NUS 4099

ANALYSIS OF HAZARDS FOR RAIL AND HIGHWAY TRANSPORTATION ROUTES NEAR THE SAN ONOFRE NUCLEAR GENERATING STATION UNIT 1

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1.0 INTRODUCTION

The San Onofre Nuclear Generating Station is located near Interstate 5, a major eight lane highway, and the Atchison, Topeka and Santa Fe railway's main coastal north-south route. The potential hazard to Unit 1 from explosions due to accidents involving hazardous materials on both I-5 and the AT&SF railroad is evaluated in this report.

The following sections of this report summarize the work, describe the detailed analytic models, describe the accident rates and give the results of the analysis.

2.0 SUMMARY

The analysis of overpressure and flammable cloud intake hazards from hazardous material activities on I-5 and the AT&SF railway has considered historic and projected shipment frequencies, historical accident rates and severity factors appropriate for the conditions near the plant and consequence models and parameters selected to provide an adequate and overall conservative description of the events.

Results of the analyses are summarized in Table 2-1. As can be seen, the total probability of exceeding 0.5 psi overpressure from an explosion is approximately 5×10^{-6} per year with accidents involving most commodities well below 10^{-7} per year. Only LPG and solid explosives are significant contributors to the total probability. The total probability of a flammable vapor cloud existing at a Unit 1 intake is 1×10^{-7} per year.

The results of the analysis are believed to be a conservative estimate of the true probability of exceeding 10 CFR 100 guidelines. Specific items of conservatism are as follows:

- The criteria selected are conservative. Exceeding the specified overpressure or having a flammable vapor cloud at an air intake will not necessarily cause any radioactivity release, much less one sufficient to exceed 10 CFR 100 guidelines. For example one floor reinforced precast concrete and reinforced masonry houses designed to comply with California earthquake codes were essentially undamaged (except for windows and doors) when subjected to peak overpressures of 1.7 psi (corresponding to about 3.4 psi peak reflected overpressure) in Nevada Nuclear Tests[45]. The probability estimated for San Onofre Unit 1 is that of exceeding 0.5 psi peak reflected overpressure.

TABLE 2-1
RESULT SUMMARY
SONGS UNIT NO. 1

	Probability of Exceeding 0.5 psi -10^{-6} per year	Probability of Flammable Vapor Cloud Being at the Plant -10^{-6} per year
LPG - Highway	2.09	.063
LPG - Rail	0.45	.020
LNG	----	.010
Liquid Hydrogen	0.04	.001
Compressed Hydrogen - 1	0.04	.007
Compressed Hydrogen - 2	0.01	.001
Acetylene	0.007	.001
Explosives - Highway	1.92	----
Explosives - Rail	0.02	----
TOTAL	4.58	0.10

- Most significant LPG truck accidents have involved the tank truck impacting massive obstructions or structures such as rock outcroppings, bridge abutments or drainage ditch structures. None of these types of hazards exist along I-5 near the plant.

- The Department of Transportation has mandated the retrofit of all flammable gas (LPG) tank cars with shelf-type couplers and head shields which reduce the likelihood of tank car punctures. Estimates of the degree of protection range from a 50% to a 90% reduction in punctures.[46] The lower value of 50% was used.

- An instantaneous puff release of the spilled quantity is assumed. In a significant number of accidents the spill occurs over an extended time period, thereby reducing the hazard.

- The dispersion model conservatively accounts for gravity spreading of the heavier than air vapors without dispersion, followed by atmospheric dispersion using class G stability and a low wind speed.

- The plant area for which a flammable vapor cloud is unacceptable was conservatively described as a circle with an area that is approximately twice the actual area of safety related buildings. Most of the vapor clouds of concern will tend to be of very limited vertical extent.

- The entire quantity in the puff is utilized in overpressure analysis. Analysis of a drifting puff release[7] has shown that the maximum quantity between flammable limits is on the order of 60-70% for materials of interest here and that for much of the travel distance, it is less than this amount.

3.0 ANALYTIC MODELS

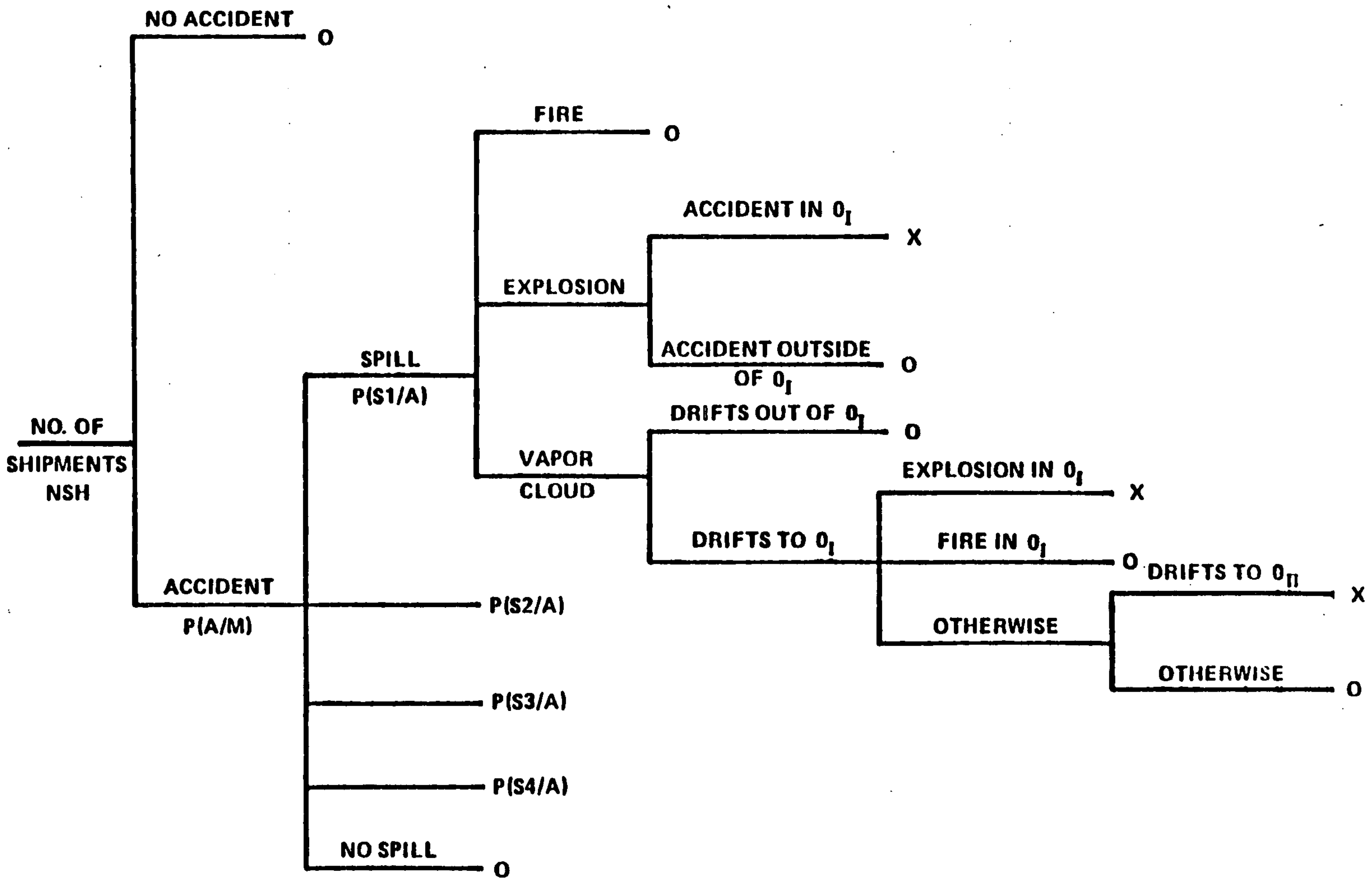
3.1 General

Prior work has indicated that the principal contributor to hazard probability is shipments of Liquified Petroleum Gas (LPG). Other contributors are compressed flammable gases, cyrogenic liquids, other flammable liquids, and solid explosives.

Event trees showing those events (excluding the munitions) which contribute to either the overpressure or air intake flammable cloud hazards are shown in Figures 3-1 and 3-2. In these event trees Region I (Circle I or O_I) designates that area surrounding the plant in which an explosion would lead to an overpressure in excess of the specified value. Region II (Circle II or O_{II}) designates that area of the plant which incorporates all safety-related air intakes. These areas are shown schematically in Figure 3-3.

In general, a spill of flammable material can lead to either a fire, an explosion, or a flammable vapor cloud which disperses without a fire or explosion. The fire or explosion may occur at the accident site or away from the site. The explosion will affect the plant only if it occurs within Region I. The flammable cloud will be swept into an air intake only if an unignited cloud gets to Region II before the concentration drops below the lower flammable limit. As indicated, the consequences are a function of spill size and spill location.

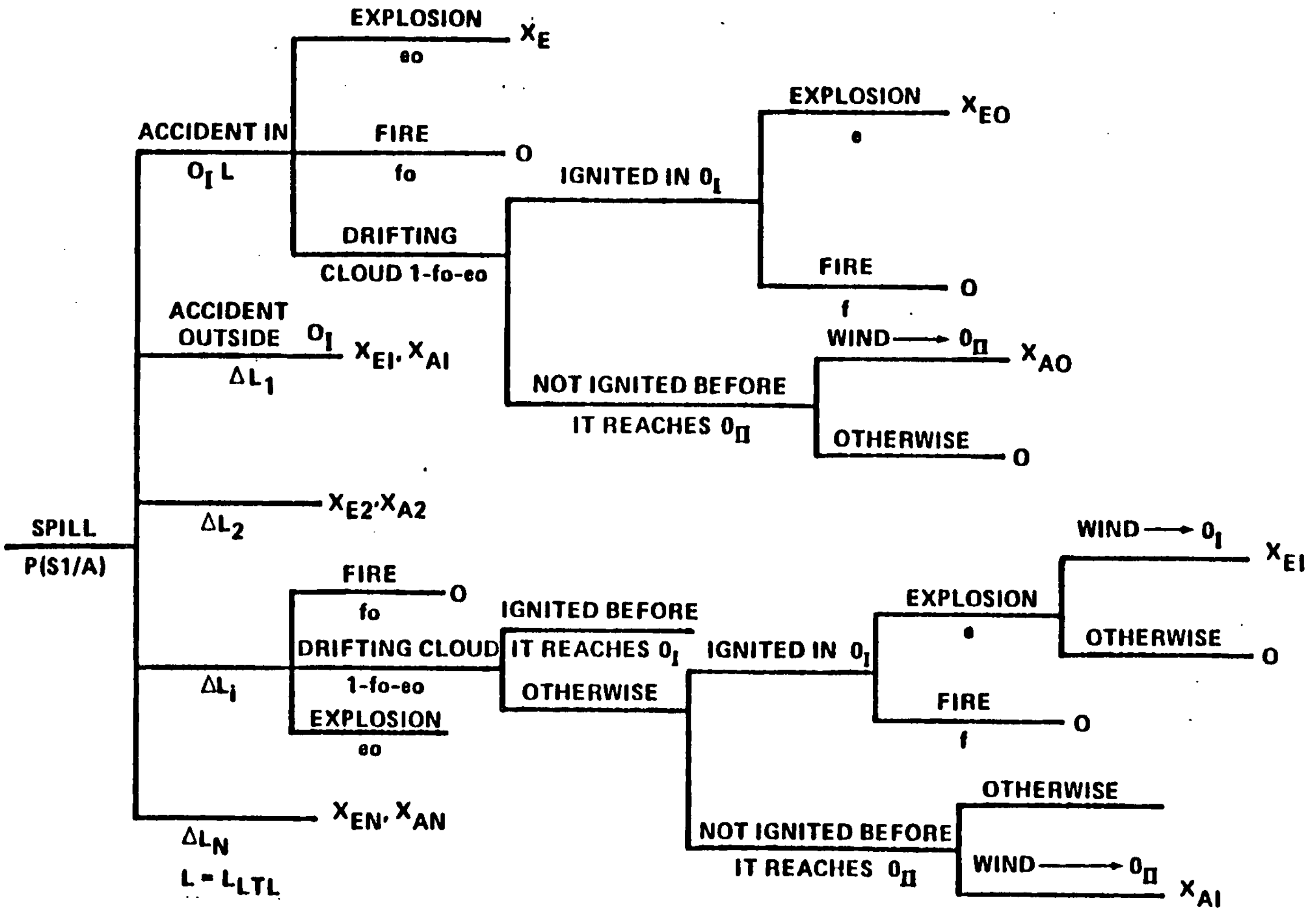
The above applies only to materials which vaporize to form drifting clouds. For solid explosives or munitions, only those portions of the event trees for accident site explosions are applicable.



X : POTENTIAL HAZARD

O : NO HAZARD

Figure 3-1. Simplified Event Tree For Transportation Hazards



L_{LFL} = DISTANCE TO THE LOWER FLAMMABLE LIMIT DETERMINED BY THE DISPERSION MODEL
X_E = OVERPRESSURE HAZARD
X_A = AIR INTAKE HAZARD
O = NO HAZARD

Figure 3-2. Event Tree For A Spill

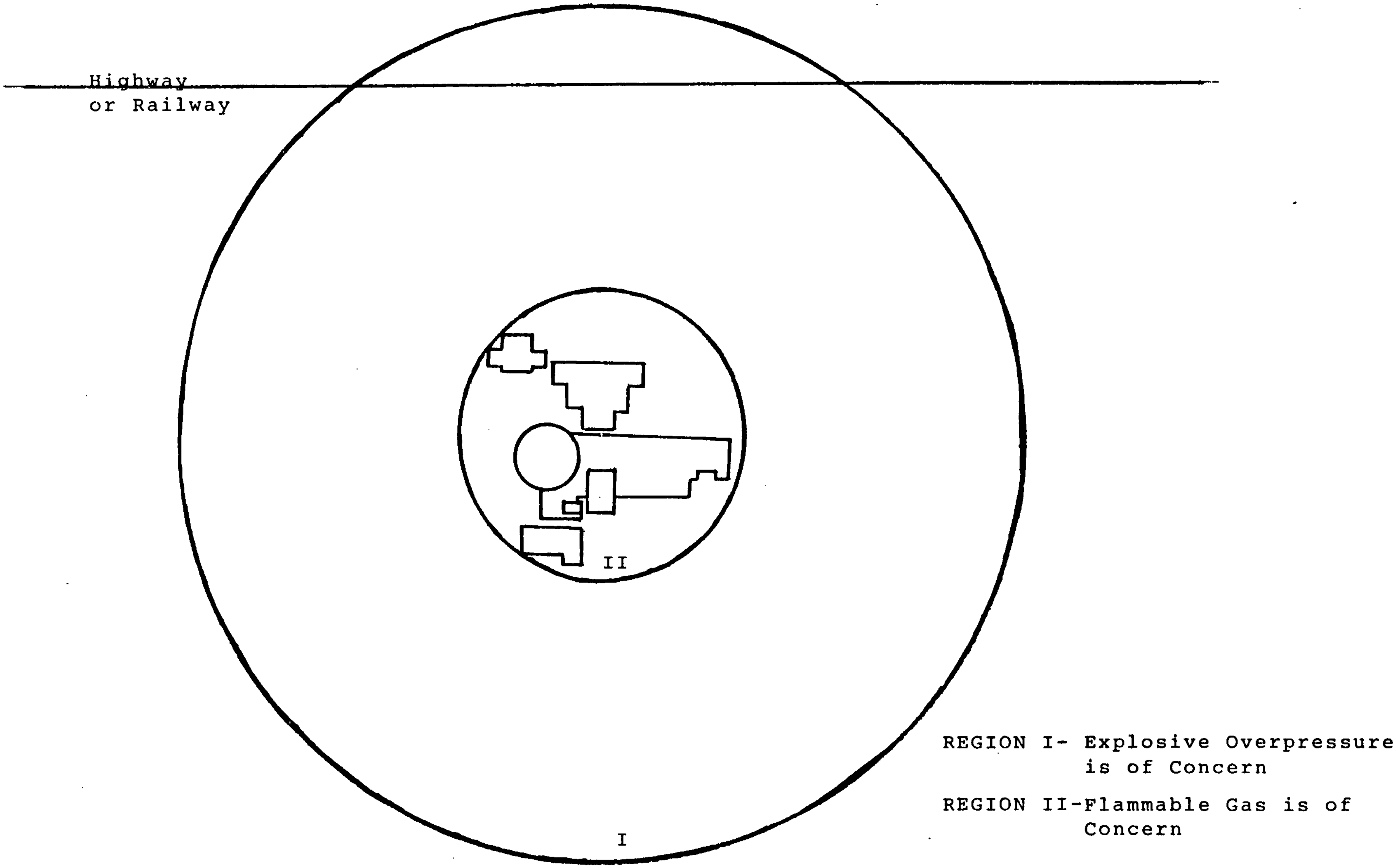


FIGURE 3-3

REGION DEFINITIONS

3.2 Explosive Overpressure due to Unconfined Vapor Cloud Explosions

The probability of exposing the plant to an overpressure greater than a certain value is the sum of the contributions from accident site explosions plus drifting cloud explosions. The former is:

$$P'_E = NSH \cdot P(A/M) \cdot \sum_{i=1}^{N} \left[P(Si/A) \cdot P(E/S) \cdot Li \right] \qquad (3\text{-}1)$$

where:

NSH	=	number of shipments of the commodity being evaluated
P(A/M)	=	conditional probability of an accident per shipment mile
P(Si/A)	=	conditional probability of the spill size given an accident
P(E/S)	=	conditional probability of an explosion with a significant overpressure given a spill
Li	=	length of route along which an explosion would yield an overpressure in excess of a specified value

The summation allows an historical spill size distribution to be utilized.

The size of Region I and the length of highway or railway covered by the region is obtained from consideration of geometry and an explosion overpressure range relationship.

The distance R from an exploding charge to a specified pressure is calculated by the equation[1].

$$R = K(W)^{1/3} \text{ ft} \qquad (3\text{-}2)$$

K = constant determined by the allowable pressure

= 131 ft/lb$^{1/3}$ - for a peak reflected overpressure of 0.5 psi from a ground level detonation. For a different criterion, the constant K can be obtained from Figure 4-12 of the Reference 1.

W = pounds of TNT

For vapor cloud explosions, it is common practice[2, 3, 4, 5] to utilize a TNT equivalent calculated as follows:

$$W_i = \left[F \frac{Si\ Q_\rho}{A} \Delta H_c E\right] \Big/ \ 500 \text{ Kcal/lb - TNT} \qquad (3\text{-}3)$$

F = Fraction of spill quantity involved in vapor cloud

$\frac{Si\ Q_\rho}{A}$ = gm-mole of combustible chemicals spilled

Si = spill fraction

Q = maximum quantity of shipment in volume

ρ = density of liquid

A = molecular weight

ΔH_c = Heat of combustion $(\frac{Kcal}{gm\ mole})$,

E = Yield of explosion

For liquified gases shipped at atmospheric temperature under their own vapor pressure, the fraction of spill quantity in the vapor cloud is the isenthalpic flash fraction. For compressed gases it is 1.0. These values are consistent with the conservatively assumed instantaneous puff release model. For cyrogenic liquids shipped at essentially atmospheric pressure, a 10% flash fraction was used to account for initial vaporization on mixing with warm air and boiling from the spilled liquid pool.

The entire quantity in the cloud was assumed to be involved in the fuel air reaction. The change in the quantity of vapor between upper and lower flammable limits as the cloud disperses was conservatively neglected. Analysis of a drifting puff release[7] has shown that the maximum quantity between flammable limits is on the order of 60-70% for materials of interest here and that for much of the travel distance, it is less than this amount.

To obtain the equivalent TNT yield, the range of explosion yields reported in the literature were surveyed and Table 3-1 compiled, relying mainly on References 5, 6, and 53.

The incidents in Table 3-1 were chosen using the following criteria:

- o Only releases of 5,000 kg or greater are considered as typical of road or rail accidents
- o The fuels involved should belong to the "normal" class as defined by Lewis 54
- o In the event of conflict between the three references, Eichler and Napadensky are favored since their analysis appears to be the most thorough

In Table 3-2, the yields of Table 3-1 are roughly combined so as to approximate a value for probability distribution. The given values of the yield are applied to the total quantity of material released from the rail or road tanker, rather than the flash fraction. This is consistent with the way that the yield has been defined in References 5, 6, and 53.

Equations 3-2 and 3-3 give the maximum distance from any structure at which the explosion involving a particular commodity could yield the specified overpressure. The length of highway or rail-line within this distance of a plant safety-related structure can be obtained from the geometrical plant layout shown in Figure 3-4. This length (and the size of Region I) is spill size and commodity dependent.

TABLE 3-1

INCIDENTS USED TO COMPILE PROBABILITY DISTRIBUTIONS

Quantity Released (Te)	Material Released	Source of Release	Place	Date	Estimated Yield % E	Reference
5.5	Propylene	Process Plant	Beek, Holland	Nov. 1975	4.0	Gugan
6.9	Hydrogen	Dirigible	Hull,UK	Aug. 1921	0.25	Gugan
7.6	Pentane	Process Plant	Texas	1974	2.0	Gugan
9.1	Isobutylene	Process Plant	Lake Chester, La.	Aug. 1967	12.0	Gugan
17.3	Ethyl Choride	Process Plant	Baton Rouge	1965	0.25	Gugan
36	Cyclohexane	Process Plant	Fleixborough, UK	June 1974	7.8	Eichler
57	Propane	Pipeline	Port Hudson, Mo.	Dec. 1970	8.7	Eichler
63	Propane	Railcar	Decatur, Ill.	July 1974	7.0	Eichler
68	Isobutane	Railcar	Dallas, Tx.	Feb. 1977	0.25	Gugan
50/100	Light HC's	Storage	Pernix, Holland	Jan. 1968	6.0	Gugan
<80	Butadiene	Railcar	Houston, Tx.	Sept. 1974	5.0	Eichler
114	Heavy HC's + hydrogen	Process Plant	New Jersey, USA	1970	4.0	Gugan
118	Propylene	Railcar	East St. Louis, Ill.	Jan. 1972	10.0	Eichler
18	Propane	Road (?)	St-Amand-les-Eaux	1973	3.0	Gobert

TABLE 3-2

DISTRIBUTION OF EXPLOSION YIELDS

Range of Yields*	No. of Incidents	Typical Yield E*	Probability
10-12	2	10.0	0.14
6-10	4	7.5	0.29
2-6	5	5.0	0.36
2	3	0.25	0.21

* Energy Equivalence (%) of Contents of Single Container

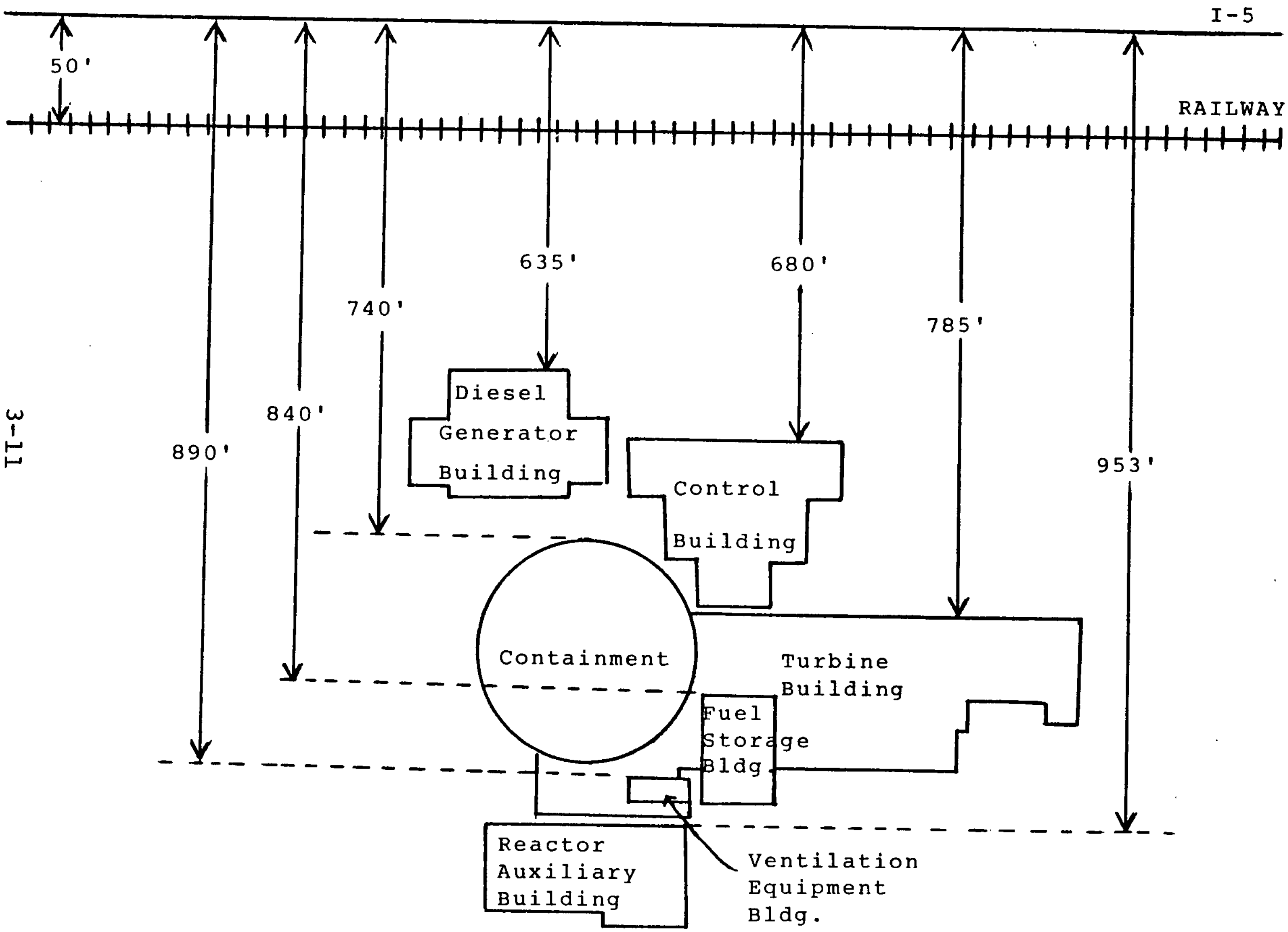


FIGURE 3-4

CRITICAL BUILDINGS TO OVERPRESSURE DAMAGE

For drifting cloud explosions, the probability of exposing the plant to an overpressure greater than a certain value is:

$$P_E = NSH \cdot P(A/M) \cdot \sum_{i=1}^{N} \left\{ P(Si/A) \cdot \left[1 - P(F/S) - P(E/S) \right] \cdot \sum_{j=1}^{M} P_j \text{ (Ignition } O_I) \cdot P(E/I) \, \Delta L_j \right\} \quad (3\text{-}4)$$

where:

$P(F/S)$	=	conditional probability of a fire given a spill
$P_j(\text{Ignition } O_I)$	=	probability of ignition (fire or explosion) in Region I given a spill at accident site j
$P(E/I)$	=	conditional probability of an explosion given an ignition
ΔL_j	=	incremental length of route located a given distance and direction from the plant

The probability of ignition in Region I is a function of where the accident occurs (inside Region I, outside Region I and distance away), the wind direction, and a probability of ignition as a function of cloud travel distance. The first summation allows for varying spill sizes, while the second summation allows for different accident sites.

For accidents inside Region I, the wind blows with a seaward component about half of the time and a landward component the other half of the time. The distance traveled in Region I used for calculating the ignition probability was the maximum distance normal to the transportation route to the edge of Region I for each of the wind directions (seaward and landward).

The transportation routes outside Region I were divided into small (approximately 500 ft.) increments. For each increment, the probability of the cloud centerline being blown through Region I was calculated utilizing site wind direction probabilities from the SONGS Units 2 and 3 FSAR. The probability of an ignition in Region I was based on the shortest distance from the accident site to the Region I boundary and the maximum cloud path length in Region I (which is the Region I diameter). The maximum accident site to plant distance considered was the maximum downwind distance to the lower flammable limit calculated by the dispersion model described later.

3.3 Flammable Vapor Cloud at Air Intakes

In order for a flammable vapor cloud to be swept into a plant air intake, the flammable cloud must intersect Region II without prior ignition.

The probability of this occurring is given by:

$$P_A = NSH \cdot P(A/M) \sum_{i=1}^{N} \left\{ P(Si/A) \cdot \left[1 - P(F/S) - P(E/S) \right] \sum_{j=1}^{M} \left[1 - P_j \text{ (Ignition before } O_{II}) \right] \cdot P_j \text{ (wind blowing to } O_{II}) \cdot \Delta L_j \right\} \quad (3-5)$$

where:

P_j (Ignition before O_{II}) = probability that the cloud ignited before it gets to plant (O_{II}).

P_j (Wind blowing to O_{II}) = probability that the wind is blowing toward O_{II} from a given accident site j.

The probability of ignition before the cloud reaches Region II is based on the minimum distance from the accident site to Region II. The probability of a flammable cloud intersecting Region II is based on the FSAR wind direction probabilities and crosswind distance from cloud centerline to the lower flammable limit based on the dispersion model described later. Region II was analytically defined as a circle enclosing plant air intakes as shown in Figure 3-5.

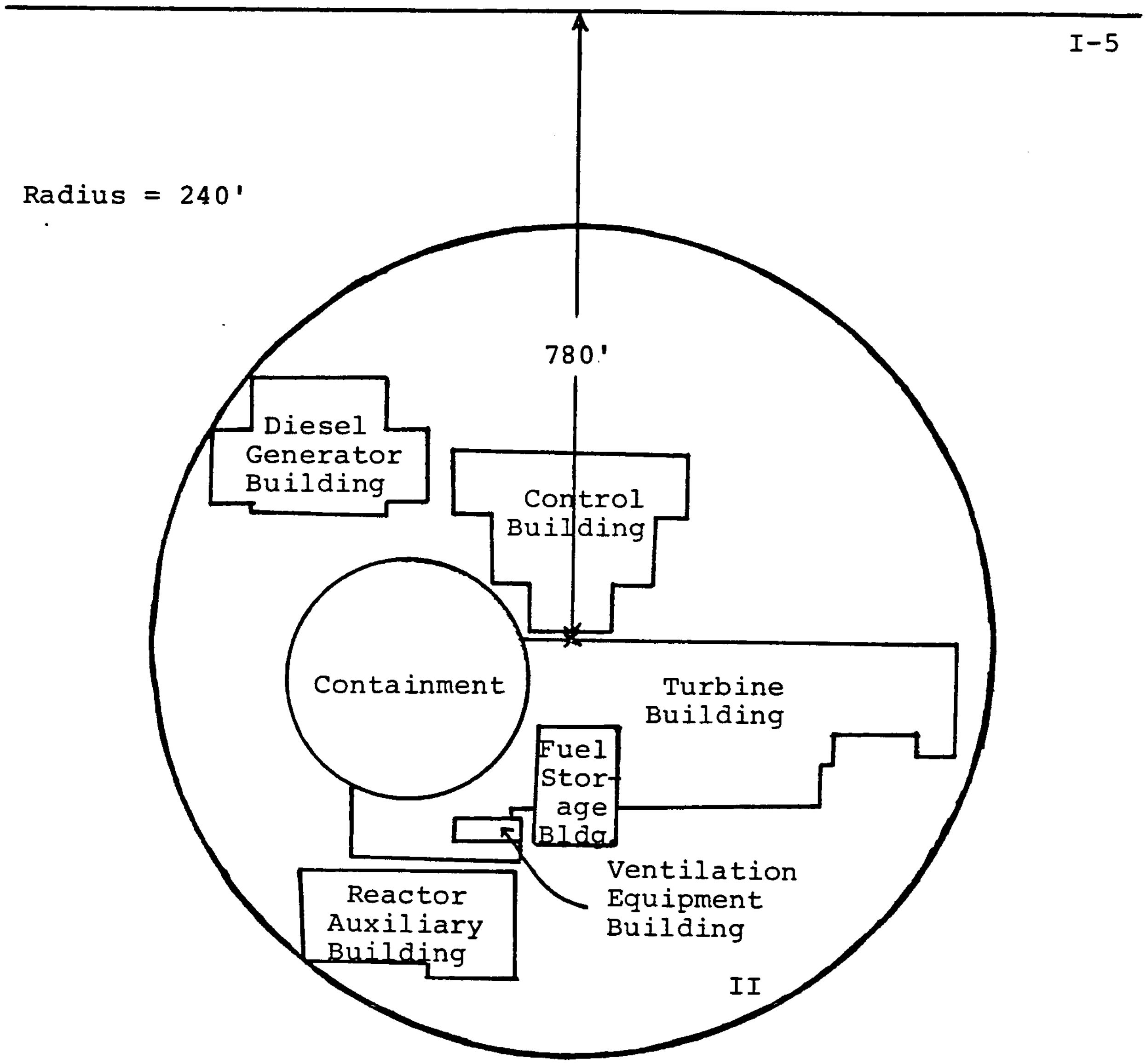


FIGURE 3-5

REGION II DEFINED BY THE BUILDING LAYOUT

3.4 Dispersion Model

The dispersion model is used to determine the distance that the vapor cloud has to travel to reach the lower flammable limit and the crosswind distance to the lower flammable limit. The downwind distance is used only to determine the maximum length of transportation route which must be considered. The crosswind distance is effectively added to the boundary of Region II to determine the probability of a flammable cloud intersecting Region II and being swept into a plant air intake.

An instantaneous puff dispersion model modified to account for initial gravity slumping of heavier than air vapors is utilized. The diffusion equation for an instantaneous (puff) ground level release with a finite initial volume is[8]:

$$\frac{X(d)}{Q_I} = \left[7.87\left(\sigma y^2 + \sigma Iy^2\right)\left(\sigma z^2 + \sigma Iz^2\right)^{1/2}\right]^{-1}$$

$$\cdot \exp\left[-1/2\left(\frac{y^2}{\sigma y^2 + \sigma Iy^2} + \frac{z^2}{\sigma z^2 + \sigma Iz^2}\right)\right] \tag{3-6}$$

$\frac{X(d)}{Q_I}$ = unit concentration at coordinates y, z from the center of the puff, m^{-3}

$\sigma_y(d)$, $\sigma_z(d)$ = standard deviation of the puff in the horizontal and vertical direction respectively, m

d = distance from the origin of the puff release

σ_{Iy}, σ_{Iz} = initial standard deviation of the puff in the horizontal and verical direction respectively, m

($\sigma_{Iy} \neq \sigma_{Iz}$ for heavier than air gas. For neutral of lighter than air gas $\sigma_{Iy} = \sigma_{Iz}$)

y, z = distance from the puff center in the horizontal and vertical directions respectively, m

For those gases heavier than air, σ_{Iy} and σ_{Iz} are determined from the Van Ulden gravity spreading model (Reference 9). The initial cloud formed at the accident site is assumed to be cylindrical in shape with the axis perpendicular to the ground and spreads according to the density difference between the cloud and the air. It is assumed that during the gravity spreading phase, the flammable vapor concentration in the cloud remains unchanged. The cloud spreads until the turbulent energy of the spreading equals the potential energy difference between the heavy gas layer and the surrounding air.

From Reference 9:

$$R^2 = Ro^2 + 2 \sqrt{\frac{g \ (\rho_o - \rho_a) \ Vo}{\pi \ \rho_o}} \ t \qquad (3\text{-}7)$$

$$H = Ho \left(\frac{Ro}{R}\right)^2 \qquad (3\text{-}8)$$

where:

R	=	cloud radius
H	=	cloud height
Ro = Ho	=	initial size of the cloud of the cylinder (m)
g	=	gravitational constant = 9.8 m/sec^2
Vo	=	initial volume of the mixture (m^3)
ρo	=	initial density of the mixture (kg/m^3)
ρa	=	density of the air (kg/m^3)

The gravity spreading ends at time t_s which satisfies the equation:

$$2u^* = u_f \tag{3-9}$$

where:

$$u_f = \frac{1}{R} \sqrt{\frac{g \; (\rho o - \rho a) \; Vo}{\pi \; \rho o}} \tag{3-10}$$

$$u^* = \frac{uk}{\ln \; (z/z_o)} \tag{3-11}$$

u is a fixed wind velocity at a specified height z

k is the Von Karman's constant = 0.4

z_o = roughness length = 0.05 m

If this criterion leads to a final cloud height of less than one meter, then slumping is stopped when the one meter height is reached. One meter represents the height of terrain features within the cloud.

The distance that the cloud travels during the spreading period is as follows:

$$d_s = \int_0^{t_s} \frac{u^*}{k} \ln \left(\frac{H/2}{z_o}\right) dt \qquad (3\text{-}12)$$

At the end of the gravity spreading, the concentration of the cloud is assumed to have a Gaussian distribution with the center point concentration being one (or pure vapor). The σ_{yI}, σ_{zI} are obtained from:

$$\sigma_{yI} = \gamma R$$

$$\sigma_{zI} = \gamma H \qquad (3\text{-}13)$$

R = Radius of the cloud at the end of the spreading

H = Height of the cloud at the end of the spreading

$$\gamma = \left(\frac{1}{\sqrt{2\pi}} \quad \frac{C_o}{C_L}\right)^{1/3} \qquad (3\text{-}14)$$

C_o = assumed initial puff concentration

C_L = Gaussian cloud center point concentration = 1.0 (or pure vapor)

The equation for γ comes from equating the amount of vapor in the cylindrical cloud to that in the Gaussian cloud.

An initial puff concentration of 0.25 was assumed for the base analysis to account for dilution due to turbulent mixing at the release point. Several analysis and tests have shown(10, 11) that momentum transfer of the rapidly expanding gas induces considerable mixing which if uninhibited is sufficient to reduce the resulting gas cloud concentration to below the flammable limit. Sensitivity studies of this initial concentration have shown that the results are not strongly affected by the assumed value.

The Gaussian cloud disperses in accordance with equation 3-6 starting at distance d_s from the spill site.

3.5 Vapor Cloud Ignition

As indicated in Section 4.0, most spills of flammable vapor are ignited essentially at the accident site. For example, James(12) quotes statistics from the Association of American Railroads where for 81 vapor cloud ignitions, 58% occurred from a few feet up to 50 feet, 18% between 50 and 100 feet and 24% from 100 feet to 300 feet.

A curve of integrated ignition probability as a function of distance from historical data of LPG spill accidents was published in Reference 13. The curve is shown in Figure 3-6 and is represented as a line:

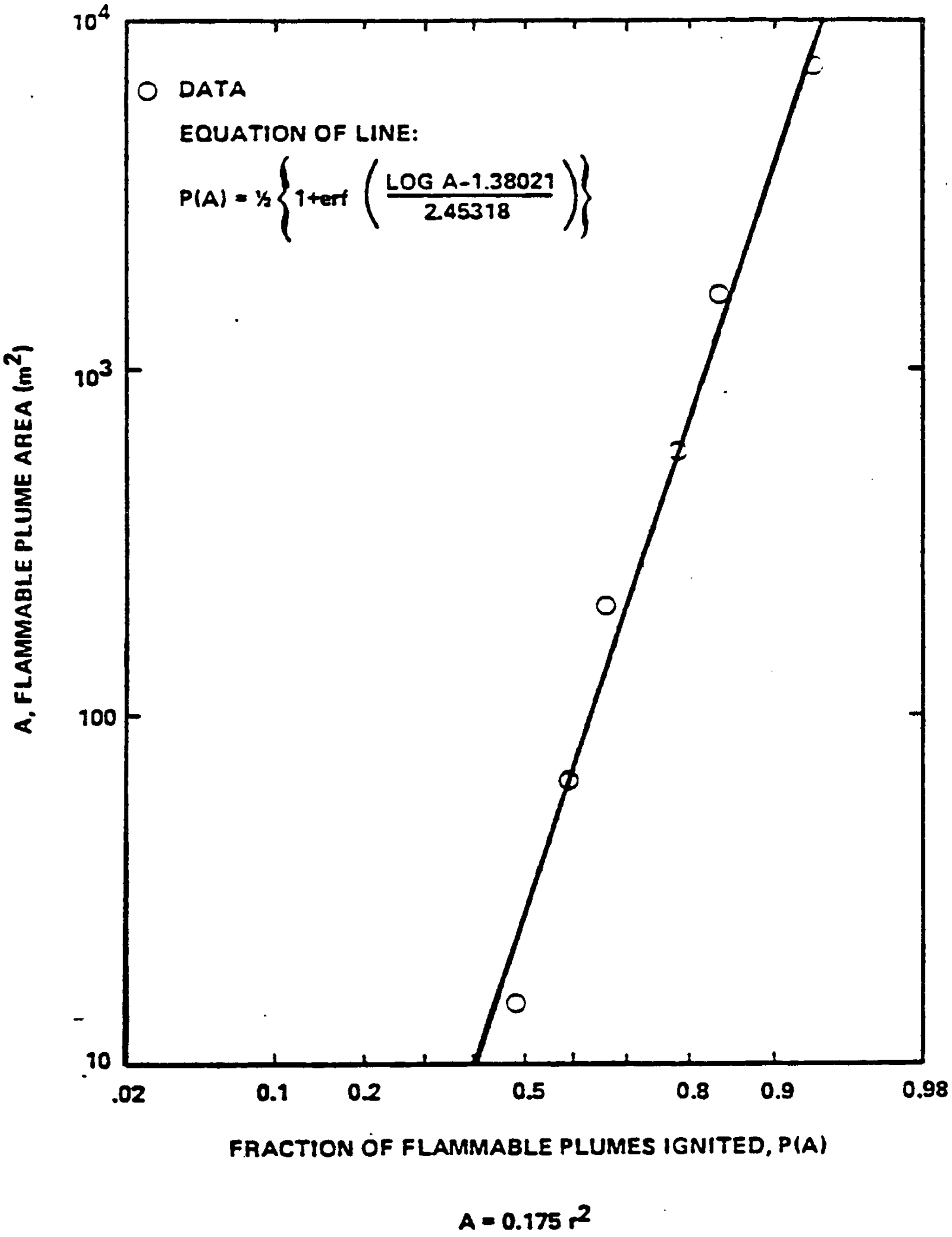


Figure 3-6. Probability of Flammable Plume Ignition Versus Plume Area at the Time of Ignition

$$P_I = \frac{1}{2}\left\{1 + \mathrm{erf}\left(\frac{\log_{10} A - 1.38021}{2.45318}\right)\right\} \quad (3\text{-}15)$$

$$A = 0.175\, r^2 \quad (3\text{-}16)$$

where:

r is the distance in meters.

The information in Reference 12 agrees reasonably well with this curve. The data of Reference 13 also indicates that 10.5% of the drifting cloud ignitions resulted in an explosion while 89.5% resulted in a fire. This agrees well with the data discussed in Section 4.0.

3.6 Solid Explosives

For solid explosives, the probability of exceeding a certain overpressure was obtained from:

$$P'_E = P(A/M) \cdot P(E/A) \cdot \sum\left[NSH_i \cdot L_i\right] \quad (3\text{-}17)$$

where:

P(A/M) = conditional probability of an accident per shipment mile

P(E/A) = conditional probability of an explosion per accident

NSH_i = annual number of shipments of size i

L_i = length of route along which explosion of shipment size would yield an overpressure in excess of a specified value.

The length of route is obtained from the geometrical configuration of the plant and the route and the overpressure range relationship of equation 3-2. Note that it is conservatively assumed that if an explosion occurs, it will involve all explosives in the shipment simultaneously. Staggered explosions will not yield the same overpressure as simultaneous explosions.

4.0 ACCIDENT RATES AND ACCIDENT SEVERITY ASSESSMENT

Truck and railroad traffic density and number of accidents along transportation routes adjacent to the SONGS site were analyzed to evaluate basic site specific accident rates. These local accident rates were adjusted by nationwide accident statistics, where the data base was larger, to assess for commodity classes accident rates and severity of accidents. These accident rates and severity density functions which are used as input data to the analytical risk model were derived in References 60 and 61 and the basis for this derivation is reproduced in this section.

4.1 Accident Rates for Trucks Transporting Hazardous Materials

Truck accident rates are determined from data collected on Interstate Route 5 (I-5) adjacent to the SONGS site. Adjustment factors and severity rates are determined from a nationwide data base collected by the U.S. Department of Transportation.

4.1.1 Truck Accident Rates on California I-5

Accident rates for all trucks* and commodities are determined for a 10 mile segment of I-5 extending approximately equidistant in both directions from the SONGS site. California State Department of Transportation supplied data is summarized in Table 4-1. From this data, an observed truck accident rate of 0.566×10^{-6} accidents per truck mile is evaluated. The data given in Table 4-1 is for I-5 from mile post R61.38 to mile post R71.38. Truck traffic rates are based on weighted sample counting and extrapolated to annual counts. Northbound and southbound data are combined. Traffic accidents are

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* Truck is defined as any vehicle 5,000 pounds or more excluding pickup trucks, vans, and buses.

TABLE 4-1

SUMMARY OF DATA SUPPLIED BY
CALIFORNIA DEPARTMENT OF TRANSPORTATION

Calendar Year	Truck Miles on I-5	Number of Accidents	Accidents Per 10^6 miles
1974	20.38×10^6	12	0.589
1975	19.88×10^6	9	0.453
1976	21.83×10^6	15	0.687
1977	22.65×10^6	12	0.530
Combined	84.74×10^6	48	0.566

accidents that are reported to the state if property damage is \$200.00 or greater or there has been personal injury or death.

Later in this analysis, I-5 accident rates are combined with U.S. DOT data where the property damage threshold for reporting accidents has been increased from \$250.00 to \$2,000.00. To correct for the data base inequities, U.S. DOT experience before and after the reporting threshold change is used to generate a correction factor. Table 4-2 presents data covering the transition period.[14, 15]

Correction Factor:

$$\frac{\text{1973 Accident Rate}}{\text{1971-72 Accident Rate}} = \frac{0.952 \times 10^{-6}}{2.25 \times 10^{-6}} = 0.423 \ \frac{\$2{,}000 \text{ Accidents}}{\$\ 250 \text{ Accidents}}$$

The 2.25×10^{-6} rate is the average of 1971 and 1972 rates.

This factor is applied to the I-5 accident rates based on the assumption that California accident rates would be reduced by the same proportion as that observed on the national level. The fact that the California threshold is \$200.00 vs. \$250.00 for the U.S. DOT would make the correction factor a conservative assumption.

The accident rate corrected to the \$2,000.00 death or injury reporting criteria for all trucks on I-5 is:

$$0.423 \times 0.566 \times 10^{-6} = 0.239 \times 10^{-6} \text{ accidents/mile}$$

4.1.2 I-5 Tank Truck Accident Rate

The bulk of hazardous commodities carried on I-5 past the San Onofre Site are in tank trucks.

TABLE 4-2

U.S. DOT INTERCITY HIGHWAY TRUCK ACCIDENT RATES PER MILE

Year	Accident Reported If Over*	Accident Rate x 10-6	Injury Rate x 10-6	Fatality Rate x 10-6
1971	$ 250	2.19	1.00	0.083
1972	250	2.31	0.996	0.081
1973	2,000	0.952	1.02	0.071

* Accident also reported if there was an injury or fatality.

Therefore, the I-5 tank-truck accident rates are assessed by applying a correction factor based on nationwide experience. An Arthur D. Little, Inc. Report[16] evaluated a national tank-truck accident rate of 1.33×10^{-6} per loaded tank-truck mile.

This accident rate is based on data from 1968 through 1972 (5 years). The average number of loaded tank-truck accidents was 1,650 accidents per year and the average loaded tank-truck usage was 1.24×10^{9} miles per year. During the same five year period, the Bureau of Motor Carrier Safety published[14] data yielding an inter-city truck accident rate of 2.41×10^{-6} accidents per mile. This accident rate is the ratio of 160,347 accidents and $66,389 \times 10^{6}$ truck miles. (Data extracted from reference 14 for this evaluation is shown in Table 4-3.)

Nationwide truck accident statistics show that loaded tank trucks have a lower accident rate than all types of trucks combined. (1.33×10^{-6} vs. 2.41×10^{-6} for years 1968 through 1972 with the same reporting criteria.) Therefore, the I-5 accident rate for all types of trucks (0.239×10^{-6}) is corrected to loaded tank-truck accident rate by assuming the same relative improvement exists in California (I-5) as observed nationwide.

Loaded Tank Truck Accident Rate on I-5:

$$0.239 \times 10^{-6} \quad \frac{1.33 \times 10^{-6}}{2.41 \times 10^{-6}} = 0.132 \times 10^{-6} \text{ accidents/mile}$$

4.1.3 Accident Locations on I-5

A review of LPG shipment data on I-5 shows that most shipments are southbound or on the side of the highway nearest the plant. The possible accident locations used in the realistic analysis were derived from actual truck accident locations along the ten-mile stretch of I-5 near the plant. The resulting locations and the assigned relative probabilities are:

West edge of right-of-way	0.22
West edge of roadway	0.38
Center of roadway	0.24
East edge of roadway	0.16

4.1.4 Spill Rate and Distribution

Compressed gases in the liquified state pose a hazard only if they are released from the pressurized containment and vaporize. Most accidents reported and used in determining the tank-truck accident rate did not result in a loss of lading (spill). Therefore, to assess the potential hazard of a pressurized tank-truck carrying flammable gases, the fraction of spills per accident (probability of spill given an accident has occurred) must be determined.

The I-5 data base is insufficient to generate this ratio, hence the Bureau of Motor Carrier Safety (BMCS) of the U.S Department of Transportation accident reporting system was consulted. Submission of accident report form MCS 50-T by carriers is required if the accident has property damage greater than $2,000.00 or personal injury or death. The standard annual report published by the BMCS does not analyze spill frequencies of flammable or hazardous materials. Therefore, NUS Corporation requested and received computer magnetic tape records of the accident report forms for calendar years 1973 through 1977.

TABLE 4-3

NATIONAL TRUCK ACCIDENT RATES

Calendar Year	Total Intercity Vehicle Miles	Total Intercity Accidents	Accident Rate per 10^6 Miles
1968	$11\ 704 \times 10^6$	29 209	2.50
1969	$12\ 461 \times 10^6$	30 672	2.46
1970	$12\ 390 \times 10^6$	33 203	2.68
1971	$13\ 951 \times 10^6$	30 581	2.19
1972	$15\ 883 \times 10^6$	36 682	2.31
Combined	$66\ 389 \times 10^6$	160 347	2.41

A computer program was written to select and print accidents which had the following characteristics: transporting hazardous material and tank type of body and during an over the road (intercity) trip. The magnitude of this data sort is illustrated by 1977 accident data.

30,567	Accident reports were submitted
24,216	Were over the road trips
3,457	Had tank truck bodies
1,886	Involved transporting hazardous materials
977	Had all characteristics

The 977 accidents were manually reviewed to further select accidents which involved compressed flammable gases, LPG, propane, butane, etc.; were on divided highways when the accident occurred; and were not on an entrance or exit ramp when the accident occurred. This reduced the number of accidents for 1977 to 33. Two of the 33 accidents had spills. This process was performed for each year 1973 through 1977; the results are summarized in Table 4-4. As indicated 7 out of 109 accidents had spills.

A spill quantity distribution was obtained from the data submitted to the Office of the Hazardous Materials Operations on Hazardous Materials Incident Report forms. The data base period was from mid-1973 through 1977. All traffic accident-induced spills for LPG and bulk anhydrous ammonia were considered. Both commodities are carried in trucks built to DOT specifications MC 330 and MC 331. Differences in tank truck load volume is accounted for by normalizing all truck capacities to a nominal 10,000 gallon maximum load quantity. Spills which did not give both spill size and truck capacity or fraction of load spilled were censored. The distribution is generated from a total of 35 truck spills. The results are

TABLE 4-4

SUMMARY OF BMCS REPORTS FOR
COMPRESSED HYDROCARBON GASES

Accident Result, Code		Calendar Year 1973	1974	1975	1976	1977	Total
No Spill	A	14	17	17	23	31	102
Spill	B	1	1	1	2	2	7
Fire	C	0	0	0	0	0	0
Explosion	D	0	0	0	0	0	0
TOTAL		15	18	18	25	33	109

This analysis gives the probability of spill given an accident has occurred of 7/109 = 0.064. This is for compressed LPG Truck MC 330 and MC 331, on highways typified by I-5 passing in front of the SONGS site.

shown in Figure 4-1. Table 4-5 gives the distribution used in the analysis.

4.1.5 Explosion Rates

Given that a tank-truck accident has occurred and a loss of lading has occurred, three things can happen: (1) the spilled LPG can vaporize, expand and form a drifting cloud (the possible outcomes of the drifting cloud will be treated elsewhere in this analysis) or (2) the spilled LPG can be ignited forming a fireball (the size of the fireball can vary from small to large) or (3) the spilled LPG can expand and be ignited to form an explosion.

Spill data have been examined to determine and classify the results of the spill into one of the three classifications above. To perform this analysis, data from the Materials Transportation Bureau, U.S. Department of Transportation has been obtained and sorted to eliminate those accidents which are inappropriate for analysis of LPG Tank-Trucks. Since mid-1973, the Materials Transportation Bureau (MTB) has required reporting of hazardous materials incidents in accordance with the Hazardous Materials Control Act of 1970. Hazardous materials spills while in transit or temporary storage are required to be reported.

For this analysis, only those spills which were the result of a highway accident and where trucks were carrying LPG products are included. Analysis of incident reports from mid-1973 through 1977 revealed 34 events which satisfied the above criteria. However, 11 of these 34 incidents involved property damage of less than $2,000.00 and to be consistent with other accident statistics in this analysis, they were censored. The 23 remaining LPG spill events plus one additional which will be explained are presented in Table 4-6 along with the

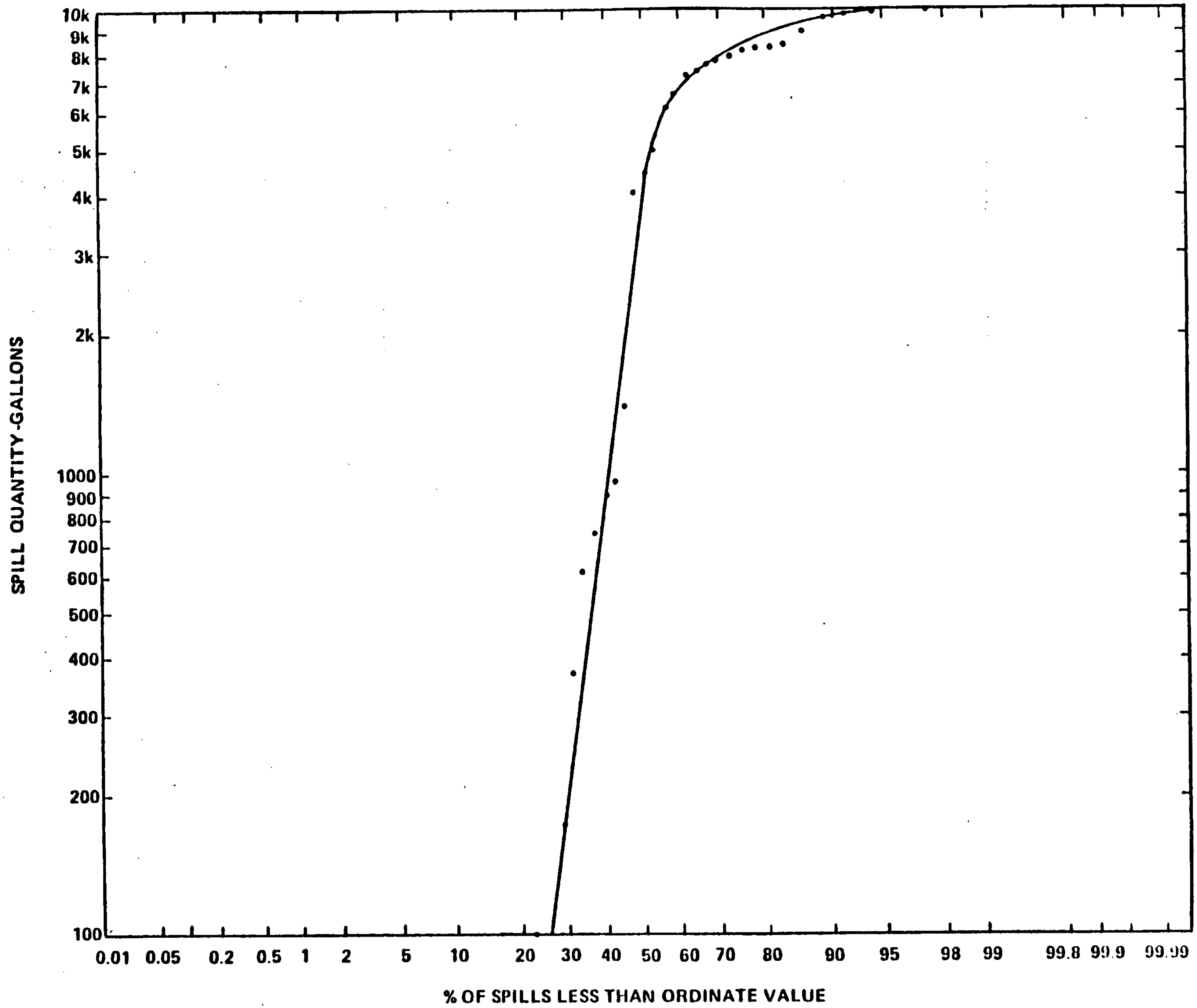

Figure 4-1. Trucks – LPG & NH_3 Spill Quantity - Gal - Normalized
To Max Truck Load of 10,000 gal

TABLE 4-5

TRUCK SPILL QUANTITY

Fraction of Spills	Spill Quantity Gallons
0.2	10,000
0.2	9,000
0.2	7,000
0.4	1,000

TABLE 4-6

HAZARDOUS MATERIAL INCIDENT REPORTS
LPG TRUCKS

Severity,i	Number of Incidents 1973	1974	1975	1976	1977	Sub-Total	One Added	Total	Pi
Spill	1	2	4	2	3	12	--	12	.500
Fire	1	1	0	3	3	8	--	8	.333
BLEVE*	0	0	1	1	1	3	--	3	.125
Explosion	0	0	0	0	0	0	1	1	.042
TOTAL	2	3	5	6	7	23	1	24	1.000

*Boiling Liquid Expanding Vapor Explosion.

resulting severity density function. None of these LPG spills occurred within one hundred miles of San Onofre.

As indicated in Table 4-6 no vapor cloud explosions were observed in the 5 year period ending in 1977. In Mexico, during 1978, there was strong evidence that a vapor cloud explosion occurred from an LPG truck spill.[17] A post accident examination showed severe tree limb breakage at approximately 350 feet from the center of the blast area. Also a sonic boom was reported. This accident was included to obtain the 0.042 mean explosion rate. This is conservative since the LPG truck acidents which did not lead to an explosion have not been accounted for.

Three other accidents are discussed, those classified as Boiling Liquid Expanding Vapor Explosions (BLEVE). Although originally classified as explosions by the MTB, an investigation by NUS revealed that overpressures were not severe.

1. April 29, 1975, Eagle Pass, Texas. A tank-truck with 8,748 gallons of LP gas overturned, ruptured and was ignited. A prefab sheet metal building 200 feet from the location of the truck accident experienced no structural damage and only one broken window.[18] According to the owner of the Border Diesel Service located in the building, the entire window frame was knocked out because of faulty assembly when the building was put together. One witness was exiting his pick-up truck at 150 feet from the accident when the blast occurred. The pick-up truck had the rear window knocked out, but otherwise sustained no damage.[19] The observed level of damage is consistent with an explosion of approximately 100 lb. of TNT. The equivalent yield on an energy basis is less than 0.1% which is typical of a boiling liquid expanding vapor explosion (BLEVE).

2. August 19, 1976, Flint, Michigan. A tank truck with approximately 9,000 gallons of LPG, propane, impacted the guard rail on an exit ramp, slid along the rail for 258 feet and on to an overpass. The truck fell from the overpass to the pavement below. Ignition occurred on or below the overpass. Seven vehicles and occupants within 400 ft. suffered burns and fire damage, but no indications of overpressure damage--there were no body panel indentations; broken windows were minimal and might have been fire-caused. The closest building, a house, at approximately 600 ft. had no structural damage and no broken windows although fires were started on the property. At a distance of 1/4 mile a vibration was felt, but no sonic boom was reported.[20] Overpressure evidence suggest that the accident produced a boiling liquid expanding vapor explosion (BLEVE).

3. February 7, 1977, Detroit, Michigan. A tank truck loaded with approximately 9,000 gallons of LPG, propane, collided with a guard rail on an overpass exit ramp. The truck broke through the guard rail and fell 20 feet to an embankment below, adjacent to a freeway. Ignition occurred at impact with the embankment. The closest building 300 to 400 feet away had no structural damage and no broken windows, although the tarred roof caught fire.[21] A highway light fixture at approximately 80 feet had a broken globe and was burned; the next light fixture at 160 feet was intact but burned. None of the witnesses reported a concussion or sonic boom.[22] Evidence suggests that the overpressure was generated by a BLEVE.

4.1.6 Accident Rates for Carriers of Explosives

Accident rates for trucks carrying explosives are evaluated by adjusting I-5 accident rates with nationwide experience. The

BMCS evaluates accident rates for various categories of comodities. One of these groups is explosives or dangerous articles. Table 4-7 presents accident data extracted from BMCS annual reports (14, 15, 23, 24).

Nationwide truck accident statistics show that trucks carrying explosives or dangerous articles have a lower accident rate than all types of trucks (0.958×10^{-6} vs. 2.41×10^{-6} accidents per mile). Assuming that trucks carrying explosives on I-5 would experience the same relative improvement, I-5 accident rates are corrected as follows:

I-5 Explosives Trucks Accident Rate:

$$\frac{0.958 \times 10^{-6}}{2.41 \times 10^{-6}} \times 0.239 \times 10^{6} = .095 \times 10^{-6} \text{ accidents/mile}$$

The probability that an accident would result in an explosion was determined by data provided by the Institute of Makers of Explosives on the accident statistics for commercial shipments of explosives. During the four year period of 1972-1975, there were 70 accidents reported of which three involved explosions. From this information, it is estimated that the conditional probability of an explosion given an accident is 3/70 or 0.043. Accident Reports are filed when an explosive shipment accident results in (1) fire, (2) death or injury, (3) property damage exceeding $1,000.

The accident rate of 0.095×10^{-6} accidents per mile and the condition probability of explosion of 0.043 are used in the analytical hazard model.

TABLE 4-7

NATIONWIDE ACCIDENT RATES
FOR EXPLOSIVES OR DANGEROUS ARTICLES

Year	Carriers Reporting	Truck Miles Thousands	Number of Accidents	Accidents per 10^6 Miles
1969	5	65 046	110	1.69
1970	1	1 764	1	0.57
1971	7	52 971	28	0.53
1972	7	56 568	30	0.53
Combined	-	176 349	169	0.958

4.1.7 Cylinders of Compressed Flammable Gases and Cryogenic Flammable Gases

Nationwide accident rates for compressed gases in cylinders and cryogenic gases are assumed to be represented by tank truck accident rates. Therefore, the I-5 accident rates evaluated for loaded tank trucks are assigned to trucks transporting cylinders of compressed flammable gases and cryogenic flammable gases.

BMCS data was searched for the period 1973 through 1977 to determine a loss of lading rate per accident for compressed gases in cylinders. Accidents included in the data were over-the-road (intercity) trips transporting hazardous materials. Accidents occurring on individual highways and exit and entrance ramps were also included. A total of 16 confirmed accidents with cylinders of flammable compressed gases were identified. By including non-flammable gases the number of accidents increased to 19. Two of the 19 accidents resulted in loss of lading giving a spill rate per accident of:

$$\frac{\text{2 spills}}{\text{19 accidents}} = \text{0.105 spills/accident}$$

Reviewing BMCS data for cryogenic truck accidents and spills as a result of accidents showed insufficient data to derive a parameter. Therefore the spills per accident for LPG tank trucks (.064 spills/accident) was assumed applicable for cryogenic tank trucks.

Reviewing the MTB data for severity of accidents involving flammable gases in cylinders and cryogenic gases revealed insufficient data to form fire and explosion rates given a spill. Therefore the parameters determined for LPG products were assumed applicable as follows:

Probability of explosion given a spill	=	0.042
Probability of fire given a spill	=	0.458
Probability of no fire or explosion given a spill	=	0.50

These parameters were used as input data to the analytical risk model.

4.2 <u>Transportation Accidents on the Railroad Passing by the San Onofre Nuclear Generating Station</u>

Hazardous materials transported on the Atchison, Topeka, and Sante Fe (ATSF) rail line by the SONGS site are military ordnance and LPG. The ATSF Railway Company does not anticipate any other hazardous materials being shipped along this track. Railroad accident rates and accident effect rates are evaluated from ATSF supplied data and national data. These accident rates are applicable to the track and materials understudy.

4.2.1 Train Accident Rates for Track Passing SONGS

From data supplied by ATSF for a section of Track from Fullerton to San Diego and passing by SONGS, Table 4-8 is developed. Data is from 11 years less the month of December 1978 and the track is from mile post 165.5 to 268.0, a distance of 102.5 miles. While there are sidings, there are no splits on this section of track.

From Table 4-8, the average accident rate for the 11-year period is:

$$\frac{10 \text{ accidents}}{(102.5 \text{ miles}) \times (26{,}378 \text{ Trains})} = 3.70 \times 10^{-6} \text{ accidents per train mile}$$

4.2.2 Pressurized Tank Car Loss of Lading Rate

Loss of lading rate as a result of a train accident is evaluated for pressurized non-insulated tank cars transporting LPG gases past the SONGS site. These tank cars are referenced by specification numbers 112A and 114A. They transport gases in the liquid state under pressure at ambient temperatures.

A loaded tank car loss of lading rate is determined in an Association of American Railroad Report[25] to be 0.152×10^{-6} loss of ladings per tank car mile. This spill rate is based on data from 1965 through 1970 (6 years) where a total of 49 loss of lading accidents were observed. During this period, the average loaded pressurized tank car traffic (flammable gases) was 5.38×10^{7} miles per year (from 1% Waybill statistics). Thus, the nationwide loss of lading rate for liquified compressed flammable gases is:

$$\frac{49 \text{ accidents}}{5.38 \times 10^{7} \frac{\text{car miles}}{\text{year}} \cdot 6 \text{ years}} = 0.152 \times 10^{-6} \frac{\text{accidents}}{\text{car mile}}$$

Next, the nationwide pressurized tank car loss of lading rate is adjusted to the ATSF track passing by the SONGS site. This adjustment is based on the assumption that the ATSF pressurized tank car rates will show the same relative improvement over nationwide rates as ATSF train accident rates show to nationwide train accident rates.

Table 4-9 presents the annual data for the past ten years.(47) (This is the same time period from which the ATSF train accident rate was evaluated.) The nationwide average train accident rate for this ten year period is 10.95 accidents per million train miles.

The loss of lading rate for pressurized LPG tank cars on the ATSF track in the vicinity of the plant site is:

$$\frac{3.70 \times 10^{-6}}{10.95 \times 10^{-6}} \times 0.152 \times 10^{-6} = 0.0514 \times 10^{-6} \text{ Loss of Lading Per Loaded Tank Car Mile}$$

This loss of lading rate is used elsewhere in this report and as an input parameter to the analytical model.

The quantity of lading spilled as a result of an accident is determined for railroad tank cars from Hazardous Materials Incident Report forms submitted to the Office of Hazardous Materials Operation, DOT. The data base period for this analysis is mid-1973 through 1977. All spills in this assessment are DOT specification 112A or 114A tank cars loaded with flammable compressed gases (LPG). Tank car volume is normalized to a nominal maximum load capacity of 33,000 gallons. A distribution of spill quantity is generated from 76 tank car spills. The results are shown in Figure 4-2. Table 4-10 presents the distribution values used in the analysis.

4.2.3 Severity of LPG Loss of Lading Accidents

This section presents definitions for categorizing the severity of LPG loss of lading accidents and using these definitions to analyze accident data developes a probability density function. Jones et. al.,[26] in their evaluation of the

TABLE 4-9

NATIONWIDE TRAIN ACCIDENT RATE

Year	Total Train Miles-Thousands	Train Accidents	Train Accident Rate Per 10^6 Miles
1968	876 489	8 028	9.16
1969	864 081	8 543	9.89
1970	838 674	8 095	9.65
1971	783 844	7 304	9.32
1972	781 408	7 532	9.64
1973	831 347	9 698	11.67
1974	833 261	10 694	12.83
1975	755 033	8 041	10.65
1976	774 764	10 248	13.23
1977	750 042	10 362	13.82
	88 88943	88 545	10.95

TABLE 4-10

RAIL QUANTITY OF SPILL

Fraction of Spills	Spill Quantity--Gallons
0.60	33,000
0.10	30,000
0.05	27,000
0.05	10,000
0.20	1,000

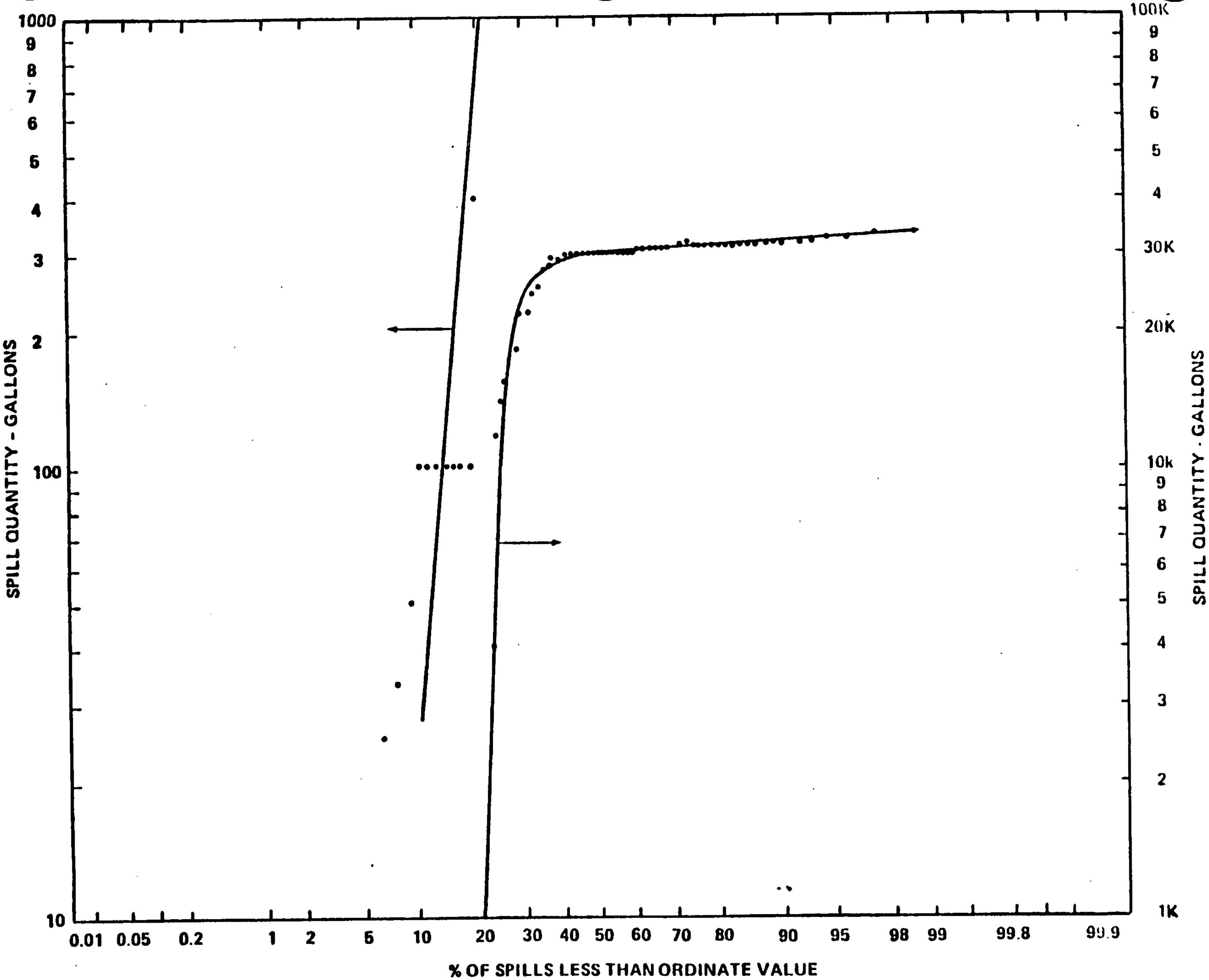

Figure 4-2. Railroad Loss of Lading Quantity - Normalized at Maximum Car Load of 33,000 Gallons

risks of propane rail car shipments have defined five severity categories for propane loss of lading accidents. The same five categories are applied to all compressed flammable gases; the categories are as follows:

> Type I: This type of incident could be caused by a major rupture of the containment vessel resulting in a gross spill without ignition. The result would be that a very large vapor cloud would be formed. If this cloud would be ignited after an explosive fuel-air mixture had been formed, a maximum incident explosion would result. This type of incident is characterized by an unconfined fuel/air detonation.

> Type II: This type of incident would be caused by a separate fire or a tank puncture resulting in a fire that would overheat the punctured propane tank or another propane tank in the near vicinity. The result would be an explosive pressure rupture of the heated tank, causing nearby overpressure damage and possible schrapnel damage from the ruptured tank. This type of incident is characterized by a propane tank explosion.

> Type III: This type of incident would result from a leak or a tank puncture resulting in a large spill with ignition occurring immediately or shortly after the incident. The propane would burn uncontrollably in a large, intense fireball. No tank explosion would occur since the tank puncture would be large enough to relieve the pressure. This type of incident is characterized by a large uncontrollable fireball with no explosion.

> Type IV: This type of incident would be caused by a leak, a tank puncture, a released safety valve or a bust transfer line or valve resulting in a controllable fire.

The fire may be of considerable time duration and does not result in tank rupture, either due to fire control measures or protective insulation. This type of incident is characterized by a controllable fire with no explosion.

Type V: This type of incident would involve a leak or a puncture, either small or large, in a propane tank or loading lines which does not result in fire. If no source of ignition occurs, the propane will be dispersed in the atmosphere in a relatively short time. This type of incident is characterized by loss of lading, but no fire.

From the detailed analysis of LPG, tank car accident data from the period 1965 through 1977 accidents are categorized into one of the five severity types and presented in Table 4-11. For this analysis, the differentiation between Type III and Type IV severity is not important and where the size of fire was not quickly determined, a worst case classification of Type III was assigned. To avoid misinterpretation, these two types are combined in the probability density function given in Table 4-12.

In addition to mechanical damage induced loss of lading, exposure to fire can lead to rupture by heating, loss of lading and rocketing tankage parts. Incidents with this result are categorized as Type II. Review of the University of Southern California report (26) and the AAR-RPI reports (28, 29) show that there were 17 incidents involving 49 LPG tank cars during the period of 1965-1970. These accidents can be classified as shown in Table 4-13.

The probability of a directly occurring Type II accident due to mechanical damage is .117 (from Table 4-12). The

TABLE 4-11

SUMMARY OF MECHANICAL DAMAGE INDUCED
LOSS OF LADING ACCIDENT SEVERITY

Period	Severity by Category Types					Total Number of Cars	Accident Data Source
	I	II	III	IV[3]	V		
1965 thru 1970	0	2	20	2	26	50	25, 28, 29
1971	0	3	4	0	6	13	Note 1
1972	1	1	1	0	10	13	Note 1
1973	0	5	8	0	8	21	Note 1
1974	2	3	10	1	12	28	Note 1
1975	0	4	6	1	5	16	Note 1
1976	0	0	2	0	5	7	Note 2
1977	0	1	3	0	11	15	Note 2
TOTALS	3	19	54	4	83	163	

Note 1: From Federal Railroad Administration Unpublished Summary List of Tank-Car Accidents--Hazardous Materials Section.

Note 2: Data Source Hazardous Material Incident Reports, MTB, DOT.

Note 3: Where accident reports did not have a positive identification of fire size, a worst case assignment of Type III was made.

TABLE 4-12

RAILROAD--COMPRESSED FLAMMABLE GASES

SUMMARY OF RESULTS--LOSS OF LADING CAUSED BY MECHANICAL DAMAGE

	Results Classification	Number of Events	Probability of Event (i) Given Spill (Loss of Lading)
I	Explosion (Detonation)	3	0.018
II	Heated Tank Violent Rupture	19	.117
III & IV	Uncontrollable Fire and Controllable Fire(1)	58	.356
V	Spill	83	.509
	TOTAL	163	1.00

(1) Accident reports did not have a good indication of fire size, therefore, unknown fire sizes were classified as Type III events.

TABLE 4-13

LOSS OF LADING CAUSED BY FIRE

Type	Number	Frequency of Occurrence
I	0	0.0
II	39	0.796
III	2	0.041
IV	7	0.143
V	1	0.020
Total	49	1.00

probability of a Type II event occurring due to a fire is 0.796 (from Table 4-13).

Most Type II LPG tank car accidents (10 out of 12 in years 1965-1970) are caused by fires from other LPG tank cars. These other tank car fires were the result of Type II or Type III accidents which occur with a probability of 0.473 (0.117 + 0.356 from Table 4-12). The overall probability that a fire in one LPG tank car will result in a Type II event in a second LPG tank car is therefore:

$$0.473 \times \frac{10}{12} \times 0.796 = 0.314$$

Therefore the total probability of Type II event due to puncture accident of an LPG tank car is 0.431 (0.117 + 0.314). For 124 LPG rail shipments per year the annual probability for Type II occurrence due to mechanical puncture of an LPG car per AT&SF track mile is 2.75×10^{-6} ($0.514 \times 10^{-7} \times 124 \times 0.431$).

In addition to the probability of an LPG tank car fire, there is the probability that a train fire will be initiated by means of other than a puncture of an LPG tank car. WASH 1238 (30) states that fire occurs in about 1.5% of all train accidents. Conservatively assuming that none of these fires are caused by LPG tank punctures, the probability of a fire per train accident accident is 1.5×10^{-2}. The average accident rate of AT&SF trains is 3.7×10^{-6} accidents per train mile (see Section 4.2.1). Using 62 LPG trains per year carrying 2 LPG cars the annual probability of a train fire is 3.44×10^{-6} ($3.7 \times 10^{-6} \times 62 \times 1.5 \times 10^{-2}$) per track mile.

Using an average train length of 70 cars and 10 cars involved in the accident (30) with the probability that a non-LPG tank car will cause a Type II rupture (2/12 = 0.167) and the probability that either or both of the LPG cars are involved in the accident, the annual probability for a Type II rupture due to non-LPG tank car induced fire is 6.5×10^{-8} ($3.44 \times 10^{-6} \times 10/70 \times 0.796 \times 0.167$) per track mile.

The combined annual probability for Type II rupture from all causes is therefore:

$$2.75 \times 10^{-6} + 6.5 \times 10^{-8} = 2.82 \times 10^{-6} \text{ per mile per year}$$

4.2.4 Tank Car Modifications

Railroad tank cars transporting liquefied gases under pressure have been retrofitted to include safety features. The safety features consist of three modifications: (1) addition of shelves on the couplers to prevent coupler separation in a vertical direction when subject to compressive loads; (2) head shields to deflect objects and strengthen tank heads to reduce the chance of tank puncture by couplers and other projectiles; and (3) the addition of an insulating tank covering to reduce sun heating and protect against fire heating.

Engineering assessments of the effectiveness of shelf couplers and head shields is summarized by statements taken from Reference 46.

"According to AAR, Association of American Railroads, testimony, shelf couplers provide adequate protection in 60 percent of the accident situations." "FRA, Federal Railroad Administration, research concluded that the head shields would protect the tank car from punctures in the tank head in 85 percent of accident situations. The AAR believes that 50 percent reflected a more accurate figure for head shield protection." During these hearings, Reference 46, all parties agreed that installing both shelf couplers and head shields would provide the best protection, with puncture protection provided in over 85 percent of accident situations involving coupler override.

At present, there has not been sufficient accident experience to draw statistical conclusions about the effectiveness of the safety modifications; however, expert analysis of accident sequences has yielded encouraging results in support of the safety features.

An NTSB (National Transportation Safety Board) accident study, Reference 11, provides analysis of a rail accident in Paxton, Texas involving tank cars with and without protective head shields and shelf couplers. With respect to shelf coupler performance, a post-accident investigation showed that 21 of 21 shelf couplers remained coupled, while only 1 of 27 non-shelf couplers remained coupled. The shelf couplers were so effective that the head shields were not subjected to a test. In another accident, 5 of 6 hazardous material cars were equipped with head shields and shelf couplers. All 5 retained their loads.

Initial accident experience does not refute the engineering assessment that the safety modifications could be 85 percent effective. For this assessment, a factor of two reduction in spill rate has been assumed.

4.2.5 Explosives, Accident Rates and Severity of Accident

Reference 27 estimated that there were 1.98×10^7 explosive train-miles per year based on statistics for a 57 year period from 1917 to 1973. The annual average train miles during this same period was 1.36×10^9. During this 57 year period there were 35 explosions involving in-transit shipments of explosive. The national probability of an explosion due to a train accident involving explosives is 3.1×10^{-8} explosions per explosive train mile. The accident rate for the Santa Fe Railroad is significantly less than the national average and therefore using the ratio of Santa Fe Railroad accident rate to the national railroad rate, the explosions per explosive train mile for the track in the vicinity of the SONGS site is:

$$\frac{3.70 \times 10^{-6}}{10.95 \times 10^{-6}} \times 3.10 \times 10^{-8} = 1.05 \times 10^{-8} \text{ Explosions per Explosive Train Mile}$$

Reference 27 also determined a significance factor to account for those accidents which did not yield a significant explosive overpressure. This significance factor is 0.154 yielding a final explosive overpresure rate of:

$$1.05 \times 10^{-8} \times .154 = 1.62 \times 10^{-9} \text{ Significant Explosions per Explosive Train Mile}$$

4.3 Use of Regionally Adjusted Accident Rates

The accident rates for both the railroad and Interstate-5 used in this analysis were derived to be representative of the specific conditions existing in the vicinity of the plant. The local ATSF railroad accident rate is lower than the national average. This is attributed to the fact that financially sound railroads such as the Atchison, Topeka, and Santa Fe can afford to spend the funds to: (55)

- o Maintain track (i.e., frequent quality inspections with follow-up to correct deficiencies)
- o Motivate personnel (i.e., operator training, advancement and monitoring of performance)

- o Repair operating equipment (i.e., replace worn wheels or brakes) and modernization of rolling equipment and tracks

This trend towards lower accident rates for financially sound railroads is further supported by the data from the Federal Railroad Administration provided in Table 4-14.

In the case of I-5, interstate highways generally have lower accident rates than other highway because: (56)

- o There are fewer interruptions to traffic flow resulting in an orderly traffic flow at approximately the same speed

- o The median strip reduces the incidence of head-on collisions

- o Interstate highways have wider shoulders which are clear of obstructions such as trees, rocks, parked cars, culverts, openings, etc.

- o There are no grade crossings

- o "U" turns, stop lights, cross streets and slow-moving traffic pulling onto the highway are eliminated

Both nationwide and California statistics support the trend of rural interstate highways having considerably lower accident rates than average. The even lower local I-5 rate is attributed to generally better weather and associated pavement conditions, frequent patrolling and heavy but not overly congested traffic. The local I-5 truck accident rate is based on 48 accidents over a 4-year period. Detailed review of the locations of this statistically large sample shows a relatively uniform distribution in either direction and along the 10 miles of highway near the plant.

TABLE 4-14

RAILROAD ACCIDENT RATES
(Accidents per 10^6 Train Miles)

Railroad	Federal Railway Administration* 1974	Federal Railway Administration* 1977	SONGS Analysis 1968-78
Local ATSF	--	--	3.7
ATSF	4.9	5.7	
Southern Pacific	5.8	12.1	
Union Pacific	5.4	7.4	
Nation Wide	12.8	13.8	11.0

* Accident/Incident Bulletin No. 143, Calendar year 1974, U.S.D.O.T., Federal Railroad Administration, August 1975.

Accident/Incident Bulletin No. 146, Calendar year 1977, U.S.D.O.T., Federal Railroad Administation, August 1978.

5.0 ANALYSES AND RESULTS

5.1 General

The parameters used in the analysis of overpressure, and flammable vapor cloud hazards at SONGS Unit 1 from highway and rail transport of hazardous materials are summarized in Tables 5-1 and 5-2. The basis for the accident rate parameters is discussed in detail in Section 4. The atmospheric dispersion parameters of Table 5-2 correspond to five percentile worst case conditions. These were used for all accidents even though they occur only infrequently.

The overpressure criteria used in this analysis was obtained from Bechtel Corporation and are tabulated in Table 5-3. The risks of overpressurization and flammable gas intake hazards were evaluated for each SONGS 1 safety-related building given in Table 5-3 using its individual overpressure criterion, building area, and proximity to the transportation routes. In addition, the risks were also calculated for a plant area that encompasses all the above buildings using an overpressure criteria of 0.503 psi (this is the lowest resistance to overpressurization for all the buildings). The results of this analysis are given in Table 5-4. As can be seen from this table, the total plant probability is not the sum of all the individual probabilities of each individual building. Instead it can be approximated by the highest probability among the individual buildings.

For the remainder of this section, the probabilities discussed are calculated using 1) the entire plant area covering all safety-related buildings and 2) an overpressure criteria of 0.503 psi.

TABLE 5-1

COMMODITY DEPENDENT INPUT PARAMETERS

	Highway						Railroad	
	LPG	LNG	Hydrogen Liquid	Hydrogen Gas-1	Hydrogen Gas-2	Acetylene	LPG	Explosives
Number of Annual Shipments	2200	420	52	260	24	52	124	8
Accidents per Loaded Truck Mile	0.132×10^{-6}	0.132×10^{-6}	0.132×10^{-6}	$.0952 \times 10^{-6}$	$.0952 \times 10^{-6}$	$.0952 \times 10^{-6}$	$\{.0514 \times 10^{-6}$	$\{1.62 \times 10^{-9}$ (1)
Probability of Spill Given Accident	.064	.064	.064	.105	.105	.105		-
Probability Explosion Given Spill	.042	0	.042	.042	.042	.043	.0184	-
Probability Fire Given Spill	.458	0.5	.458	.458	.458	.458	.473	-
Probability of No Explosion or Fire	.500	0.5	.500	.500	.500	.500	.509	-
Probability of BLEVE	0.125	-	-	-	-	-	.117	-
Vapor Cloud Probability of Ignition			Figure 3-6				Figure 3-6	-
Vapor Cloud Probability Fire Given Ignition	.895	1.0	.895	.895	.895	.895	.895	-
Vapor Cloud Probability Explosion Given Ignition	.105	0.0	.105	.105	.105	.105	.105	-
Maximum Shipment Quantity	10,000 gal.(3)	9,200 gal.	8,500 gal.	16,425 ft^3 gas	114,000 ft^3	3,300 ft^3	30,000	20,548 lbs.
Flash Fraction	.352	0.1	0.1	1.0	1.0	1.0	.352	-
Quantity of Vapor(2) - Lbs.	14,665	3,185	502	92	640	241	43,994	-
Lower Flammability Limit - %	2.1	5.0	4.0	4.0	4.0	2.5	2.1	-
Spill or Shipment Size Distribution	Table 4-3	100%	100%	100%	100%	100%	Table 4-4	100%

1. Probability of significant explosion per explosive train mile.
2. For maximum quantity spilled.
3. 5,000 gallons 60% of the time and 10,000 gallons the other 40% of the time.

TABLE 5-2

OVERPRESSURE AND FLAMMABLE
VAPOR CLOUD INPUT PARAMETERS

Stability Class	-	G
Wind Speed	-	1.5 ^{m}/sec at 10 m height
Initial Dilution	-	Air/Gas = 3/1
Minimum Cloud Height	-	1 m.
Ambient Temperature	-	78^{o}F
Temperature of the Gas	-	Saturation Temperature at 14.7 psia for Liquified Gas
	-	Ambient Temperature for Compressed Gas
Wind Direction Frequency	-	FSAR Table 2.3-22
Explosive Equivalent Yield Based on Energy	-	See Table 3-2
Region II Radius	-	240 feet
Peak Refelcted Overpressure	-	0.5 psi

TABLE 5-3

PROVIDED RESISTANCE TO OVERPRESSURIZATION

Building	psi
Control	0.671
Reactor Auxiliary	0.503
Fuel Storage	1.165
Turbine	0.856
Ventilation Equipment	1.249
Diesel Generator	4.476
Sphere Enclosure	10.132

TABLE 5-4
RISKS FROM COMPRESSIBLE GASES TO THE INDIVIDUAL BUILDINGS

	Total* Probability of Exceeding Resistance to Overpressurization Per Year	Total* Probability of Flammable Vapor Cloud Being at the Building Per Year
Control Building	1.96-6	5.52-8
Reactor Auxiliary Building	2.40-6	3.71-8
Fuel Storage Building	1.10-6	3.44-8
Turbine Building	1.63-6	7.61-8
Ventilation Equipment Building	1.00-6	2.90-8
Diesel Generator Building	2.19-7	5.69-8
Sphere Enclosure Building	2.14-8	4.45-8
Circle Encompassing all the Above Buildings	2.63-6	1.04-7

* This totals includes risks from LPG, LNG, liquid hydrogen, compressed hydrogen-1, compressed hydrogen-2, and acetylene.

5.2 LPG

Liquid Petroleum Gas is transported on both Interstate-5 and on the Atchison Topeka and Santa Fe Railroad. In addition to using the previously discussed transportation parameters, two other considerations were made.

The risks from transportation of LPG on I-5 is divided into two calculations; one where the shipment quantity is 5,000 gallons and the other where the shipment quantity is 10,000 gallons. This is to account for the use of tandem trucks. The largest shipper of LPG on I-5 has indicated that 60% of their fleet consists of tandem trucks composed of two 5,000 gallon tanks.[58, 59] If a tandem truck should be involved in an accident on Interstate-5, it is assumed that, at most, the contents of one vessel will contribute to a vapor cloud explosion. This assumption is based upon the fact that there is no known transportation accident in which the contents of more than one storage tank contributed to the material involved in a vapor cloud explosion. The criteria of applying TNT equivalency to potential accidents can, therefore, include the mass limitation equal to the contents of the largest storage vessel under most conditions.

The risk from transportation of LPG on the AT&SF railroad was reduced by a factor of two to account for tank car modifications (see Section 4.2.4).

The results of the analyses are given in Table 5-5.

5.3 Other Hazardous Gases

Results of the detailed analysis for LNG, liquid hydrogen, acetylene and gaseous hydrogen are summarized in Table 5-6. Note that in accordance with references 33, 34, 35, and 36,

TABLE 5-5

RESULTS - LPG

	Probability of Overpressure Greater Than 0.5 psi	Probability of Flammable Gas at Intake
I-5 Shipments		
10,000 gallon tanks (frequency = 40%)	2.39-6	6.84-8
5,000 gallon tanks (frequency = 60%)	1.89-6	5.99-8
Total Probability from I-5	2.09-6	6.33-8
AT&SF Shipments		
Without Credit for Tank Car Modifications	8.99-7	3.89-8
With Credit for Tank Car Modifications	4.50-7	1.95-8

TABLE 5-6

OTHER HIGHWAY RESULTS

	Probability of Exceeding 0.5 psi Per Year	Probability of Flammable Vapor Cloud Being Swept Into Plant Per Year
LNG	0	1.03-8
Liquid Hydrogen	3.93-8	1.44-9
Compressed Hydrogen - 1	3.75-8	7.10-9
Compressed Hydrogen - 2	9.72-9	7.63-10
Acetylene	6.71-9	1.24-9

the generation of a significant overpressure from an unconfined methane-air ignition from the LNG spill is not considered credible.

5.4 Explosives

As stated in reference 37, the recent annual number of shipments of military explosives past the site is 1411 by highway and eight by rail. Reference 38 further states that changes in shipment routes and requirements for 911 of the current shipments will occur after 1980 so that there will be less than 10% of the 911 shipments in the future. Assuming that the remaining 500 shipments (1411 - 911) are unaffected yields a projected I-5 military explosive shipment frequency of 500 + 0.1 x 911 or 592.

The maximum net explosive weight is 20548 lbs by rail.[37] For the highway shipments 994 of the 1411 shipments were further divided by weight (ref. 38, 48, 49, 50, 51, 52) as shown in Table 5-7.

Utilizing this information and the accident rates of Sections 4.1.5 and 4.2.3 yields annual probabilities of exceeding 0.5 psi due to shipments of explosives of 1.9×10^{-6} and 0.02×10^{-6} for highway and rail respectively. Note that all rail shipments were assumed to be of maximum size.

TABLE 5-7

HIGHWAY MILITARY EXPLOSIVE
SHIPMENT SIZE DISTRIBUTION

Net Explosive Weight (lbs)	Shipments	Size Distribution for Highway Shipment of Explosives Frequency
3400	938	.944
3400-4400	11	.011
4400-5400	10	.010
5400-6400	7	.007
6400-7400	8	.008
7400-8400	6	.006
8400-9400	5	.005
9400-10400	4	.004
10400-11400	5	.005
	994	

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