15	< 15	N	
Methyl isothiocyanate	UN2477	3	119	11,14,16,17,18,20,23,24,25,26,27,28,29,30,31,46,47,48,49,50,52,53,54,56,57,58,60,61,62,64,97,103	< 15	< 15	N	
Methyl mercaptan	UN1064	2.3	314		39.0	47.0	N	
Methyl orthosilicate	UN2606	3	119	11,14,16,17,18,23,24,25,26,27,28,29,30,31,46,47,48,49,50,52,53,54,56,57,58,60,61,62,64,97,101,103	< 15	< 15	N	
Methyl phosphonic dichloride	NA9206	6.1	271	17,18,23,25,53,61,99,103	< 15	< 15	N	
Methyl phosphonous dichloride	NA2845	6.1	134		< 15	< 15	N	
Methylamine, anhydrous	UN1061	2.3	314		71.0	87.0	N	
n-Butyl chloroformate	UN2743	6.1	288	53,55	< 15	< 15	N	
n-Butyl isocyanate	UN2485	6.1	119	11,14,16,17,18,20,23,24,25,26,27,28,29,30,31,46,47,48,49,50,52,53,54,56,57,58,60,61,62,64,97,103	< 15	< 15	N	
n-Propyl chloroformate	UN2740	6.1	N/A				N	
n-Propyl isocyonate	UN2482	3	119	11,14,16,17,18,20,23,24,25,26,27,29,30,31,46,47,48,49,50,52,53,54,56,57,58,60,61,62,97,99,100,103	< 15	< 15	N	
Nickel carbonyl	UN1259	6.1	126				N	
Nitric acid, fuming	UN2032	8	268	14,23,51,59,63	< 15	< 15	N	
Nitric oxide / Nitrogen tetroxide mixture	UN1975	2.3	336				N	
Nitric oxide [NO]	UN1660	2.3	337				N	
Nitrogen trifluoride	UN2451	2.3	302				N	
Nitrogen trioxide	UN2421	2.3	336				N	
Nitrosyl chloride	UN1069	2.3	314		64.0	77.0	N	

Table A.4 continued

CHEM_NAME	ID_NO	CLASS	BULK_PACK	CARNUMB	VAPOR_41C	VAPOR_46C	TOP125_90	TOP125RNK
Organic phosphate, Organic phosphate compound or Organic phosphate mixture, liquid	UN1955	6.1	358				N	
Organic phosphate, Organic phosphate compound, or Organic phosphate / compressed gas mixture	NA1955	2.3	334				N	
Oxygen difluoride	UN2190	2.3	N/A				N	
Parathion and compressed gas mixture	NA1967	2.3	334				N	
Pentaborane	UN1380	4.2	138				N	
Perchloromethyl mercaptan	UN1670	6.1	360		226.0	252.0	N	
Perchloryl fluoride	UN3083	2.3	314		< 15	< 15	N	
Phenyl carbylamine chloride	UN1672	6.1	346	13,18,20,26,27,29,31,49,52,53, 55,60,61,97,99,100,101,102,103	< 15	< 15	N	
Phenyl isocyanate	UN2487	6.1	346	13,18,20,26,27,29,31,49,52,53, 55,60,61,97,99,100,101,102,103	< 15	< 15	N	
Phenyl mercaptan	UN2337	6.1	346	13,14,18,20,26,27,29,30,31,48, 49,50,52,53,55,58,60,61,97,99, 100,101,102,103			N	
Phosgene	UN1076	2.3	333				N	
Phosphine	UN2199	2.3	328		< 15	< 15	N	
Phosphorus oxychloride	UN1810	8	271	17,18,23,25,61,99,103			N	
Phosphorus pentafluoride	UN2198	2.3	N/A		< 15	< 15	N	
Phosphorus trichloride	UN1809	8	271	17,18,23,25,61,99,103			N	
Phosphorus trifluoride	NA9273	2.3	314				N	
Poisonous liquid, corrosive, n.o.s., PIH, HAZ 1A	UN2927	6.1	328	32,33,34,35,36,77,79,80,93,94	< 15	< 15	N	
Poisonous liquid, corrosive, n.o.s., PIH, HAZ 1B	UN2927	6.1	346	13,14,18,20,26,27,29,30,31,48, 49,50,52,53,55,58,60,61,97,99, 100,101,102,103			N	
Poisonous liquid, flammable, n.o.s., PIH, HAZ 1A	UN2929	6.1	328	32,33,34,35,36,77,79,80,93,94	< 15	< 15	N	
Poisonous liquid, flammable, n.o.s., PIH, HAZ 1B	UN2929	6.1	346	13,14,18,20,26,27,29,30,31,48, 49,50,52,53,55,58,60,61,97,99,			N	

Table A.4 continued

CHEM_NAME	ID_NO	CLASS	BULK_PACK	CARNUMB	VAPOR_41C	VAPOR_46C	TOP125_90	TOP125RNK
				100,101,102,103				
Poisonous liquid, n.o.s., PIH, HAZ 1A	UN2810	6.1	328	32,33,34,35,36,77,79,80,93,94	< 15	< 15	N	
Poisonous liquid, n.o.s., PIH, HAZ 1B	UN2810	6.1	346	13,14,18,20,26,27,29,30,31,48, 49,50,52,53,55,58,60,61,97,99, 100,101,102,103	< 15	< 15	N	
sec-butyl chloroformate	NA2742	6.1	288	53,55			N	
Selenium hexafluoride	UN2194	2.3	328				N	
Silicon tetrafluoride	UN1859	2.3	302				N	
Stibine	UN2676	2.3	328		< 15	< 15	N	
Sulfur dioxide	UN1079	2.3	314	31	76.0	93.0	Y	55
Sulfur tetrafluoride	UN2418	2.3	328				N	
Sulfur trioxide, inhibited	UN1829	8	273	18,29,31,53,61,99,103			N	
Sulfuric acid, fuming, or Oleum	UN1831	8	272	18,19,20,23,53,56,57,61,62,97, 99,103	< 15	< 15	Y	2
Sulfuryl chloride	UN1834	3	277	18,53,61,99,103			N	
Sulfuryl fluoride	UN2191	2.3	314		357.0	390.0	N	
Tellurium hexafluoride	UN2195	2.3	328				N	
tert-Butyl isocyanate	UN2484	3	119	11,14,16,17,18,20,23,24,25,26, 27,28,29,30,46,47,48,49,50,52, 53,54,56,57,58,60,61,62,64,97, 103	< 15	< 15	N	
tert-Octyl mercaptan	UN3023	6.1	346	13,14,18,20,26,27,29,30,31,48, 49,50,52,53,55,58,60,61,97,99, 100,101,102,103	< 15	< 15	N	
Tetraethyl dithiopyrophosphate	UN1704	6.1	358	30	< 15	< 15	N	
Tetraethyl dithiopyrophosphate/compressed gas mixture	UN1703	2.3	334	30			N	
Tetraethyl pyrophosphate/compressed gas mixture	UN1705	2.3	334	30			N	
Tetramethoxy silane	UN1992	3	119	11,14,16,17,18,20,23,24,25,26, 27,28,29,30,31,46,47,48,49,50, 52,53,54,56,57,58,60,61,62,64,	< 15	< 15	N	

Table A.4 continued

CHEM_NAME	ID_NO	CLASS	BULK_PACK	CARNUMB	VAPOR_41C	VAPOR_46C	TOP125_90	TOP125RNK
				97,103				
Tetranitromethane	UN1510	5.1	203				N	
Thionyl chloride	UN1836	8	247	18,61,99,103	< 15	< 15	N	
Thiophosgene	UN2474	6.1	356		< 15	< 15	N	
Titanium tetrachloride	UN1838	8	247		< 15	< 15	N	
Trichloroacetyl chloride	UN2442	8	245	17,18,20,23,24,25,26,27,29,31,49,52,53,54,55,56,57,60,61,97,103	< 15	< 15	N	
Trimethoxysilane	NA9269	6.1	119	11,14,16,17,18,20,23,24,25,26,27,29,30,31,46,47,48,49,50,52,53,54,56,57,58,60,61,62,64,97,103	< 15	< 15	N	
Trimethylacetyl chloride	UN2438	8	245	11,17,18,20,23,24,25,26,27,29,31,49,52,53,54,56,57,60,61,62,97,103	< 15	< 15	N	
Tungsten hexafluoride	UN2196	2.3	284				N	

(1) The information in this field has been compiled from 49 CFR (pre 1990) & therefore differs from information in the same columns in Table A.2 & A.3

Table A ontinued

TABLE A.5

Flammable Gases and Liquids Data Base

This table contains a listing of flammable gas and liquid materials from HM-181 appearing on the 1990 AAR Top 125 Commodities List. Listed are the chemical names, UN or NA identification numbers, hazard class, bulk packaging section, and packing group number. Also provided are chemical vapor pressures at 41 °C and 46 °C as well as the minimum tank car safety valve set-to-discharge pressure / chemical vapor pressure ratio for each material.

CHEM_NAME	ID_NO	CLASS	BULK_PACK	PACK_GROUP	BULK_SPROV	CAR_NOTE[1]	VAPOR_41C	VAPOR_46C	MIN_VALVE[2]	REQ_RATIO	RATIO_41C	RATIO_46C	TOP125RNK
Class 3 Flammable Liquids													
Acyetalhyde	UN1089	3	243	I	B16	3	15.7	21.5	35	1.0	2.2	1.6	48
Acetone	UN1090	3	242	II		2			35	1.0			49
Acrylonitrile, Inhibited	UN1093	3	243	I	B9	3			35	1.0			45
Alcoholic Beverages	UN3065	3	242	III	B1	2			35	1.0			83
Benzene	UN1114	3	242	II		2			35	1.0			29
Butyl Acetate	UN1123	3	242	II		2			35	1.0			110
Butyl Alcohol (n-Butanol)	UN1120	3	242	II		2			35	1.0			78
Butyraldehyde	UN1129	3	242	II		2			35	1.0			101
Carbon Bisulfide	UN1131	3	243	I	B16	3			35	1.0			98
Chloroprene	UN1134	3	243	I	B59	3			35	1.0			111
Crude Oil, Petroleum	UN1267	3	243	I		3			35	1.0			19
Cyclohexane	UN1145	3	242	II		2			35	1.0			36
Denatured Alcohol	UN1986	3	243			3			35	1.0			20
Ehthylene Dichloride	UN1184	3	243	II		3			35	1.0			54
Ethyl Acetate	UN1173	3	242	II		2			35	1.0			84
Ethyl Acrylate, Inhibited	UN1917	3	242	II		2			35	1.0			82
Ethyl Alcohol	UN1170	3	242	II		2			35	1.0			90
Fuel, Aviation, Turbine	UN1863	3	243	I		3			35	1.0			46
Gasoline	UN1203	3	242	II		2			35	1.0			22
Hexane	UN1208	3	242	II		2			35	1.0			87
Isopropanol	UN1219	3	242	II		2			35	1.0			58
Methyl Alcohol	UN1230	3	243	II		3			35	1.0			11
Methyl Ethyl Ketone	UN1193	3	242	II		2			35	1.0			80
Methyl Methacrylate Mono.	UN1247	3	242	II		2			35	1.0			38
Petroleum Naphtha	UN1255	3	243	I		3			35	1.0			35
Propylene Oxide	UN1280	3	243	I		3	3.60	7.37	35	1.0	9.7	4.7	37
Styrene Monomer, Inhibited	UN2055	3	242	III		2			35	1.0			4
Toluene	UN1294	3	242	II		2			35	1.0			43
Vinyl Acetate, Inhibited	UN1301	3	242	II		2			35	1.0			34
Vinylidene Chloride, Inhibited	UN1303	3	243	I		3	5.3	9.21	35	1.0	6.6	3.8	120
Xylene	UN1307	3	242	II		2			35	1.0			40

Table A.5: Flammable Gases and Liquids Data Base

CHEM_NAME	ID_NO	CLASS	BULK_PACK	PACK_GROUP	BULK_SPROV	CAR_NOTE[1]	VAPOR_41C	VAPOR_46C	MIN_VALVE[2]	REQ_RATIO	RATIO_41C	RATIO_46C	TOP125RNK
Class 2.1 Flammable Gases													
Butane (LPG)	UN1011	2.1	314			4	41.3	50.4	75	1.0	1.8	1.5	12
Butene (LPG)	UN1012	2.1	314			4	52.9	62.3	75	1.0	1.4	1.2	53
Isobutane (LPG)	UN1969	2.1	314			4	55.0	76.0	75	1.0	1.4	2.0 (3)	42
Propane (LPG)	UN1075	2.1	314			4	187.	214.4	225	1.0	1.2	1.0	10
Propylene (LPG)	UN1077	2.1	314			4	235.0	260.0	255	1.0	1.1	1.2 (4)	37
Vinyl Chloride	UN1086	2.1	314		B44	4	66.3	78.8	75	1.0	1.1	1.9 (3)	9
Methyl Chloride	UN1063	2.1	314			4	111.0	131.0	150	1.0	1.4	1.1	88
Ethyl Chloride	UN1037	2.1	314		B63	4	23.7	30.5	75	1.0	3.2	2.5	109
Isobutylene	UN1055	2.1	314			4	55.0	65.0	75	1.0	1.4	1.2	59
Dimethylamine, anhydrous	UN1032	2.1	314			4	35.6	44.9	75	1.0	2.1	1.7	114

(1) Refer to Table 3.5 for listing of authorized cars

(2) From Table 3.5 column "Minimum Valve Pressure"

(3) Ratio based on 200 psig tank/150 psig safety valve

(4) Ratio based on 400 psig tank/300 psig safety valve

Table A.5 continued

TABLE A.6

Tank Car Data Base

This table contains a listing of DOT and AAR Tank Cars and corresponding safety valve set-to-discharge pressures for those cars listed in the retest tables of 49 CFR Part 179. Also provided for each tank car are the number of PIH chemicals that car is authorized to carry. For each tank car listed, an identification number has been assigned which corresponds to the "CARNUMB" fields of the post 1990 49 CFR PIH data base listed in Table A.2 and the pre 1990 49 CFR PIH data base listed in Table A.4.

CARNUMB	CARSPEC	VALVE_PSIG	NUM_PIH	NOTE
10	AAR-203W	75	0	
11	AAR-206W	75	0	
12	AAR-211W	35	0	
13	DOT-103	35	0	
14	DOT-103A-ALW	35	0	
15	DOT-103AL	35	0	
16	DOT-103ALW	35	0	
17	DOT-103ANW	35	0	
18	DOT-103AW	35	0	
19	DOT-103B	60	0	
20	DOT-103BW	60	0	
21	DOT-103C	35	0	
22	DOT-103CAL	35	0	
23	DOT-103CW	35	0	
24	DOT-103DW	35	0	
25	DOT-103EW	35	0	
26	DOT-103W	35	0	
27	DOT-104W	35	0	
28	DOT-105A100ALW	75	0	
29	DOT-105A100W	75	2	
30	DOT-105A200ALW	150	0	
31	DOT-105A200W	150	3	
32	DOT-105A300ALW	225	0	
33	DOT-105A300W	225	11	
34	DOT-105A400W	300	11	
35	DOT-105A500W	375	15	
36	DOT-105A600W	450	16	
37	DOT-105J100ALW	75	0	
38	DOT-105J100W	75	2	
39	DOT-105J200ALW	150	0	
40	DOT-105J200W	150	3	
41	DOT-105J300ALW	225	3	
42	DOT-105J300W	225	90	
43	DOT-105J400W	300	91	
44	DOT-105J500W	375	116	
45	DOT-105J600W	450	117	
46	DOT-109A100ALW	75	0	
47	DOT-109A200ALW	150	0	
48	DOT-109A300ALW	225	0	
49	DOT-109A300W	225	0	
50	DOT-111A100ALW1	75	0	
51	DOT-111A100ALW2	75	0	
52	DOT-111A100W1	75	0	
53	DOT-111A100W2	75	0	
54	DOT-111A100W3	75	0	
55	DOT-111A100W4	75	0	
56	DOT-111A100W5	100	0	
57	DOT-111A100W6	75	0	

Table A.6: Tank Car Data Base

CARNUMB	CARSPEC	VALVE_PSIG	NUM_PIH	NOTE
58	DOT-111A60ALW1	35	0	
59	DOT-111A60ALW2	35	0	
60	DOT-111A60W1	35	0	
61	DOT-111A60W2	35	0	
62	DOT-111A60W5	60	0	
63	DOT-111A60W7	35	0	
64	DOT-112A200W	150	0	
65	DOT-112A340W	255	0	
66	DOT-112A400W	300	0	
67	DOT-112A500W	375	0	
68	DOT-112J340W	255	82	
69	DOT-112J400W	300	83	
70	DOT-112J400F	300	0	
71	DOT-112J500W	375	83	
72	DOT-112S340W	255	2	
73	DOT-112S400F	300	1	
74	DOT-112S400W	300	2	
75	DOT-112S500W	375	2	
76	DOT-112T200W	150	0	
77	DOT-112T340W	255	83	
78	DOT-112T400F	300	0	
79	DOT-112T400W	300	83	
80	DOT-112T500W	375	83	
81	DOT-113A175W	115	0	
82	DOT-113A60W	30	0	
83	DOT-113C120W	75	0	
84	DOT-113C60W	45	0	
85	DOT-113D120W	75	0	
86	DOT-113D60W	45	0	
87	DOT-114A340W	255	0	
88	DOT-114A400W	300	0	
89	DOT-114J340W	255	83	
90	DOT-114J400W	300	83	
91	DOT-114S340W	255	2	
92	DOT-114S400W	300	2	
93	DOT-114T340W	255	83	
94	DOT-114T400W	300	83	
95	DOT-115A60ALW	35	0	
96	DOT-115A60W1	35	0	
97	DOT-115A60W6	35	0	
98	DOT-105A200F	150	0	
99	DOT-103A	35	0	
100	DOT-104A	35	0	
101	DOT-105A100	75	0	
102	DOT-111A60F1	35	0	
103	DOT-111A100F2	75	0	
104	DOT-111A100W4	75	2	

Table A.6: continued

TABLE A.7

Safety Valve/PIH Chemical Vapor Pressure Ratios

This table contains a listing of PIH chemicals for which vapor pressures were available and tank cars authorized per HM-181. For the materials listed, the table list each authorized tank car and corresponding safety valve pressure, the reference temperature at which the vapor pressure was calculated, the resulting vapor pressure, and the calculated valve pressure/.vapor pressure ratio.

CHEM_NAME	ID_NO	CAR_SPEC	REF_TEMP_C[1]	VALVE_PSIG	VAPOR_PSIG	PRATIO[2]
Ammonia, anhydrous (D)[3]	UN1005	DOT-112T500W	46	375	237.0	1.58
		DOT-105J600W	41	450	213.0	2.11
		DOT-105J500W	41	375	213.0	1.76
		DOT-112T400W	46	300	237.0	1.27
		DOT-105J400W	41	300	213.0	1.41
		DOT-114J340W	46	255	237.0	1.08
		DOT-105A300W	41	225	213.0	1.06
		DOT-105A400W	41	300	213.0	1.41
		DOT-112S500W	46	375	237.0	1.58
		DOT-105J300W	41	225	213.0	1.06
		DOT-112J340W	46	255	237.0	1.08
		DOT-112S340W	46	255	237.0	1.08
		DOT-112T340W	46	255	237.0	1.08
		DOT-105A600W	41	450	213.0	2.11
		DOT-105A500W	41	375	213.0	1.76
		DOT-112S400W	46	300	237.0	1.27
		DOT-112J400W	46	300	237.0	1.27
		DOT-112J500W	46	375	237.0	1.58
		DOT-114T340W	46	255	237.0	1.08
		DOT-114S400W	46	300	237.0	1.27
		DOT-114S340W	46	255	237.0	1.08
		DOT-114J400W	46	300	237.0	1.27
		DOT-114T400W	46	300	237.0	1.27
Ammonia, anhydrous (I)[3]	UN1005	DOT-105A300W	41	225	213.0	1.06
		DOT-112J500W	46	375	237.0	1.58
		DOT-112S340W	46	255	237.0	1.08
		DOT-105A400W	41	300	213.0	1.41
		DOT-114J340W	46	255	237.0	1.08
		DOT-112J340W	46	255	237.0	1.08
		DOT-112S500W	46	375	237.0	1.58
		DOT-105A500W	41	375	213.0	1.76
		DOT-112T340W	46	255	237.0	1.08
		DOT-105J500W	41	375	213.0	1.76
		DOT-112T400W	46	300	237.0	1.27
		DOT-105J400W	41	300	213.0	1.41
		DOT-105J600W	41	450	213.0	2.11
		DOT-112J400W	46	300	237.0	1.27
		DOT-105J300W	41	225	213.0	1.06
		DOT-112S400W	46	300	237.0	1.27
		DOT-112T500W	46	375	237.0	1.58
		DOT-105A600W	41	450	213.0	2.11
		DOT-114T400W	46	300	237.0	1.27
		DOT-114J400W	46	300	237.0	1.27
		DOT-114S400W	46	300	237.0	1.27
		DOT-114S340W	46	255	237.0	1.08
		DOT-114T340W	46	255	237.0	1.08

Table A.7: Safety Valve/PIH Chemical Vapor Pressure Ratios

CHEM_NAME	ID_NO	CAR_SPEC	REF_TEMP_C	VALVE_PSIG	VAPOR_PSIG	PRATIO
Boron trichloride	UN1741	DOT-105A300W	41	225	22.0	10.23
		DOT-105A400W	41	300	22.0	13.64
		DOT-105A600W	41	450	22.0	20.45
		DOT-105J300W	41	225	22.0	10.23
		DOT-105J400W	41	300	22.0	13.64
		DOT-105A500W	41	375	22.0	17.05
		DOT-105J500W	41	375	22.0	17.05
		DOT-105J600W	41	450	22.0	20.45
Carbonyl sulfide	UN2204	DOT-105J600W	41	450	249.0	1.81
		DOT-112T500W	41	375	249.0	1.51
		DOT-105J500W	41	375	249.0	1.51
		DOT-105J400W	41	300	249.0	1.20
		DOT-114J340W	41	255	249.0	1.02
		DOT-112J340W	41	255	249.0	1.02
		DOT-112J400W	41	300	249.0	1.20
		DOT-112T340W	41	255	249.0	1.02
		DOT-112J500W	41	375	249.0	1.51
		DOT-112T400W	41	300	249.0	1.20
		DOT-114T400W	41	300	249.0	1.20
		DOT-114J400W	41	300	249.0	1.20
		DOT-114T340W	41	255	249.0	1.02
Chlorine	UN1017	DOT-105J600W	41	450	154.2	2.92
		DOT-105A500W	41	375	154.2	2.43
		DOT-105J500W	41	375	154.2	2.43
		DOT-105A600W	41	450	154.2	2.92
Chloropicrin / methyl bromide mixtures	UN1581	DOT-105J300W	41	225	36.0	6.25
		DOT-112J340W	41	255	36.0	7.08
		DOT-112T500W	41	375	36.0	10.42
		DOT-112T400W	41	300	36.0	8.33
		DOT-105J600W	41	450	36.0	12.50
		DOT-105J500W	41	375	36.0	10.42
		DOT-105J400W	41	300	36.0	8.33
		DOT-112T340W	41	255	36.0	7.08
		DOT-112J400W	41	300	36.0	8.33
		DOT-112J500W	41	375	36.0	10.42
		DOT-114J340W	41	255	36.0	7.08
		DOT-114T400W	41	300	36.0	8.33
		DOT-114T340W	41	255	36.0	7.08
		DOT-114J400W	41	300	36.0	8.33
		DOT-112T400W	41	300	110.0	2.73
		DOT-112J400W	41	300	110.0	2.73
		DOT-105J300W	41	225	110.0	2.05
		DOT-112T500W	41	375	110.0	3.41

Table A.7 continued

CHEM_NAME	ID_NO	CAR_SPEC	REF_TEMP_C	VALVE_PSIG	VAPOR_PSIG	PRATIO
		DOT-112J340W	41	255	110.0	2.32
		DOT-114J340W	41	255	110.0	2.32
		DOT-105J500W	41	375	110.0	3.41
		DOT-105J400W	41	300	110.0	2.73
		DOT-105J600W	41	450	110.0	4.09
		DOT-112T340W	41	255	110.0	2.32
		DOT-112J500W	41	375	110.0	3.41
		DOT-114T340W	41	255	110.0	2.32
		DOT-114T400W	41	300	110.0	2.73
		DOT-114J400W	41	300	110.0	2.73
Dichlorosilane	UN2189	DOT-105J400W	41	300	30.0	10.00
		DOT-112J500W	41	375	30.0	12.50
		DOT-105J600W	41	450	30.0	15.00
		DOT-112T400W	41	300	30.0	10.00
		DOT-112T500W	41	375	30.0	12.50
		DOT-105J300W	41	225	30.0	7.50
		DOT-112J340W	41	255	30.0	8.50
		DOT-112T340W	41	255	30.0	8.50
		DOT-105J500W	41	375	30.0	12.50
		DOT-112J400W	41	300	30.0	10.00
		DOT-114J400W	41	300	30.0	10.00
		DOT-114J340W	41	255	30.0	8.50
		DOT-114T340W	41	255	30.0	8.50
		DOT-114T400W	41	300	30.0	10.00
Dinitrogen tetroxide	UN1067	DOT-105J500W	41	375	20.0	18.75
		DOT-105J600W	41	450	20.0	22.50
		DOT-105A500W	41	375	20.0	18.75
		DOT-105A600W	41	450	20.0	22.50
Ethylene oxide	UN1040	DOT-105J300W	41	225	28.0	8.04
		DOT-105J200W	41	150	28.0	5.36
		DOT-105A500W	41	375	28.0	13.39
		DOT-105A400W	41	300	28.0	10.71
		DOT-105A600W	41	450	28.0	16.07
		DOT-105A100W	41	75	28.0	2.68
		DOT-105J500W	41	375	28.0	13.39
		DOT-105A300W	41	225	28.0	8.04
		DOT-105J100W	41	75	28.0	2.68
		DOT-105J400W	41	300	28.0	10.71
		DOT-105J600W	41	450	28.0	16.07
		DOT-111A100W4	41	75	28.0	2.68
		DOT-111J100W4	41	75	28.0	2.68
Hexafluoroacetone	UN2420	DOT-112J500W	41	375	132.0	2.84
		DOT-105A300ALW	41	225	132.0	1.70
		DOT-105J600W	41	450	132.0	3.41

Table A.7 continued

CHEM_NAME	ID_NO	CAR_SPEC	REF_TEMP_C	VALVE_PSIG	VAPOR_PSIG	PRATIO
		DOT-105J400W	41	300	132.0	2.27
		DOT-105J300W	41	225	132.0	1.70
		DOT-105J500W	41	375	132.0	2.84
		DOT-112T400W	41	300	132.0	2.27
		DOT-112T340W	41	255	132.0	1.93
		DOT-112J400W	41	300	132.0	2.27
		DOT-112T500W	41	375	132.0	2.84
		DOT-112J340W	41	255	132.0	1.93
		DOT-114T340W	41	255	132.0	1.93
		DOT-114T400W	41	300	132.0	2.27
		DOT-114J340W	41	255	132.0	1.93
		DOT-114J400W	41	300	132.0	2.27
Hydrogen cyanide, anhydrous, stabilized	UN1051	DOT-105A600W	41	225	10.44	21.60
		DOT-105A500W	41	225	10.44	21.60
		DOT-105J500W	41	225	10.44	21.60
		DOT-105J600W	41	225	10.44	21.60
Methyl bromide	UN1062	DOT-105J300W	41	225	35.0	6.43
		DOT-105J100W	41	75	35.0	2.14
		DOT-105J400W	41	300	35.0	8.57
		DOT-105J500W	41	375	35.0	10.71
		DOT-105J600W	41	450	35.0	12.86
		DOT-105J200W	41	150	35.0	4.29
		DOT-105A100W	41	75	35.0	2.14
		DOT-105A200W	41	150	35.0	4.29
		DOT-105A600W	41	450	35.0	12.86
		DOT-105A300W	41	225	35.0	6.43
		DOT-105A500W	41	375	35.0	10.71
		DOT-105A400W	41	300	35.0	8.57
		DOT-111A100W4	41	75	35.0	2.14
Methyl chlorosilane	UN2534	DOT-112T400W	41	300	38.0	7.89
		DOT-105J300W	41	225	38.0	5.92
		DOT-112J400W	41	300	38.0	7.89
		DOT-112J500W	41	375	38.0	9.87
		DOT-105J500W	41	375	38.0	9.87
		DOT-105J400W	41	300	38.0	7.89
		DOT-112T500W	41	375	38.0	9.87
		DOT-112J340W	41	255	38.0	6.71
		DOT-105J600W	41	450	38.0	11.84
		DOT-112T340W	41	255	38.0	6.71
		DOT-114J400W	41	300	38.0	7.89
		DOT-114T400W	41	300	38.0	7.89
		DOT-114T340W	41	255	38.0	6.71
		DOT-114J340W	41	255	38.0	6.71

Table A.7 continued

CHEM_NAME	ID_NO	CAR_SPEC	REF_TEMP_C	VALVE_PSIG	VAPOR_PSIG	PRATIO
Methyl mercaptan	UN1064	DOT-105A400W	41	300	39.0	7.69
		DOT-105J300W	41	225	39.0	5.77
		DOT-105A500W	41	375	39.0	9.62
		DOT-105A600W	41	450	39.0	11.54
		DOT-105J600W	41	450	39.0	11.54
		DOT-105A300W	41	225	39.0	5.77
		DOT-105J500W	41	375	39.0	9.62
		DOT-105J400W	41	300	39.0	7.69
Methylamine, anhydrous	UN1061	DOT-105J500W	41	375	71.0	5.28
		DOT-105A300W	41	225	71.0	3.17
		DOT-105A500W	41	375	71.0	5.28
		DOT-112J500W	41	375	71.0	5.28
		DOT-112J400W	41	300	71.0	4.23
		DOT-112J340W	41	255	71.0	3.59
		DOT-112T340W	41	255	71.0	3.59
		DOT-105A400W	41	300	71.0	4.23
		DOT-105J400W	41	300	71.0	4.23
		DOT-105J600W	41	450	71.0	6.34
		DOT-112T500W	41	375	71.0	5.28
		DOT-105J300W	41	225	71.0	3.17
		DOT-112T400W	41	300	71.0	4.23
		DOT-105A600W	41	450	71.0	6.34
		DOT-114J340W	41	255	71.0	3.59
		DOT-114T400W	41	300	71.0	4.23
		DOT-114J400W	41	300	71.0	4.23
		DOT-114T340W	41	255	71.0	3.59
Nitrosyl chloride	UN1069	DOT-105A400W	41	300	64.0	4.69
		DOT-105J500W	41	375	64.0	5.86
		DOT-105A300W	41	225	64.0	3.52
		DOT-105J600W	41	450	64.0	7.03
		DOT-105A600W	41	450	64.0	7.03
		DOT-105J400W	41	300	64.0	4.69
		DOT-105A500W	41	375	64.0	5.86
		DOT-105J300W	41	225	64.0	3.52
Perchloryl fluoride	UN3083	DOT-105J400W	41	300	226.0	1.33
		DOT-112J500W	41	375	226.0	1.66
		DOT-105J500W	41	375	226.0	1.66
		DOT-105J600W	41	450	226.0	1.99
		DOT-112T340W	41	255	226.0	1.13
		DOT-112J400W	41	300	226.0	1.33
		DOT-112T400W	41	300	226.0	1.33
		DOT-105J300W	41	225	226.0	1.00
		DOT-112T500W	41	375	226.0	1.66
		DOT-114J340W	41	255	226.0	1.13
		DOT-114J400W	41	300	226.0	1.33

Table A.7 continued

CHEM_NAME	ID_NO	CAR_SPEC	REF_TEMP_C	VALVE_PSIG	VAPOR_PSIG	PRATIO
		DOT-114T340W	41	255	226.0	1.13
		DOT-114T400W	41	300	226.0	1.33
Sulfur dioxide	UN1079	DOT-105J400W	41	300	76.0	3.95
		DOT-105J500W	41	375	76.0	4.93
		DOT-105A500W	41	375	76.0	4.93
		DOT-105A200W	41	150	76.0	1.97
		DOT-105J300W	41	225	76.0	2.96
		DOT-105A400W	41	300	76.0	3.95
		DOT-105A600W	41	450	76.0	5.92
		DOT-105J200W	41	150	76.0	1.97
		DOT-105A300W	41	225	76.0	2.96
		DOT-105J600W	41	450	76.0	5.92
Sulfuryl fluoride	UN2191	DOT-105A600W	41	450	357.0	1.26
		DOT-105J500W	41	375	357.0	1.05
		DOT-105J600W	41	450	357.0	1.26
		DOT-105A500W	41	375	357.0	1.05
		DOT-114T400W	41	300	110.0	2.73

(1) Reference temperature of 41°C valid provided tank car is insulated.

(3) HM-181 does not require insulated tank cars for this commodity.

(2) All ratios in this column calculated in units of psig.

Table A.7 continued

APPENDIX B

Methodology For Defining Exposure Limits for Toxic Vapors

A key parameter in the determination of toxic hazard areas resulting from the release of a hazardous material is the toxic limit concentration to which the public is potentially exposed. These values have been determined by various institutions for several hazardous materials currently used in industry.

In this appendix, we discuss the different toxicity indices used by Regulatory Agencies and industry, evaluate the applicability of these for use in risk assessment procedures and describe the use of one of the standards in risk analysis when the duration of exposure is different from that used in defining the toxic concentration for human beings. A specific example is also utilized.

B.1 TOXIC EXPOSURE LIMIT STANDARDS

A number of toxic concentration standards are used by the industry and Regulatory Agencies. These include but not limited to;

- ACGIH Threshold Limit Values (TLVs)
- OSHA Permissible Exposure Limits (PELs)
- AIHA Workplace Environment Exposure Limits (WEELs)
- NIOSH Immediately Dangerous to Life of Health (IDLHs)
- AIHA Emergency Response Planning Guidelines (ERPGs)
- LC_{50} values.

TLV values, developed by the American Conference of Governmental Industrial Hygienists (ACGIH), are intended to set limits for male workers in chronic exposure situations. Three TLV limits were developed for different work environment exposures. These include and are defined as:

- Threshold Limit Value - Time Weighted Average (TLV-TWA). The time weighted average concentration to which nearly all workers, on a daily basis, may be exposed, repeatedly, without adverse effects. This limit is based on an 8 hour work day/40 hour work week.

- Threshold Limit Value - Short Term Exposure Limit (TLV-STEL). The time weighted average concentration to which workers should not be exposed for more than 15 minutes, at no less than 60 minute intervals, and not more than 4 times a day. These values should only be used where toxic effects have been reported from high short term exposures in humans or animals.

- Threshold Limit Value - Ceiling (TLV-C). The concentration that should not be exceeded during any part of the working exposure.

The PEL standard, developed by the Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor, was originally adopted from the ACGIH TLV-TWAs and TLV-Cs. These values were latter modified and reaffirmed by OSHA for a number of widely used chemicals. New PELs for 164 previously non-regulated materials were also developed.

WEEL values developed by the American Industrial Hygiene Association (AIHA) were determined for toxic materials for which no exposure guidelines exist. Two WEEL limits exist: the TWA value, similar to the TLV-TWA values defined by ACGIH, and the short-term TWA exposure limit, rated for an exposure duration of either 1 minute or 15 minutes.

National Institute for Occupational Safety and Health (NIOSH) IDLH values define the chemical airborne concentration from which a healthy individual could escape within 30 minutes without irreversible health effects or symptoms which would impair ones ability to take protective action.

The ERPG standard, developed by the AIHA Emergency Response Planning Guidelines Committee, defines the maximum airborne chemical concentration below which it is believed nearly all individuals could be exposed for up to one hour without experiencing irreversible health effects of symptoms which could impair a persons ability to take protective action. Three ERPG limits are in use. These are:

- ERPG-1: The maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to 1 hour without experiencing other than mild transient adverse effects or perceiving an objectionable odor.
- ERPG-2: The maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible health effects of symptoms which would impair ones ability to take protective action.
- ERPG-3: The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing life threatening health effects.

LC_{50} values for acute toxicity are defined as the airborne concentration of vapor, mist, or dust which, administered by continuous inhalation for one hour to both male and female young albino rats, causes death within 14 days of half the animals exposed.

Table B-1 summarizes the standards discussed above.

B.2 ADVANTAGES/DISADVANTAGES OF VARIOUS LIMITS

Most of the toxic limits discussed above are "chronic" exposure standards in that they are intended to define exposure limits for the occupational environment where presumably healthy workers are exposed each day of the work week throughout their careers. This holds especially true for TLV, PEL, or WEEL limits and often means that the specified values are much lower than limits which would protect the public from short-term exposures resulting from infrequent chemical releases from in-plant or transportation accidents. In a consequence analysis the use of these lower limits, set for the occupational environment, would result in an over-prediction of the downwind hazard zone area.

The AIHA ERPG-2 values are possibly the best choice among the different standards for defining the short-term exposure limit for a specific chemical and for use in defining potential hazard areas to be considered for emergency response and evacuation planning. However, since these values are not available for most hazardous materials (ERPG-2 limits have been defined for only 11 of the 167 materials studied by the AIHA), and to be consistent throughout an analysis, the use of this standard in a consequence analysis involving a large number of different materials is unreasonable.

TABLE B-1

Definitions of Various Toxic Concentration Standards

NO.	TOXIC STANDARD		EXPOSURE TIME	DESCRIPTION OF EFFECTS OR RESTRICTIONS	DEVELOPING AGENCY
	ABBREVIATION	NAME			
1	TLV - TWA	Threshold Limit Value - Time Weighted Average	8 hr/day for a 40 hr week	Chronic exposure does not result in any adverse health effects.	ACGIH
2	TVL - STEL	Threshold Limit Value - Short Term Exposure Limit	15 minutes	Same as above. Not more than 4 exposures/day at least 60 minutes apart.	ACGIH
3	TLV - C	Threshold Limit Value - Ceiling	N/A	Concentration never to be exceeded at any time.	ACGIH
4	PEL	Permissible Exposure Limit	8 hr/day for a 40 hr week	Chronic exposure does not result in any adverse health effects.	OSHA
5	WEEL - TWA	Workplace Environment Exposure Limit - time Weighted Average Long Term Limit	8 hr/day for a 40 hr week	Chronic exposure does not result in any adverse health effects.	AIHA
6	WEEL - STL	Workplace Environment Exposure Limit - time Weighted Average Short Term Limit	15 minutes	N/A	AIHA
7	IDLH	Immediately Dangerous to Life and Health	30 minutes	No impairing symptoms or irreversible health effects.	NIOSH
8	ERPG - 1	Emergency Response Planning Guideline One	1 hr	Mild transient adverse effects or detectable objectionable odor.	AIHA

NO.	TOXIC STANDARD		EXPOSURE TIME	DESCRIPTION OF EFFECTS OR RESTRICTIONS	DEVELOPING AGENCY
	ABBREVIATION	NAME			
9	ERPG - 2	Emergency Response Planning Guideline Two	1 hr	No irreversible or other health effects or symptoms impairing protective action.	AIHA
10	ERPG - 3	Emergency Response Planning Guideline Three	1 hr	No experience of development of life threatening health effects.	AIHA
11	LC 50	Acute Inhalation Toxicity	1 hr	That concentration when administered by continuous inhalation for 1 hour to young albino rats causes death to 1/2 the animals tested within 14 days.	Independent Laboratory Studies

Definitions:

ACGIH	American Conference of Governmental Industrial Hygienist
OSHA	Occupational Safety and Health Administration
AIHA	American Industrial Hygiene Association
NIOSH	National Institute for Occupational Safety and Health

NIOSH IDLH values are considerably higher than either the TLV, PEL, WEEL, or ERPG-2 values and are defined for an exposure duration of 30 minutes, a time that is considered to be more representative of the duration of exposure one would experience during many short-term spill emergencies. IDLH values are also considered to be more realistic in terms of a borderline value between that which is barely tolerable and that which may cause significant injury. However, since the values were determined assuming healthy workers being exposed, the values must be applied to the general public with a degree of caution and adjusted if the exposure time is substantially less than or greater than the 30 minute duration for the defined values.

LC_{50} values, determined solely from laboratory test conducted on animals, tend to be somewhat higher in most cases than IDLH values. In a consequence analysis, these higher values (LC_{50}) may underestimate the hazard area generated by release of a toxic substance. Also, the availability of LC_{50} values for a wide range of hazardous materials is limited. Values have been determined, however, for most materials defined by the U.S. DOT as being highly toxic, or poisonous by inhalation (PIH). LC_{50} values are experimental result performed in laboratories and are usually not the results of any one institution's efforts.

B.3 APPLICATION OF TOXIC EXPOSURE LIMITS TO CONSEQUENCE ANALYSIS AND ADJUSTMENT FOR EXPOSURE TIMES DIFFERENT FROM THE STANDARD

For the consequence analysis performed in this project, NIOSH IDLH values were used due to availability of values and because the time duration over which they are rated is representative of the duration a person may be exposed in an actual spill emergency (IDLH values are rated at 30 minute exposure times vs. 60 minutes for most other standards). Also, it was considered that IDLH values are more realistic, from a technical viewpoint, when considering the hazard area that would result from use of these values as compared to that which would result from use of other values (other values, especially EPRG values, are considerably less and would over estimate the predicted area).

Because the IDLH values are determined for a 30 minute duration, values were adjusted for exposure times substantially less or greater than 30 minutes. Specifically, if the exposure time was <u>15 minutes or less</u>, 2 times the IDLH value was used. If the exposure time was <u>60 minutes or greater</u>, one half of the IDLH value was used. For exposure times between 15 and 60 minutes, the concentration limit was determined based on:

$$C_o * t_o = \text{constant} = \text{dosage} \qquad [B-1]$$

where: C_o = IDLH concentration

t_o = time duration for IDLH standard = 30 minutes.

As an example, if, for a specific chemical, the IDLH value is 100 ppm for a 30 minute exposure, then for exposure durations of 15 minutes and less the allowable limit would be 200 ppm. Likewise, for exposure durations of 60 minutes or greater, the allowable limit would be 50 ppm. Since:

$$C_o * t_o = (100 \text{ ppm})(30 \text{ min.}) = 3000 \text{ ppm}\bullet\text{min.}$$

the allowable toxic limit for the chemical in question, given an exposure duration within the range of 15 to 60 minutes, would be:

$$C = 3000 \text{ ppm}\bullet\text{min.}/t \qquad [B-2]$$

where the value 3000 is the constant $C_o * t_o$ from equation B-1 and:

t = Duration of exposure, in minutes ($15 < t < 60$).

C = Allowable toxic limit, in ppm, for the exposure duration t.

The concentrations for exposure times less than 15 minutes become very large. It is uncertain whether human physiological response can tolerate very high concentration values, even for very short time durations, and not suffer a permanent damage. In order to take into account these uncertainties we propose a toxic limit equation of the following kind:

$$\text{Toxic Limit} = \begin{cases} 2*IDLH & t<15 \text{ minutes} \\ (30/t)*IDLH & 15 \text{ minutes}<t<60 \text{ minutes} \\ IDLH/2 & t>60 \text{ minutes} \end{cases} \qquad [B-3]$$

Figure B-1, schematically illustrates the possible human response curve for toxic chemical inhalation exposure. The curve shown in solid line is the assumed response per equation B-3. The dotted line represents a hyperbola for a specific dosage value.

FIGURE B-1

Toxic Limit vs. Exposure Time