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HERMOSA BEACH PROJECT
INTEGRATED RISK ANALYSIS

DRAFT FINAL REPORT

For
CITY OF
HERMOSA BEACH

By
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and

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EXECUTIVE SUMMARY

A. General Description of the Work Completed

An integrated risk assessment of the proposed MacPherson Oil Company Hermosa Beach Oil Project has been conducted. This assessment was conducted in response to the City of Hermosa Beach generic request for an integrated risk assessment as well as to specific requirements requested as a result of a stakeholder meeting conducted with the presentation of preliminary results from the project.

The scope of work consisted of the following principal tasks:

- Data acquisition
- Hazard scenario development
- Frequency analysis
- Consequence analysis
- Unmitigated risk assessment
- Risk mitigation
- Mitigated risk assessment
- Integrated risk assessment
- Conclusions and recommendations

The work spanned both the proposed Test Phase and the Production Phase of the project. Utilizing state-of-art techniques of risk analysis, including the Bercha Risk Software (BRISK) and a current multi-purpose consequence model (TRACE), both mitigated and unmitigated component and integrated Test and Production Phase risks for the project were determined. Results included annual individual and collective risks, as well as cumulated risks over the project life. Table 1 summarizes the salient results of the work, and Figure 1 summarizes the risk profiles, while a discussion of the principal assumptions and approximations and a systematic reporting of the conclusions for each phase follows.

B. Principal Assumptions and Approximations Made in the Work

B.1 Conservative Assumptions Made in the Work

Certain significant conservative assumptions and approximations were made, resulting in the tendency to overestimate the risks associated with the project. The principal ones among these may be summarized as follows:

- Test and Production Phase process release frequencies were based on the entire process facility releasing as one segment
- Leak and hole releases were assumed to continue to blowdown until atmospheric pressure is reached within the segment
- Modelling of ground level releases rather than elevated releases as a basis for hazard assessment

- All releases in horizontal direction
- Test Phase jet fires penetrate sound attenuation wall

B.2 Non-Conservative Assumptions Made in the Work

Certain non-conservative assumptions to simplify and facilitate the work were made, which can result in an understatement of the risks. It is believed that these understatements are not significant, but these assumptions are nevertheless summarized, as follows:

- Topography was not explicitly considered in consequence modelling
- Any outdoor receptors were considered at risk; indoor receptors were considered safe
- Population distributions were considered as remaining constant over the 35 year project life
- Wake effect of the perimeter wall was not modelled explicitly

B.3 Simplifying Assumptions and Approximation

Certain other simplifying assumptions and approximations were made during the conduct of the work in order to make its completion practicable while still providing meaningful results. These simplifying assumptions and approximations may have the effect of either overestimating or underestimating the risk, but to a negligible degree within the context of the present work. Such simplifying assumptions and approximations may be summarized as follows:

- Redondo Beach weather was considered representative of the Hermosa Beach site location
- Subdivision of release sizes into leak, hole, rupture, and double rupture for pipeline was considered representative of all release sizes
- 20% extra volume allowance was added to allow for flow during the isolation of each segment
- The injury likelihood was assessed as ten times more likely than the fatality likelihood
- Mitigating effects of the Test Phase sound attenuation wall and Production Phase structural wall were modelled only in terms of their reduction of flammable vapour cloud ignition probabilities
- Cumulative risk was based on the integrated Production Phase mitigated annual risk

C. Test Phase Annual Risks

The Test Phase risks extend over a period of one year, and both the mitigated and unmitigated risks are largely in the insignificant risk region. The maximum individual specific risk to the public associated with the Test Phase is chances of a fatality of 1 in one million per year. Figure 1 shows the Test Phase risk spectra for both the mitigated and unmitigated case. Reduction in the risks from the unmitigated level results from the following risk mitigation measures:

- Installation of a 30-foot high perimeter sound attenuation wall for the duration of the Test Phase

D. Production Phase Annual Risks

Individual specific and collective risks for the Production Phase have been assessed. The maximum individual specific risk to the public from the Production Phase is approximately a 1 in 100,000 chance of fatality per year. Figure 1 shows the unmitigated risk and mitigated risk spectra for the Production Phase. As may be seen, the unmitigated risk spectrum extends into the unacceptable region. Although the basis for the risk estimates is quite conservative, the high level of unmitigated risk demonstrates that an industrial project in an urban setting can pose unacceptable risks if not appropriately mitigated.

The mitigated risk spectrum for the Production Phase is largely in the grey area, indicating that all practicable means to reduce the risks should be utilized. In particular, the chance of 10 or more fatalities per year is 1 in one million. The principal requirement to reduce the risks for the Production Phase from the unacceptable region to the grey region was as follows:

- Installation of a perimeter structural wall to remain in place for the entire life of the project

In general, every effort should be made to further reduce associated with the Production Phase. Risk mitigation measures which have generally been proposed by MOC, but for which engineering details were not available during the course of this assessment, include the following:

- Emergency shutdown valves to reduce the frequencies and volumes of releases associated with the process components
- Automatic gas detection, shutdown, isolation, and depressurization equipment for the process segment

E. Integrated and Cumulative Risks

The following hazardous events and associated ultimate risk expectations are projected over the 35 year life of the project:

- 31 leaks, 2 major releases, and 1 rupture within the process segment
- Resulting offsite hazards including 2 jet fires, and a 4% likelihood of an offsite flash fire with potential for casualties
- A 1 in 7000 chance of 1 of more fatalities, 1 in 30,000 of 10 or more, and a 1 in 700 chance of 1 or more serious injuries of members of the public

F. Existing Facility Risks

Figure 1 also shows the risk spectrum estimated for the existing use of the site as a City yard. As may be seen, the existing risk spectrum was somewhat lower than the Test Phase risk spectrum for fatalities in excess of 2, but is at a similar level for the Test Phase risk spectrum for at least 1 or 2 fatalities. This segment of both the Test Phase risk spectrum and the Existing Facilities risk spectrum is attributable primarily to vehicle traffic hazards.

G. Acceptability of Risks

The acceptability of the annual individual and collective risks can be assessed utilizing standards adopted by other jurisdictions. The highest annual individual specific risks for the Test Phase and the Production Phase are a maximum of 1 in 100,000. This level is deemed acceptable for public, commercial, and residential medium-density land use.

The annual collective risks for the Test Phase are primarily in the insignificant region of the risk profile for both the mitigated and unmitigated case. Therefore, they may be deemed acceptable relative to the risk thresholds indicated on the risk profile.

The integrated annual collective risks for the Production Phase extend into the intolerable (unacceptable) region for the unmitigated case, necessitating risk reduction to the acceptable region. Such a risk reduction can be achieved by specific risk mitigation measures, the perimeter walls, and further risk mitigation should be implemented including some of the provisions detailed above. Inclusion of the perimeter wall risk mitigation effects in the consequence evolution modelling results in collective risks in the acceptable but grey region. Every effort should be made to reduce the risks for the Production Phase to a level as low as reasonably practicable.

The cumulative risks over the life of the project have also been estimated, but their acceptability must be assessed primarily in the light of the City of Hermosa Beach Council and residents' risk tolerance criteria. Naturally, although criteria for acceptability of the annual risks have been presented, the same City of Hermosa Beach sense of risk acceptability should be the overriding arbiter of what goes on within its jurisdiction in terms of annual risks as well.

In general, it can be said that the proposed project by a safe and reputable operator contains industry standard safety and reliability provisions, which will make it as safe as any comparable modern operation. Yet, because of its setting in a medium-density urban, commercial, and residential location, it poses risks. These risks have been quantified and presented, with an explanation of the approximations implicit in this quantification, and compared to standards and other measuring sticks that are available. The ultimate decision on the acceptability of the risks rests with the City of Hermosa Beach.

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Table 1
Summary of Hermosa Beach Oil Project Mitigated Risks

COMPONENT	TYPE OF RISK	MAXIMUM VALUE	ACCEPTABILITY	MITIGATION INCLUDED
PROJECT	Annual individual specific risk or fatality	1/100,000 per year	Acceptable	• Perimeter wall • Industry standard measures
	Annual group risk of 1 or more fatalities	1/50,000 per year	Grey-Acceptable but mitigation recommended	
	Cumulative (35 year) individual risk of fatality	1/3000 for project	Up to City	
	Cumulative (35 year) group risk of 1 or more fatalities	1/7000 for project	Up to City	
	Cumulative (35 year) group risk of 1 or more injuries	1/700 for project	Up to City	
TEST PHASE	Annual individual specific risk of fatality	1/1,000,000 per year	Acceptable	• Perimeter wall • Industry standard measures
	Annual group risk of 1 or more fatalities	1/50,000 per year	Acceptable	
	Annual group risk of 10 or more fatalities	1/30,000,000 per year	Acceptable	
	Cumulative individual risk of fatality	1/1,000,000 for phase	Acceptable	
	Cumulative group risk of 1 or more fatalities	1/50000 for phase	Acceptable	
	Cumulative (35 year) group risk of 1 or more injuries	1/5000 for phase	Up to City	

Table 1 (cont.)
Summary of Hermosa Beach Oil Project Mitigated Risks

COMPONENT	TYPE OF RISK	MAXIMUM VALUE	ACCEPTABILITY	MITIGATION INCLUDED
PRODUCTION PHASE	Annual individual specific risk of fatality	1/100,000 per year	Acceptable	• Perimeter wall • Industry standard measures
	Annual group risk of 1 or more fatalities	1/250,000 per year	Acceptable	
	Annual group risk of 10 or more fatalities	1/1,000,000 per year	Grey-Acceptable but mitigation recommended	
	Cumulative 35 year individual risk of fatality	1/3000 for project	Up to City	
	Cumulative 35 year group risk of one or more fatalities	1/7000 for project	Up to City	
	Cumulative 35 year group risk of one or more injuries	1/700 for project	Up to City	
EXISTING FACILITY	Annual individual specific risk of fatality	1/1,000,000 per year	Acceptable	• As is
	Annual group risk of 1 or more fatalities	1/50,000	Acceptable	
	Annual group risk of 10 or more fatalities	0	Acceptable	

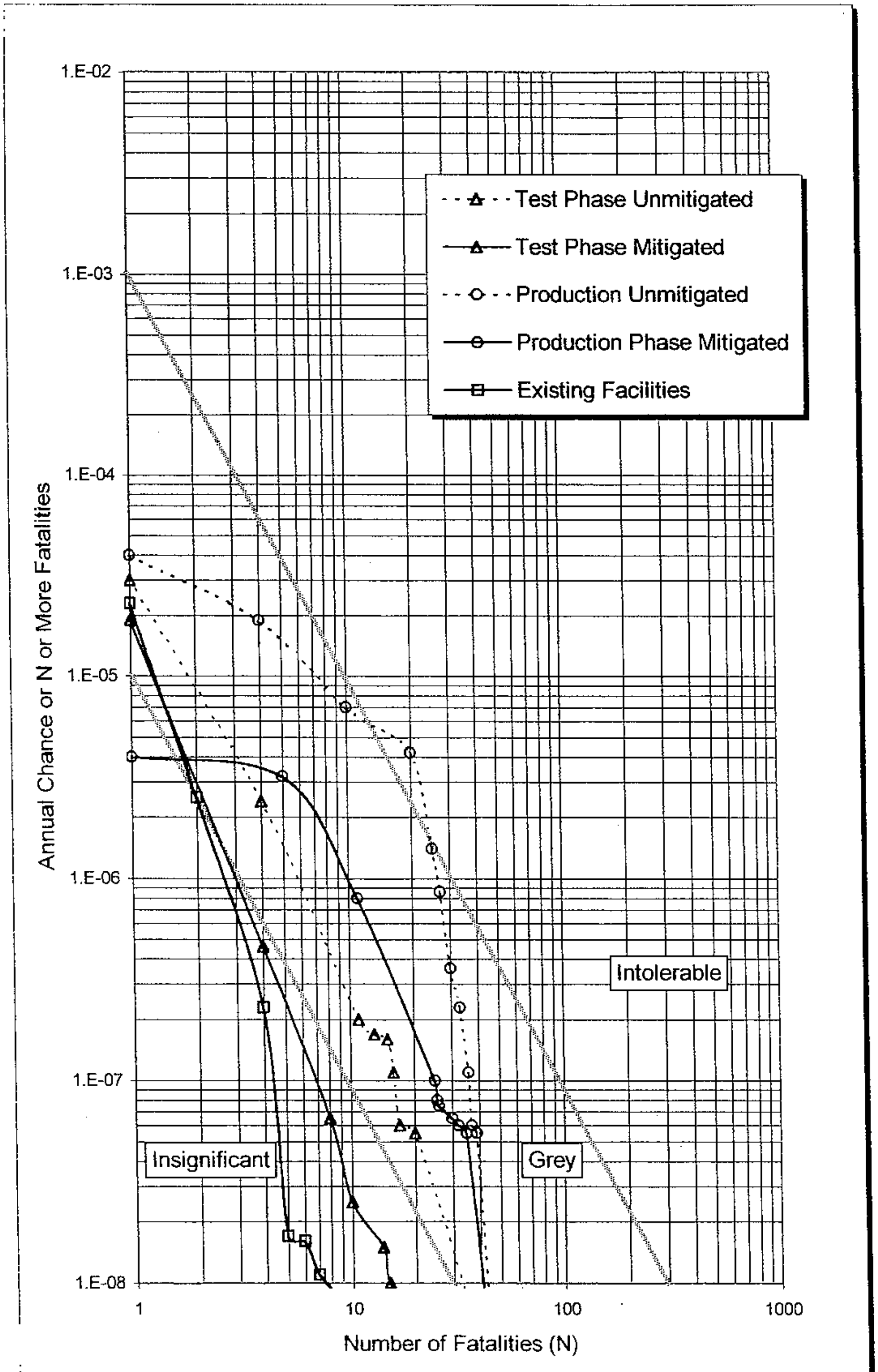

Figure 1
Project Mitigated and Unmitigated Risk Profiles

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GLOSSARY OF TERMS AND ACRONYMS

Acute Risk = Risk that has an immediate adverse effect due to a single exposure to an accident such as exposure to a gas explosion

AIChE = American Institute of Chemical Engineers

ARCHIE = Automated Resource for Chemical Hazard Incident Evaluation, a multi-purpose consequence modelling system developed by the EPA

BRISK = Bercha Risk assessment software system

Chronic Risk = Risk that has adverse effect due to a long-term series of exposures

CBA = Cost Benefit Analysis

EPA = U.S. Environmental Protection Agency

ESD = Emergency Shutdown

ESDV = Emergency Shutdown Valve

Hazard = A condition with a potential to create risks such as accidental leakage of natural gas from a pressurized vessel

IR = Individual Risk, annual risk to an individual located at a specific location continuously for one year (24 hrs/day, 365 days/yr) as a result from a nearby project or facility

ISR = Individual Specific Risk, the actual risk per year to an individual resulting from a specific facility or project considering the actual time and exposure by the individual in the zone of influence of the project

MIACC = Major Industrial Accident Council of Canada

MOP = Maximum Operating Pressure, the pressure at which a pipeline or vessel can be operated considering design conditions

NACE = National Association of Corrosion Engineers

Natural Gas = Hydrocarbons which are used as a source of energy and normally are in a gas phase at standard conditions of pressure and temperature

NGL = Natural Gas Liquids

OISR	= Outdoor Individual Specific Risk
P&ID	= Piping & Instrumentation Diagram
PFD	= Process Flow Diagram
PRV	= Pressure Relief Valve
Public Safety	= Protection of the general public from acute, immediate effects caused by a single exposure to an accident resulting in severe injury or fatality. Public safety as used in this report does not extend to occupational safety or public health, which covers the chronic effects from prolonged exposures to a hazardous substance
Risk	= A compound measure of the probability and magnitude of adverse effect
ROO	= Ratio of Occurrence
SOEP	= Sable Offshore Energy Project
Sour Gas	= Natural gas containing significant amounts of hydrogen sulphide
Sweet Gas	= Natural gas with no significant amounts of hydrogen sulphide
TRACE	= A multi-purpose consequence analysis software modelling system developed by DuPont and sold by Safer Systems

CHAPTER 1

INTRODUCTION

1.1 General Introduction

The proposed MacPherson Oil Company Hermosa Beach Oil Project consists of an oil and gas drilling, testing, and production system located in the City of Hermosa Beach. Figure 1.1 shows the location of Hermosa Beach with respect to key landmarks on the coast of Southern California.

The project consists of a two-phase oil and gas production development consisting of a one year test phase to be followed by the production phase expected to last approximately 30 additional years. In the test phase, a maximum of 3 wells will be drilled with a temporary production facility established on the site. A maximum of 27 additional wells will be drilled utilizing slant-reach technology to tap offshore and onshore reservoirs to produce approximately 8000 barrels per day of crude oil and 2.5 million standard cubic feet per day of natural gas. The production phase, in additional to wells, will have onsite production equipment and a production tank farm. The crude oil and natural gas pipelines, each approximately ½ mile long will transport the produced oil and gas to its sales destination.

The oil and gas development project is proposed for a site located within a medium density commercial and residential beach community in Hermosa Beach. The close proximity of a relatively complex industrial development to a medium density commercial and residential neighborhood thus accentuated the critical importance of the safety interface between the project and members of the public.

The safety of the project was assessed by a number of studies [4, 7, 41, 42][1] conducted throughout 1997 and 1998. Because of concerns by the city over the generality of some of these studies, Aspen was invited to review them, and its resulting recommendation [7] to conduct an integrated risk assessment of the project based on up-to-date information was accepted by the city. Accordingly, Aspen and Bercha were retained by the city to conduct an integrated risk assessment of the project. The preliminary results [5] of the risk assessment were presented at a stakeholder meeting on July 7, 1998, resulting in requests for a number of refinements and additional investigations. The current report presents the background, methodology, and results associated with both the original scope of work and the additional investigations.

1.2 General Project Description

The project is proposed to be located at the current Hermosa Beach Public Works

[1] Numbers in square brackets refer to items listed under References

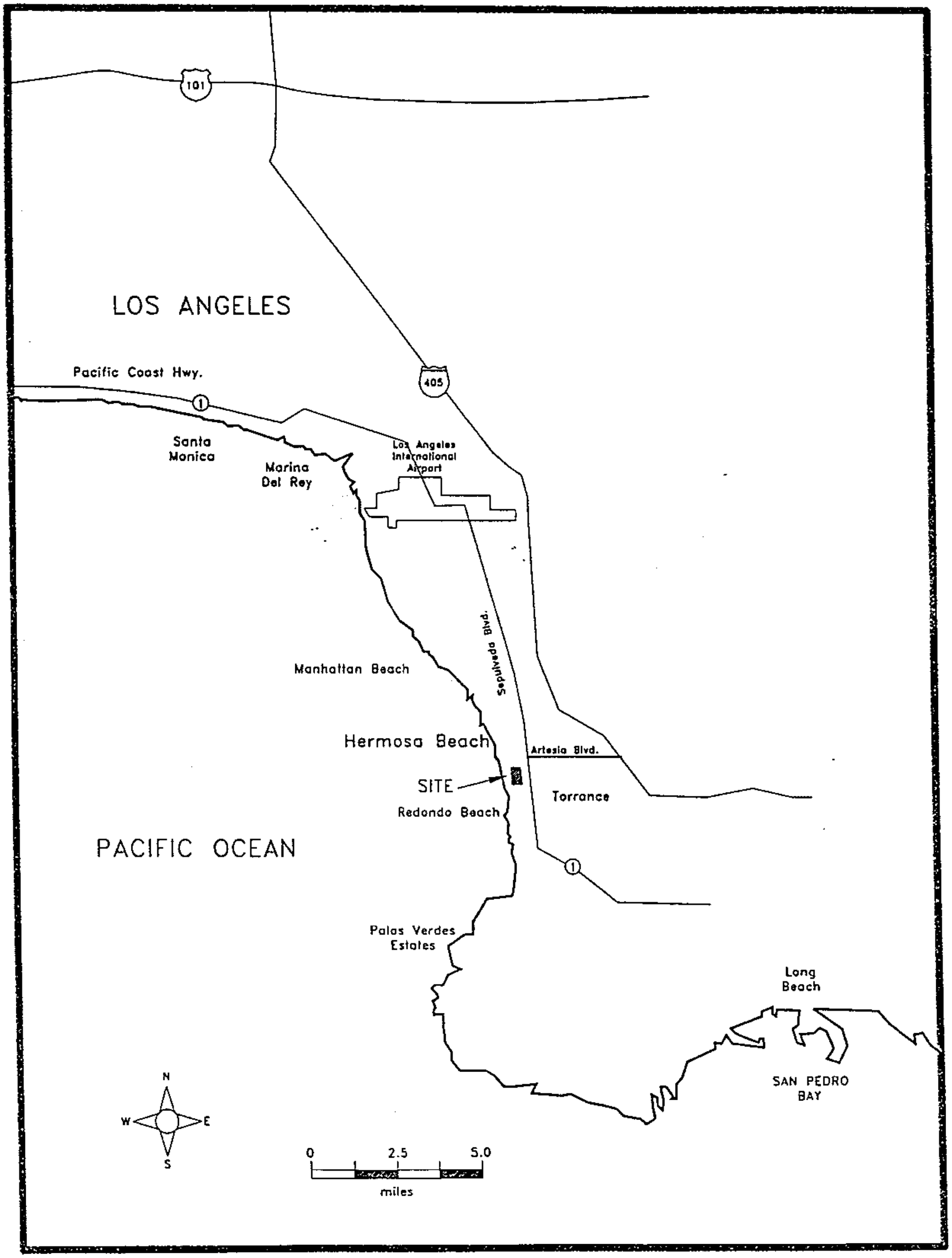


Figure 1.1
Hermosa Beach Location Map

department site at 555 6th Street, known as the "city yard." Figure 1.2 [24] shows an aerial photograph of this site and its surroundings.

The project itself will consist of two phases as follows:

- Phase 1 Test Phase
- Phase 2 Production Phase

The test phase will consist of the following principal components:

- Exploration/production wells
- Water injection well
- Temporary production facilities
- Temporary storage facilities
- Trucking operation

The production phase will consist of the following principal components:

- Production wells
- Water injection wells
- Production facility
- Storage facilities
- Oil and gas pipelines

The block diagram in Figure 1.3 shows these components for each of the two phases.

1.3 Objectives of the Present Work

The objectives of the present work may be summarized as follows:

- To quantify the acute risk to the public from the test and production phases of the proposed Hermosa Beach MacPherson Oil Project
- To consider the effect of proposed mitigation measures and quantify the risk with the mitigation measures in place
- To recommend any additional mitigation measures which may be feasible to reduce the risk to As Low As Reasonably Practicable
- To quantify the expected low-level H_2S emissions and to present a summary of the scientific literature available on risks associated with low-level H_2S emissions

1.4 Risk Analysis Methodology

What is risk? Risk is a compound measure of the probability and magnitude of adverse effect [36]. That is, risk is a description of the chances of something bad happening and how bad it will be. It is important to keep in mind that there are always these two elements of risk; namely, the probability or likelihood and the size or magnitude of the

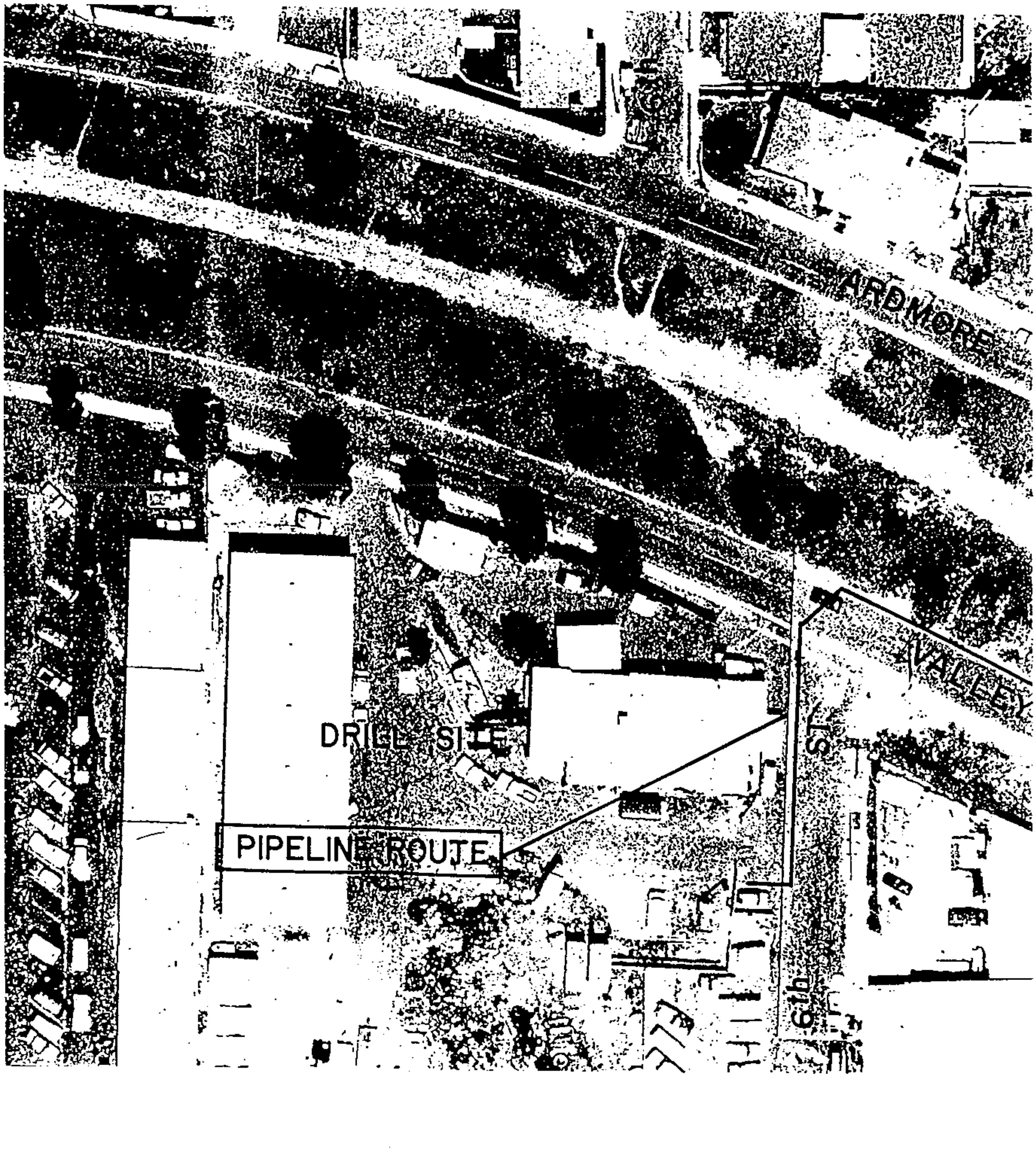
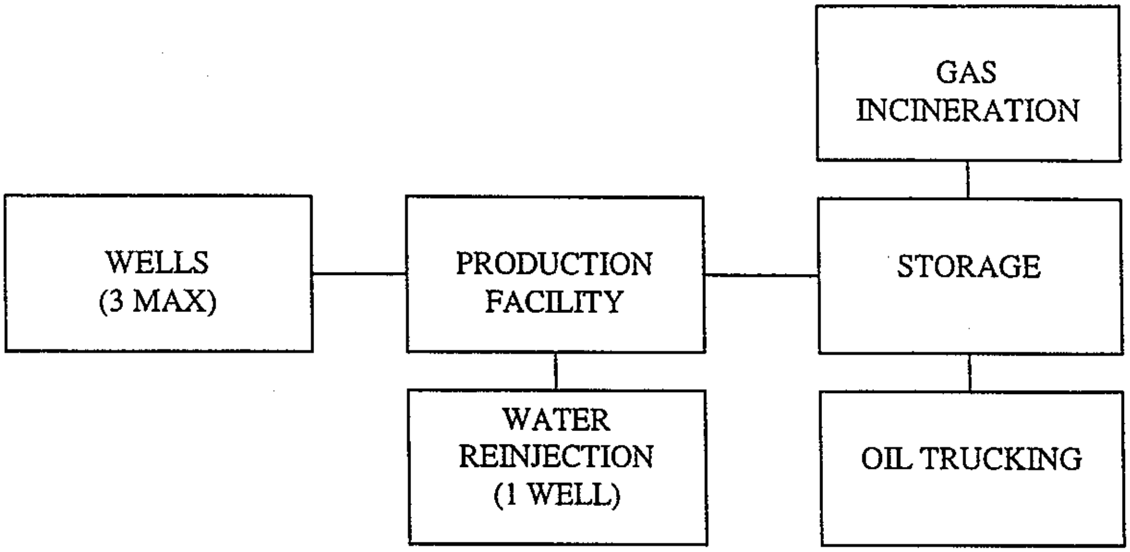
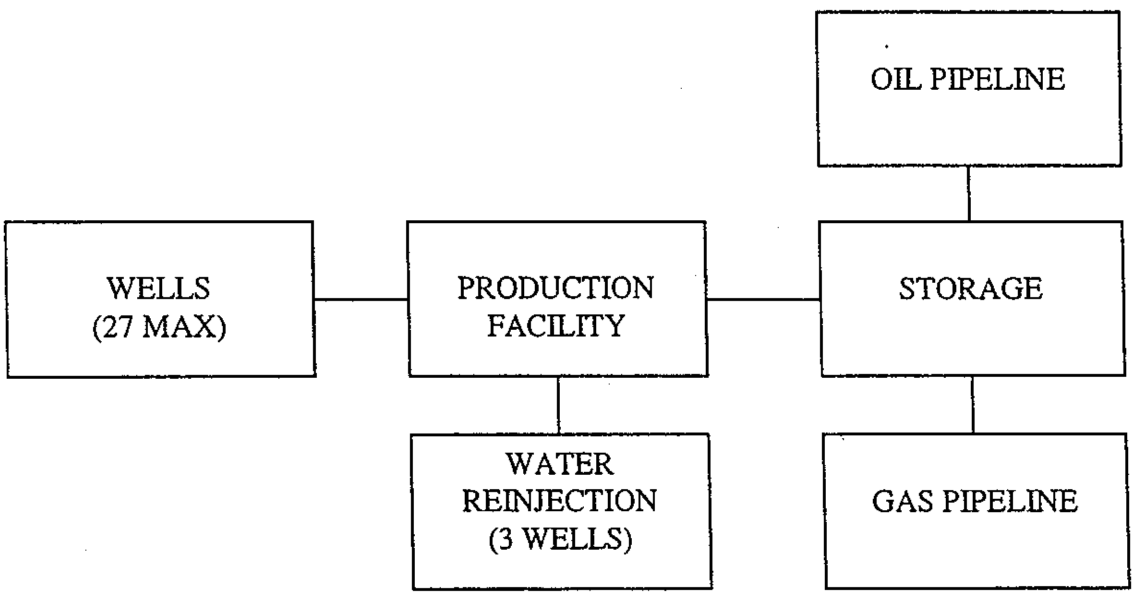


Figure 1.2
Aerial Photograph of Site



Test Phase Schematic



Production Phase Schematic

Figure 1.3
Project Components

associated damage or loss.

Risk analysis is an orderly process through which one can quantify risk as well as methods of reducing the risk. Methods of risk reduction are termed "risk mitigation".

The risk analysis process consists of three principal steps and various sub-steps illustrated in Figure 1.4. The three principal steps are hazard analysis, consequence analysis, and risk assessment.

In hazard analysis, essentially one determines the characteristics of the situation (**System Data**) which can pose a danger to the public, and how often it is likely to occur. This is called **Hazard Scenario Development** and **Frequency Analysis**. For example, for the case of a propane tank, in hazard analysis one would assess the ways in which the tank can fail, how much hazardous material could be released, and how often this is likely to happen.

In **Consequence Analysis**, one then models the evolution of consequences. First one finds the relative likelihood of different outcomes of the release, using event trees. This is called **Consequence Evolution**. That is, for the propane release what is the relative likelihood of ignition and non-ignition, and if there is ignition how likely is a jet fire, flash fire, or explosion? And if these happen, what are the Damage Criteria, or Effect Footprints. Next, our maps the zones in which damage to people could occur if they were present.

In the risk assessment, the results of the hazard analysis and the consequence analysis are melded, by considering the actual number of people expected (Receptors) in areas where they could be damaged and at the times when such damaging events could occur. The results are then integrated into Risk Assessment to provide measures of risk.

Measures of risk to people are primarily individual risk and collective risk. Individual risk describes the risk to an individual from a given project, while collective or societal risk is the likelihood of different numbers of people being affected by a project. Both individual and collective risks are generally given as an annual or per annum number of casualties.

Finally, the proactive portion of the risk analysis is performed through the definition of ways of reducing the risks and assessing just how much risk reduction can be achieved if these different **Risk Mitigation** measures are applied. Following the definition of risk mitigation measures, and their effect on the unmitigated risk, the resultant or mitigated risk results for both individual and collective risk can be presented.

The risk analysis process described above typifies the steps in assessing acute risk; assessment of chronic or long-term cumulative risks follows a similar pattern but employs somewhat different terminology within a toxicological framework.

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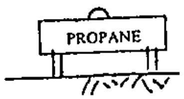
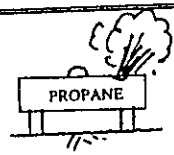
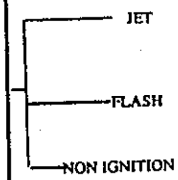
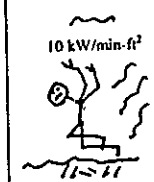
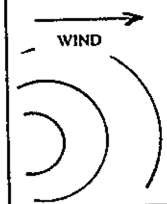
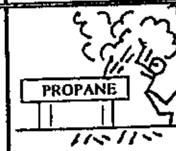
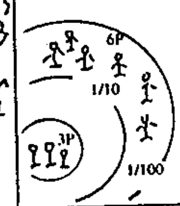
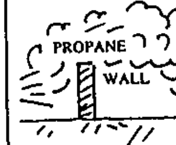
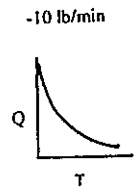
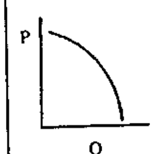
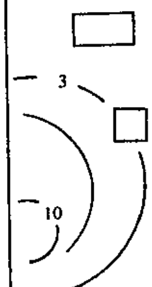
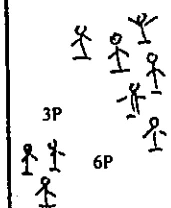
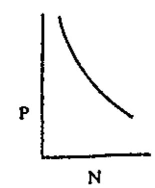
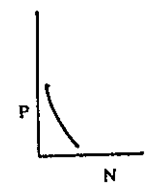
	HAZARD ANALYSIS			CONSEQUENCE ANALYSIS			RISK ASSESSMENT		
STEP	SYSTEM DATA	SCENARIO DEVELOPMENT	FREQUENCY ANALYSIS	CONSEQUENCE EVOLUTION	DAMAGE CRITERIA	EFFECT FOOTPRINTS	RECEPTORS	RISK ASSESSMENT	RISK MITIGATION
EXAMPLE			L 1/10 H 1/100 R 1/1000						
ANALYSIS PROCESS	SYSTEM PARAMETERS	HAZARD SCENARIO	ANNUAL FREQUENCY STATISTICS	EVENT TREES	DAMAGE CRITERION	MATH OR PHYSICAL MODEL	POPULATION RESOURCE DATA MAP	COMBINE RESULT OF ALL PREVIOUS STEPS	REPEAT RISK ANALYSIS FOR MITIGATED CONFIG.
RESULT	PROBLEM QUANTIFICATION	SIZE, TIME DESCRIPTION	FREQUENCY MAGNITUDE RELATION	CONDITIONAL PROBABILITY OF OUTCOMES	TIME MAGNITUDE EFFECT SPECTRUM	MAP OF HAZARDOUS EFFECTS	POPULATION TIME/SPACE DISTRIBUTION	INDIVIDUAL AND COLLECTIVE RISK	MITIGATED RISK
RESULT EXAMPLE	V = 500 gal. p = 200 psi T = 80° F			ROO JET 0.2 FLASH 0.3 NON IG. 0.5 .10	10kW/mi-ft² 60sec. 5% fatality		 OISR = .10		

Figure 1.4
Risk Analysis Process

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1.5 Scope of Work

The scope of work has been subdivided into seven principal tasks, related as shown in Figure 1.5, and associated sub-tasks as follows pertaining to Project Test and Production Phases and to a limited degree for the existing facilities:

Task 1 Data Acquisition

a) Project data
b) Environmental and population data
c) Site visit data assimilation
d) Detailed review of previous studies and background information
e) Review of literature on sour gas chronic risks

Task 2 Hazard Scenario Development

a) Definition of project components
b) Detailed definition of hazard scenarios for each project component
c) Quantification of release conditions (volume, pressure duration) associated with hazard scenarios

Task 3 Frequency Analysis

a) Probability assessment for each hazard scenario
b) Frequency distribution for leak, hole, and rupture
c) Additional consideration of specific conditions at facilities, eg pipeline route, Test Phase temporary systems, and Production Phase facilities
d) Evaluation of effect on frequencies of specific conditions identified above

Task 4 Consequence Analysis

a) Quantification of release rates for all scenarios
b) Selection of representative (day and night) atmospheric conditions, and identification, by sensitivity studies, of worst case conditions for leak, hole, and rupture
c) Qualitative evaluation of dispersion effects considering buoyant plume behavior and topography
d) Modelling of atmospheric concentrations and spill characteristic distributions for characteristic locations and release sizes for all scenarios for representative and worst case atmospheric conditions
e) Selection of damage criteria for thermal, toxic, overpressure, and nuisance effects
f) Modelling of thermal, toxic, overpressure, and nuisance hazard zones for all scenarios
g) Modelling of low-level sour gas ground level concentrations for representative releases

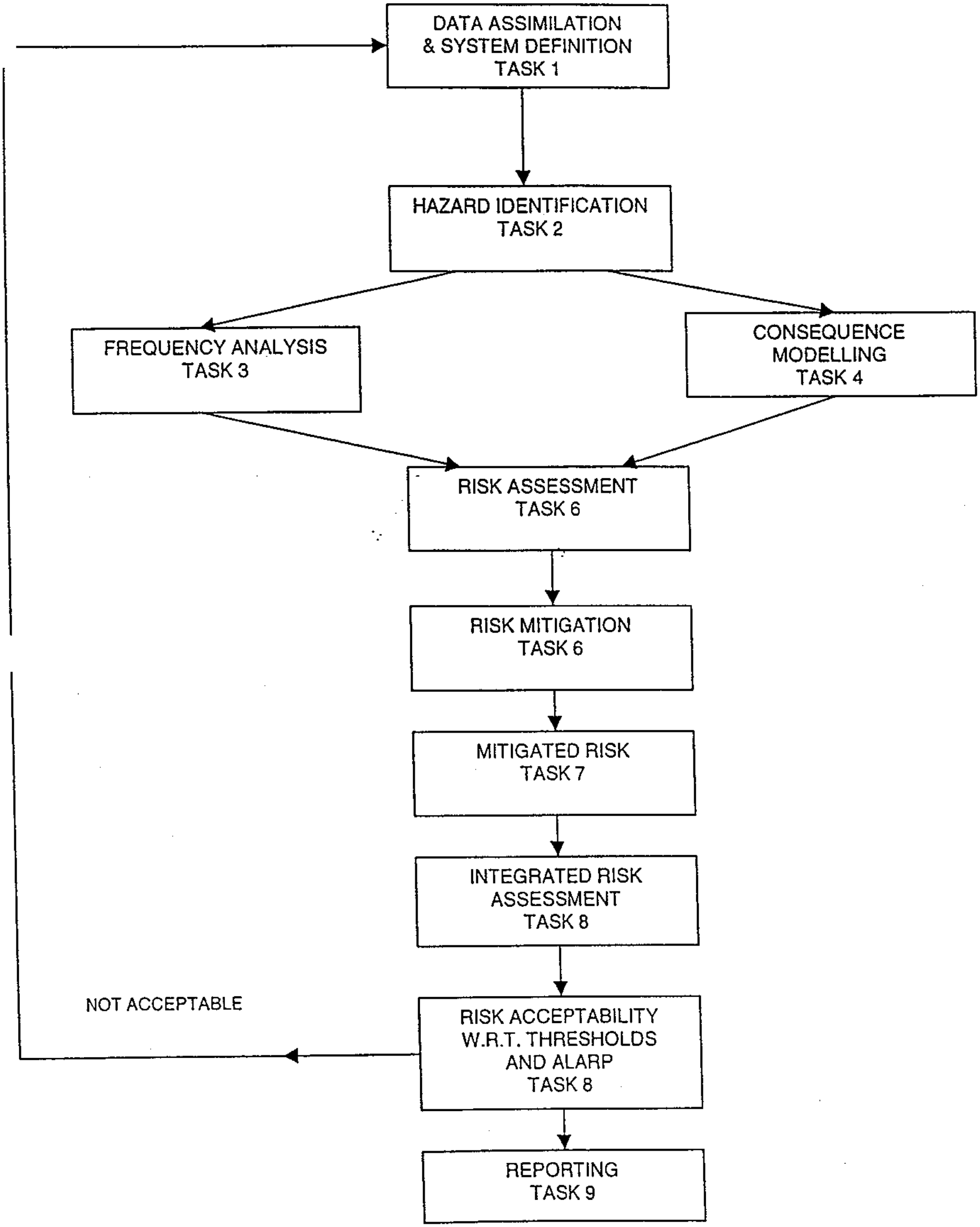

Figure 1.5
Work Flow Diagram

1.6 Outline of Report

The organization of the report generally follows the principal steps of the risk analysis process. Accordingly, following this brief introduction, the report is organized as follows:

- Chapter 2 - Project Information and Background
- Chapter 3 - Hazard and Frequency Analysis
- Chapter 4 - Consequence Analysis
- Chapter 5 - Unmitigated Risk
- Chapter 6 - Risk Mitigation
- Chapter 7 - Mitigated Risks
- Chapter 8 - Integrated Risk Analysis
- Chapter 9 - Conclusions and Recommendations

In addition, at the outset of the report, is given an Executive Summary, giving the salient details and results of the work, while the references are given following Chapter 9. A Glossary of Terms is given immediately after the Tables of Contents.

Task 5 **Unmitigated Risk Assessment**

a) Evaluation of individual risk in vicinity of facilities and presentation of results as hazard footprints

b) Evaluation of individual risk along pipeline route and presentation of individual risk in the form of risk transects

c) Definition of population distribution and location and characteristic of sensitive population foci within the IR isopleths for the facilities and transects for the pipeline. Consideration of future population forecasts for Production Phase

d) Evaluation of collective risk for estimated population distribution and population foci and presentation of collective risk as individual specific risks (ISR) and risk spectra

e) Assessment of acceptability of risks identified in Task 4 based on ISR and risk spectrum. Consideration of appropriate adjustments for Test Phase short term and Production Phase long term exposure.

Task 6 **Risk Mitigation**

a) Review of proposed and industry standard risk mitigation measures and their effect on the risks assessed.

b) Identification of any areas requiring further risk mitigation, and recommendation of associated risk mitigation measures.

c) Recommendation of optimal set of new risk mitigation measures

Task 7 **Mitigated Risk Assessment**

a) Estimation of resultant risk with risk mitigation measures in place

b) Presentation of resultant risks as individual risk spectrum.

Task 8 **Integrated Risk Assessment**

a) Integration of component risks of each phase

b) Presentation of resultant (mitigated) risks as individual risk, and risk spectrum for fatalities and injuries

c) Recommendations on risk acceptability by comparison to Santa Barbara risk spectral thresholds for societal risks and international standards for individual risk

d) Presentation of cumulative risks over project lifetime for project

Task 9 **Reporting**

a) Progress Report

b) Final Report

CHAPTER 2

PROJECT INFORMATION AND BACKGROUND

2.1 Project Information Requirements for Integrated Risk Assessment

The following general categories of information on the project and its setting are required to conduct the integrated risk assessment:

- Site characteristics
- Engineering information
- Environmental data
- Public population distributions

In addition, criteria for damage to people (from explosions, fires, and toxicity) and standards for acceptable levels of risk should be selected in order to provide meaningful outputs from the analysis. Specifically, damage criteria give quantitative values for limits on dosages which can cause serious injuries or death to people. Acceptability criteria, on the other hand, give quantitative thresholds for risk levels which may be deemed acceptable in certain jurisdictions. For example, the U.K. Health & Safety Executive [32] considers an individual specific risk level of 1 in 10 million chances of a fatality per year to be insignificant.

2.2 Site Description

The subject site is a 1.3 acre site located at the northwest quadrant of the intersection of Valley Drive and 6th Street. It is currently used as the city yard, and accommodates several industrial buildings, subterranean gasoline and diesel tanks, diesel and automobile gas pumps, and an above grade propane tank. The authors conducted several site visits, assimilating site specific data and conducting various types of inventories both on population and traffic patterns. Figure 2.1 shows an aerial photograph of the site while Figures 2.2 to 2.5 show characteristics of the immediate vicinity of the site. The site is relatively flat, sloping slightly from east to west in consonance with the prevailing gradient in the area. To the east, directly across from Valley Road is a park area, a former railway right-of-way and following Ardmore Avenue, there is a gradual ascent of the terrain to the Pacific Highway. To the west, the gradient is downwards, to Loma Road, and then gradually rises westwards to a ridge followed by a continuous slope to the seashore. For the purposes of the present investigation, the north-south gradient across the site and its neighborhood may be considered negligible. Surrounding land use is commercial and residential, as described subsequently in Section 2.4.

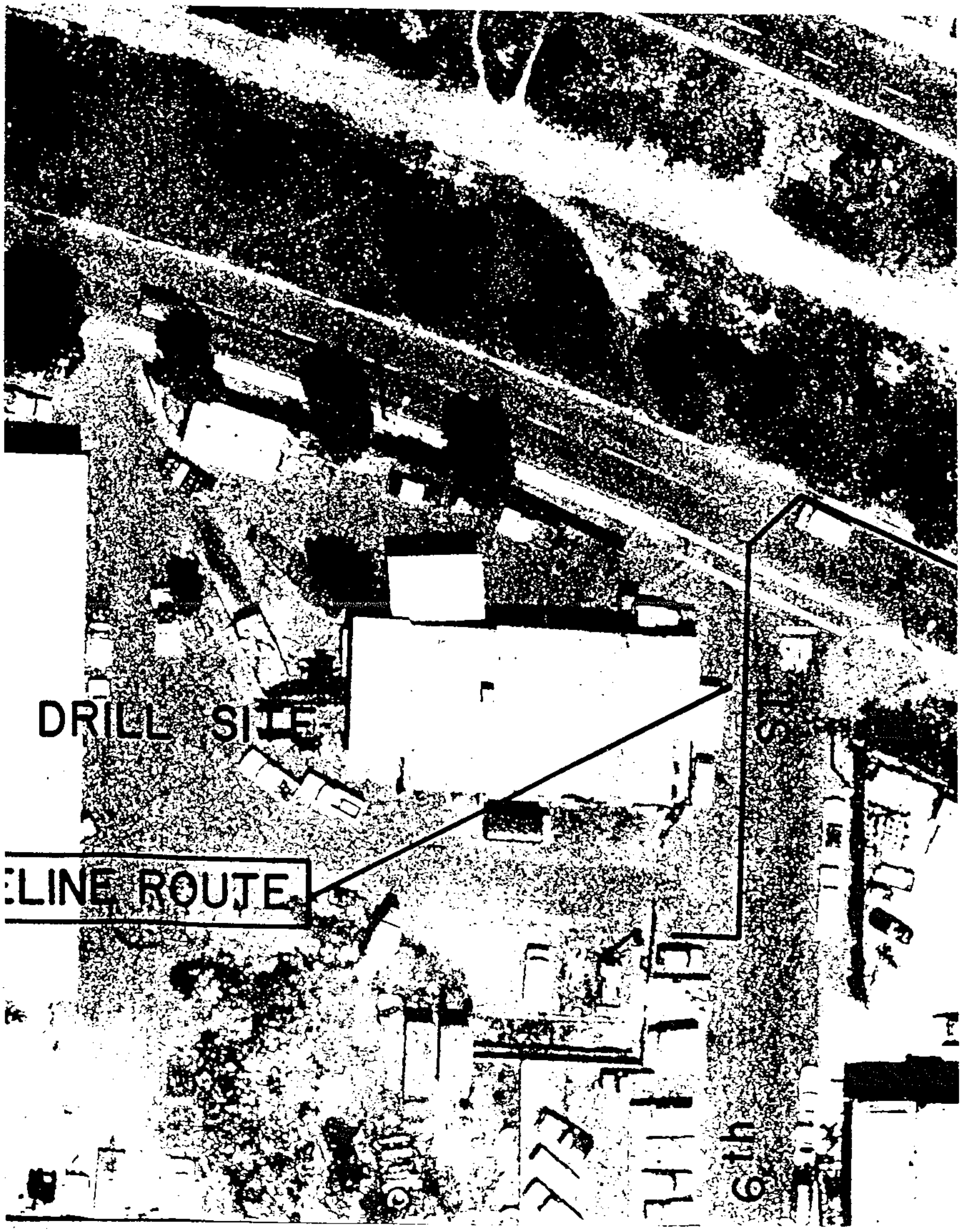

Figure 2.1
Aerial Photograph of Site

Figure 2.2
View East from Site

Figure 2.3
View West from Site

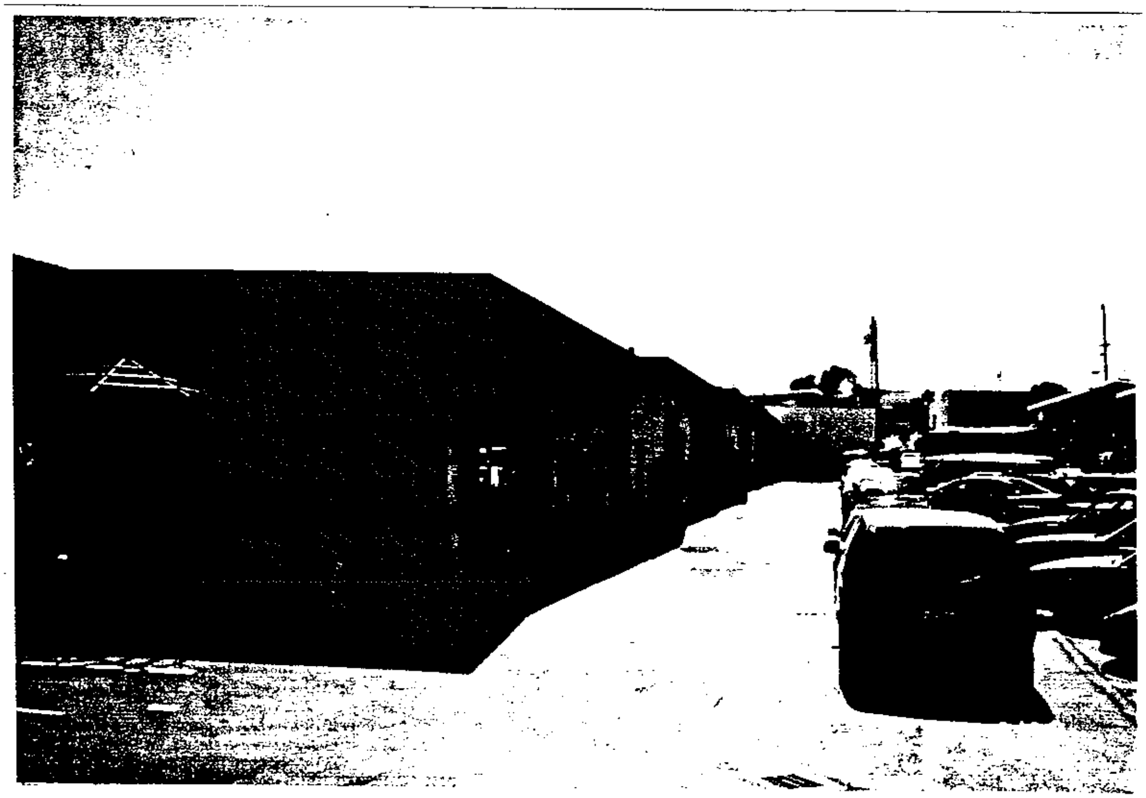

Figure 2.4
Commercial Buildings on **North Side of Site**

Figure 2.5
Commercial **Buildings South of Side**

2.3 Engineering Information

The engineering information was obtained primarily from MacPherson [29, 30, 39, 47] and supporting reports [18, 22, 37, 42]. Data on existing facilities was obtained from the city of Hermosa Beach [15, 24].

As was indicated in the general project description in Chapter 1, the proposed project is subdivided into two principal phases, namely, Phase 1, the Test Phase; and Phase 2, the Production Phase. These two phases, and the existing facilities at the site are described in the balance of this section.

2.3.1 Phase 1 - Test Phase

Phase 1 will last approximately one year. During this time, MacPherson proposes to drill up to three exploratory wells to prove the commercial value of the development. The drill rig onsite for the one year exploratory phase will stand approximately 135 feet above grade and will operate continuously during Phase 1.

Prior to drilling, MacPherson will demolish all existing maintenance yard facilities (except for a metal building located on the northeast corner of the property), and remove all paving, concrete slabs, retaining walls and debris. Phase 1 preliminary construction will include re-grading of the site (3,000 cubic yards of cut; 1,000 cubic yards of fill), installation of a 9-foot concrete block retaining wall on the west side of the parcel, a 6-foot chainlink fence topped by three-strand barbed wire on the remaining three sides of the project (these sides are separated from other development by a street's width), and a 30-foot-above-grade sound attenuation wall, a concrete well cellar, new electrical service equipment, and temporary treatment and production facilities. Figure 2.6 shows the Test Phase general layout.

If Phase 1 is unsuccessful, MacPherson Oil will remove all above-ground facilities, abandon the test well in accordance with the requirements of the State Division of Oil, Gas and Geothermal Resources, and otherwise restore the site to its pre-project condition. MacPherson must also seek a new coastal development permit for post-Phase 1 abandonment.

During Phase 1, the produced emulsion (oil and water mixture) will be processed onsite using portable equipment. All produced water will be re-injected; produced water will not be disposed via the public sewer or storm drain systems. Oil will be stored onsite in portable tanks, and the oil will be trucked offsite to a refinery via three to four tanker truck trips per day, each carrying 175 barrels of oil. Trucks will not deviate from the designated route.

MacPherson proposes to flare the produced gas during Phase 1 and has obtained the necessary approvals for flaring from the South Coast Air Quality Management District. MacPherson also agrees that permissible concentrations of hydrogen

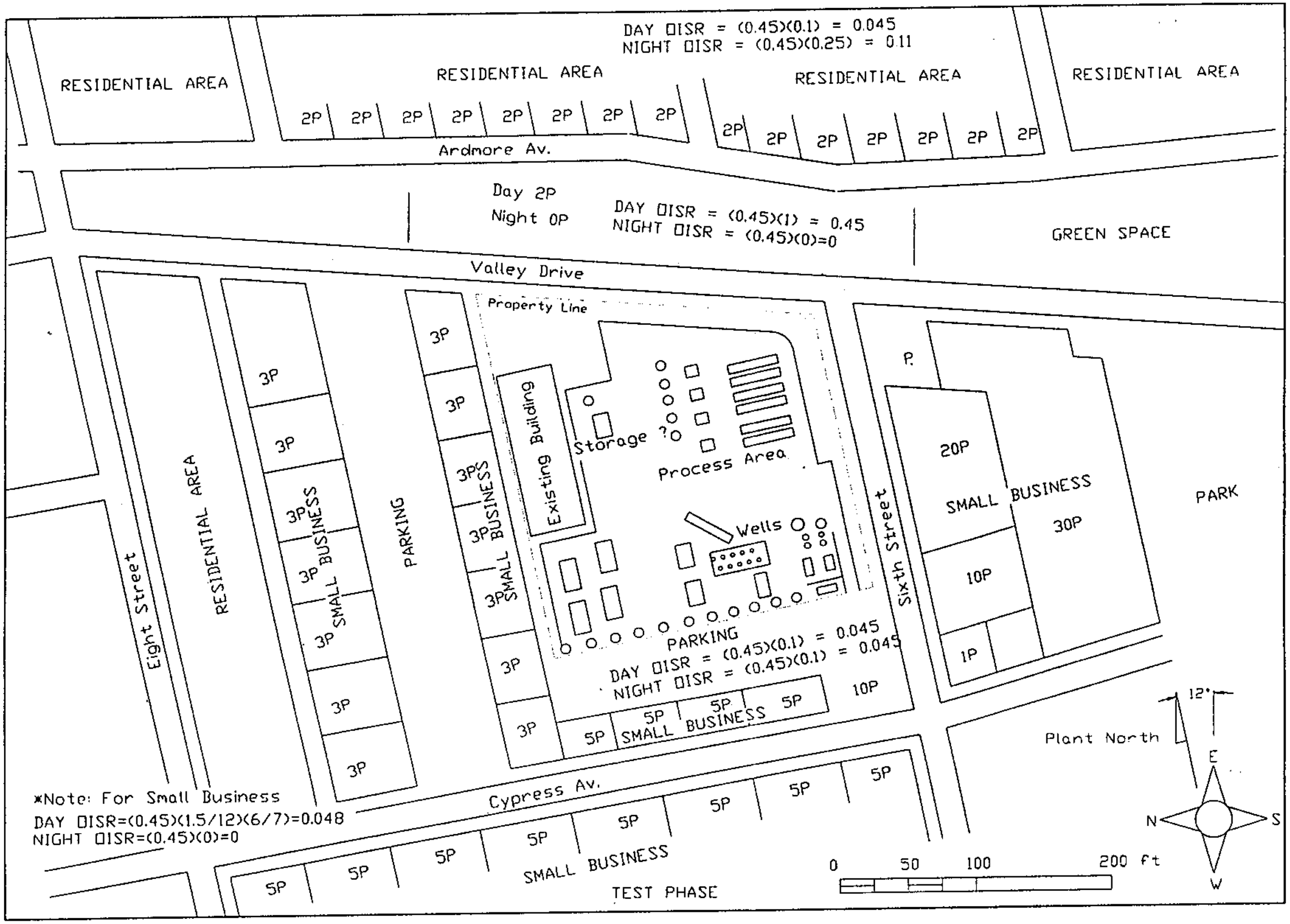

Figure 2.6
Test Phase General Layout

sulfide in raw gas (that is, gas in an untreated state as it is drawn into the well casing) will be restricted to a maximum of 40 parts per million (ppm) in any well, during both phases of the project. MacPherson agrees to stop production of any well that exceeds the hydrogen sulfide threshold authorized by this permit.

MacPherson estimates that Phase 1 crude oil production from the (up to) three test wells will be a maximum of approximately 600 barrels per day and natural gas production will be approximately 125,000 standard cubic feet per day.

2.3.2 *Phase 2 - Production Phase*

Phase 2 includes the installation of up to 27 additional oil and gas wells, three waste water disposal wells, a tank farm with five oil storage tanks, permanent processing equipment (to separate oil, natural gas, and water), additional fencing and landscape elements, electrical transformers and switches, and other ancillary structures. Figure 2.7 shows a schematic of the layout of the production site.

The drill rig for Phase 2 will be of the same height as the drill rig proposed for use during Phase 1 (approximately 135 feet above grade) and will be onsite continuously for up to three years during well completion. Workover rigs of approximately 110 feet in height will be used for well maintenance up to three months of every year thereafter for the life of the project. Thus, drilling and workover rigs of this general scale would be onsite for a cumulative total of approximately twelve years during the project's 35-year projected economic life.

The sound attenuation wall constructed during Phase 1 will be augmented during Phase 2 by a 12-foot decorative masonry perimeter wall, installation of permanent landscape plantings, and the removal of the chain link fencing.

During Phase 2, MacPherson will install two new pipelines - a 6-inch crude oil line and a 4-inch gas - each approximately ½ mile (2,500 feet) long. The pipelines will connect to crude oil and natural gas transportation systems owned by Southern California Edison. MacPherson proposes to transport all produced oil and gas offsite via these pipelines during Phase 2. MacPherson does not propose to continue truck transportation of oil or gas, or the non-emergency flaring of gas during Phase 2.

The crude oil delivered via pipeline to the Southern California Edison (SCE) Redondo Beach storage facility and pipeline system. MacPherson proposes to construct onsite oil storage facilities of sufficient capacity to contain produced oil onsite during routine or emergency interruptions of the pipeline.

2.3.3 *Existing Facilities*

Figure 2.8 shows the site as currently used by the City of Hermosa Beach as a maintenance operation facility. The operations include a variety of activities

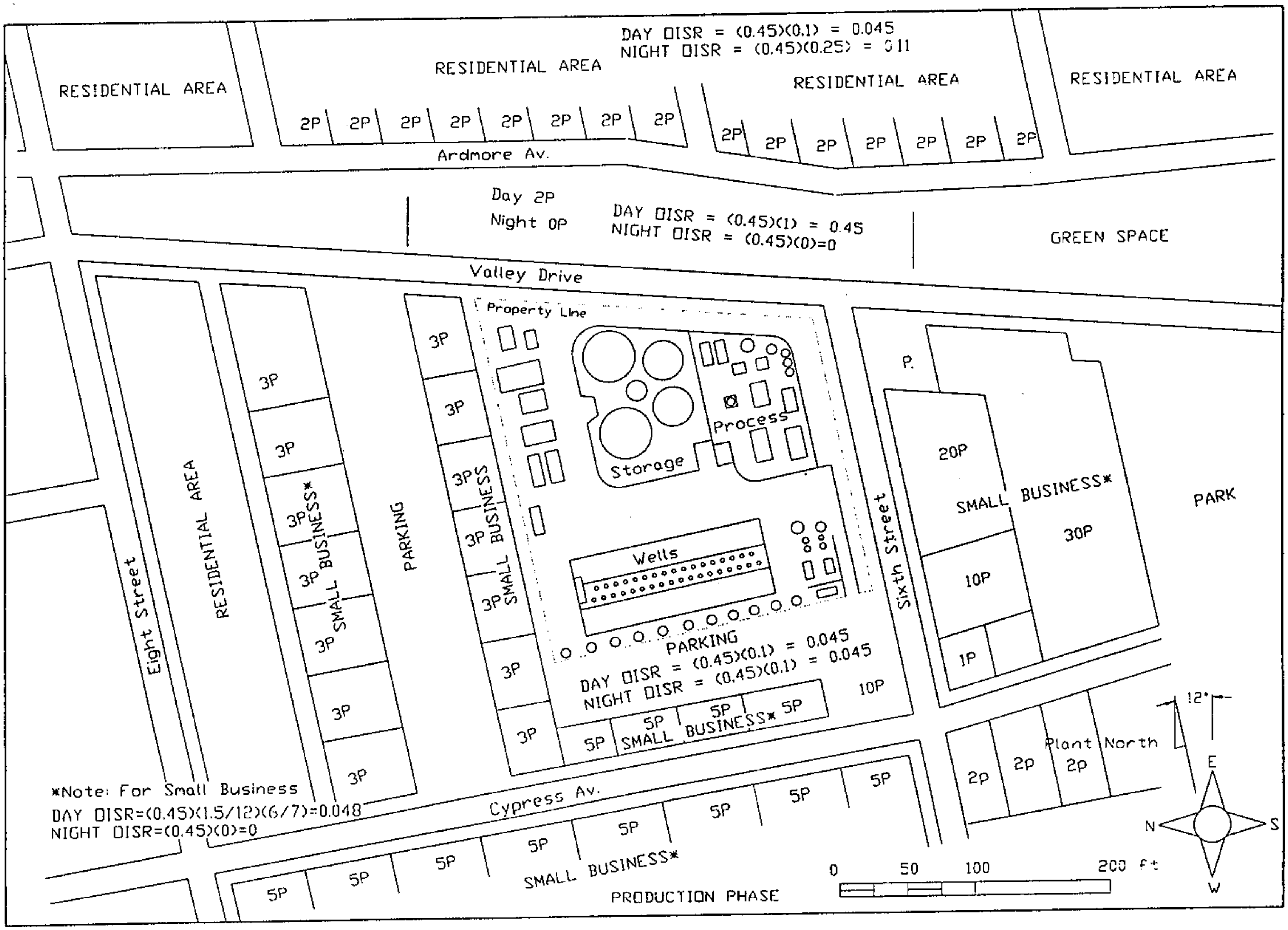

Figure 2.7

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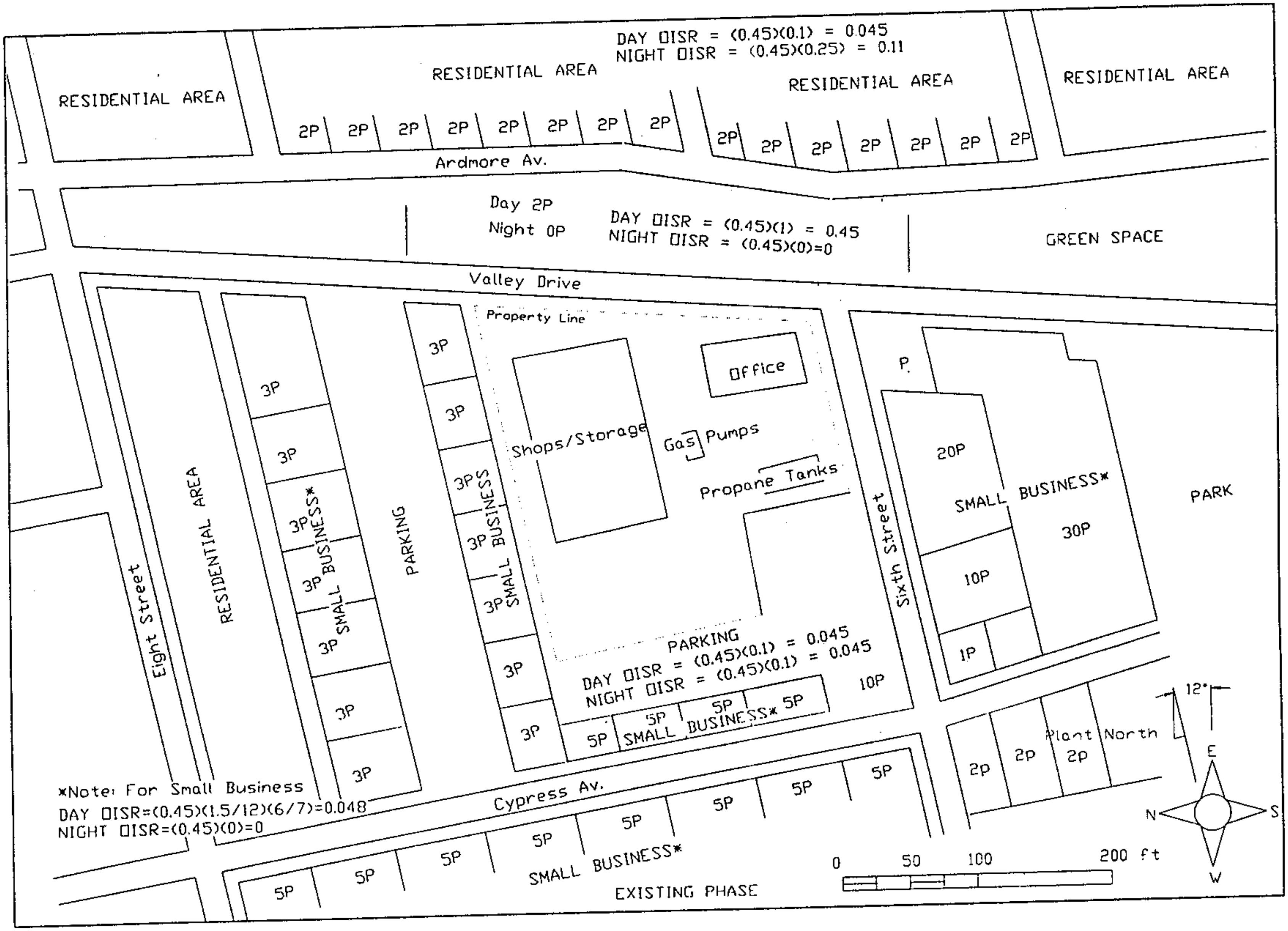

Figure 2.8
Existing Facilities Layout

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such as repair and maintenance of vehicles, storage of materials, supplies, and equipment; a workplace for city workers who repair and maintain facilities and equipment in the city; and for storage and painting of signs. The following materials and activities are associated with potential hazards [15]:

- 50 vehicle round trips per day
- 500 gallon above-grade storage tank for propane with a maximum operating pressure of 200 psi
- 8000 gallon subterranean gasoline storage tank
- 2000 gallon subterranean diesel storage tank
- Propane, gasoline, and diesel surface vehicle loading pumps
- Acetone
- Paint Thinner
- Various solvents and paints

2.4 Population Distributions

The population distributions were obtained from the City of Hermosa Beach [16] as well as from direct census for some of the transient population distribution such as the railway right-of-way utilization as well as the park utilization. Figure 2.8 used earlier, to describe the existing facilities shows the population distribution in the vicinity of the site. As may be seen, the site is surrounded on all four sides by areas utilized by the public for residential, commercial, or recreational purposes. Immediately to the east, across Valley Road is a green space which is routinely used by joggers and walkers. Further east, across Ardmore Avenue, is a medium density residential area, in which residential units have been characterized by an average occupancy of 2 persons, in accordance with advice from the City of Hermosa Beach [16]. To the west, across the fence is a parking area, followed by a small business area in which occupancy has been characterized by 5 persons per business unit. A similar business or commercial occupancy appears on the west side of Cypress Avenue. To the north, again are small businesses, in this case characterized by 3 persons per business unit. To the south, across 6th Street, are a number of medium sized enterprises, with occupancy varying from a maximum of 30 to 1 person as noted in the schematic. Other areas are characterized by appropriate population distributions obtained during the population analysis.

Table 2.1 summarizes the population numbers described above, together with the associated parameters describing the amount of time spent at the location and the percentage of that time that people are outdoors and therefore more vulnerable to possible hazards from the proposed project. Specifically, Table 2.1 gives the type of population as residential, commercial, and transient. The table gives the amount of time spent at the location and outside as a proportion of the total possible time

The right hand column gives the product of the dwell time and outdoor time ratios to give the outdoor individual specific risk (OISR) factor. The total possible exposure time for 1 year is multiplied by this factor to give the expected time that an individual in the vicinity

Table 2.1
Population Distribution Around Proposed Site

POPULATION TYPE	DAYS PER WEEK	DAYTIME			NIGHTTIME		
		HOURS	OUTSIDE FRACTION	OISR FACTOR	HOURS	OUTSIDE FRACTION	OISR FACTOR
Residential	7	12	0.1	0.05	12	0.25	0.125
Commercial	6	12	0.125	0.054	0	-	0.0
Transient	7	12	1.0	0.50	0	-	0.0

of the project would be exposed to hazards to which she/he would be vulnerable only while they are outdoors.

2.5 Environmental Data

Environmental data required for the conduct of the integrated risk assessment includes atmospheric conditions, wind intensities and directions, air parameters including temperature, quality, density, and general physical geographical data.

Data on atmospheric conditions and wind directions was obtained from the National Weather Service data for the nearest weather station located at Redondo Beach. The data give the distribution of wind directions for 16 compass directions, for each of 7 stability classes as well as summaries for the representative unstable (A, B, C) and stable (E, F, G) atmospheric stability classes. Wind intensities are also given for intensity intervals of 1 m/s, from 0 to 6 m/s. Analysis of these data for representative stable and unstable conditions is shown in Table 2.2, while their reduction to 8 directions for the two representative classes is shown in Table 2.3.

Further studies, to be described in the chapter on consequence modelling, were conducted on these data to establish the worst case atmosphere which was found to be in the wind intensity category between 0 and 1 m/s. However, the establishment of the worst case situation required the application of consequence dispersion modelling through a series of sensitivity studies to isolate the atmospheric conditions giving the largest hazard footprints for releases characterized by leaks, holes, and ruptures in the process and piping equipment.

2.6 Acute Damage Criteria

2.6.1 General Description of Damage Criteria

Damage criteria are used to quantify the dosage or effect level for which lethality or severe injury will occur to most exposed people. In the conduct of risk analysis, zones delineating the extremities of areas in which individuals who are exposed are likely to be injured or killed are defined in accordance with certain dosages or damage effect levels. For example, in a location where an explosion overpressure reaches a level of 15 psi, 99%, or virtually all persons who are unprotected outdoors are likely to be killed due to direct blast effects. The damage criteria, then, give the probability of lethality or injury for average individuals exposed to a single incident of a specific effect such as blast overpressure. It should be noted that the damage criteria given in this section pertain to acute or immediate effects as opposed to long-term cumulative effects from continued or repeated exposure. The latter effects are termed chronic; the ones largely studied in the present risk assessment are acute effects. A discussion of chronic effects is given in Section 2.8.

Table 2.2
Wind Frequency Distribution
Redondo Beach
81-01-01 to 81-12-31

PASQUILL STABILITY CLASS	FREQUENCY OF OCCURRENCE FOR WIND TRAVELLING IN THIS DIRECTION (percent)															
	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE	S
A,B,C	0.13	0.18	0.61	1.02	1.14	0.57	0.17	0.34	1.08	6.30	8.65	3.33	0.74	0.19	0.05	0.17
E,F,G	0.64	0.79	3.42	5.71	2.48	0.86	0.39	0.73	3.62	6.29	5.94	4.67	1.48	0.43	0.26	0.74

Table 2.3
Summary of Wind Frequencies

TIME OF DAY (CLASS)	DIRECTION WIND TRAVELLING	DIRECTIONAL PROBABILITY, P_d
DAY (A, B, C)	N	0.04
	NE	0.46
	E	0.32
	SE	0.02
	S	0.01
	SW	0.02
	W	0.08
	NW	0.05
NIGHT (E, F, G)	N	0.06
	NE	0.26
	E	0.22
	SE	0.06
	S	0.07
	SW	0.07
	W	0.22
	NW	0.04

2.6.2 Thermal Effects

Following the ignition of a hydrocarbon release from equipment, fires and explosions which could potentially injure either the public or a worker may occur. For the purposes of the present risk analysis, fire effects for people were considered for either direct contact with the flame or exposure to injurious levels of thermal radiation. Direct contact with a fire, for example inside a vapour cloud, will often result in fatality. The vapour cloud lower flammability limit was used to define the fatality location. A probability of fatality of 50% was used for locations within a flash fire.

Thermal radiation hazards are not significant outside of the boundary of a short duration burning vapour cloud, but they are significant near a jet fire or a pool fire. A summary of selected effects of thermal radiation on both equipment and people is given in Table 2.4. Experimental data on thermal radiation hazards show that a thermal radiation level of 37.5 kW/m^2 is sufficient to cause damage to process equipment and 50% fatality within 20 seconds. A 10% fatality criterion of 12.5 kW/m^2 was used for the present risk analysis.

2.6.3 Explosion Effects

Explosion effects on people involve either direct exposure to overpressures or impact by missiles or collapsing objects resulting from the explosion. Empirical data on blast overpressure damage is used to estimate human effect criteria for vapour cloud or vessel overpressure explosions. A summary of effects for explosion overpressures on both equipment and people is given in Table 2.5. 99% fatality may be expected from direct human exposure to 15 psi blast overpressures. Buildings, however, will be seriously damaged if exposed to 2.8 psi overpressures and therefore people inside such buildings could die as a result of structural collapse as well as suffering from direct physiological overpressure injury. An overpressure criterion of 3.5 psi causing a 5% likelihood of fatality for exposed people was utilized for the present risk analysis.

2.6.4 Acute H_2S Damage Criteria

Hydrogen Sulphide gas is known to be physiologically damaging to humans when ingested by breathing. Quantitative assessments of the 2, 3, 26, 27, 28, 44] are restricted to acute or immediate effects; long-term or chronic effects are not unambiguously understood and continue to be a subject of controversy worldwide. The current investigation is restricted to the analysis of acute effects of H_2S. The nature of the damage due to exposure to a toxic gas depends on the concentration and exposure time and condition of the receptor.

Many useful measures are available to use as benchmarks for predicting the likelihood that a release event would result in serious injury or death. Some of the established [2] toxicologic criteria and methods to assess the magnitude of

Table 2.4
Effect of Thermal Radiation

RADIATION INTENSITY		OBSERVED EFFECT
(kW/m²)	(BTU/ft²hr)	
37.5	11887	Sufficient to cause damage to process equipment. 50% fatality after 20 seconds.
25	7925	Minimum energy required to ignite wood. 50% fatality after 60 seconds.
12.5	3960	Melting of plastic tubing. 10% fatality after 60 seconds.
9.5	3000	Pain threshold reached after 8 s; second degree burns after 20 s; 1% lethality after 60 seconds.
6.3	2000	Sufficient to cause pain to personnel if unable to reach cover within 20 s; however blistering of the skin (second degree burns) is likely; 0% lethality.
1.9	600	Will cause no discomfort for long exposure.

Table 2.5
Effects from Explosion Overpressures

OVERPRESSURE			OBSERVED EFFECT
(Bars)	(kPa)	(psi)	
.02	2	.3	Typical pressure for 10% glass failure. Safe distance.
.07	7	1.0	Partial demolition of houses; made uninhabitable
.2	20	2.8	Non-reinforced concrete or cinder block walls destroyed. (1% fatality)
.25	25	3.5	Steel buildings collapse (90% eardrum rupture) (5% fatality)
.35	35	5.0	Wooden utility poles snapped; buildings destroyed (10% fatality)
1.0	100	15.0	Range for 99% fatalities among exposed populations due to direct blast effects.

damage to humans from exposure to toxic gases such as H_2S include the following:

- Emergency Response Planning Guidelines for Air Contaminants (ERPGs) issued by the American Industrial Hygiene Association (AIHA)
- Immediately Dangerous to Life or Health (IDLH) Levels established by the National Institute for Occupational Safety and Health (NIOSH)
- Emergency Exposure Guidance Levels (EEGLs) and Short-Term Public Emergency Guidance Levels (SPEGLs) issued by the National Academy of Sciences/National Research Council
- Threshold Limit Values (TLVs) established by the American Conference of Governmental Industrial Hygienists (ACGIH) including Short-Term Exposure Limits (STELs) and ceiling concentrations
- Permissible Exposure Limits (PELs) promulgated by the Occupational Safety and Health Administration (OSHA)
- Alberta Energy Resource Conservation Board (AERCB) L50 Toxic Load
- Probit functions

In the present study, a combination of some of the above guidelines together with probit functions to assess the likelihood of lethality have been utilized.

For a number of commonly known toxic substances, there exists information on dose-response relationships that can be applied to quantify the number of fatalities that are likely occur with a given exposure. Finally, probit relationships for specific substances are based on experimental animal data, resulting in some uncertainty around risk estimates in applications to human populations. Once an adequate dispersion model has been applied to give time-concentration zones, it is possible to apply a probit function to obtain additional information on the lethality of the release for substances which have been documented in the form for application to the probit method. The probit method uses a logarithmic expression to obtain a probit value, P_r, in the form:

$$P_r = a + b\log_e(C^n t) \qquad \textbf{(2.1)}$$

where, a, b, and n are constants given in Table 2.6, C is the gas concentration in ppm, and t is the exposure time in minutes.

With this expression, the toxic dose for a percentage of fatalities of the exposed population can be determined using standard probit tables. Specifically, the necessary inputs for the probit analysis for H_2S are shown in Table 2.6, showing the probit constants for a number of substances including H_2S, and the transformation of the probit value to a percentage of lethality can be obtained from Table 2.7. For the purposes of the present risk analysis, certain established toxicological criteria from among those cited above were chosen, and the probit function was used to assess associated probabilities of lethality for input into the risk model. Specifically, the following three dosage criteria were chosen:

- IDHL (new) 100 ppm, 30 minutes
- ERPG-3, 100 ppm, 60 minutes
- IDLH (old), 300 ppm, 30 minutes
- ERCB L50, 700-1000 ppm, 5 minutes

Application of the probit equation with appropriate constants for H_2S gave probabilities of lethality of 0%, 1%, 5%, and 50%, respectively for these criteria. Table 2.8 summarizes these criteria together with the above-cited results.

2.6.5 Injury Damage Criteria

Although in most industrial accidents, more injuries than fatalities usually occur, injury damage criteria are not as readily available as fatality criteria. The American Institute of Chemical Engineers [3] suggests a ratio of fatalities to injuries ranging from 1 to 5 to 1 to 15. In the instance where large numbers of individuals are exposed to partially fatal effects, it is suggested that 10 injuries per fatality be utilized. Reports on recent grim events in Kenya and Ireland generally confirm the rates of 1 fatality to 10 injuries. In a situation where a limited number of individuals is exposed, it is suggested that injuries be considered 10 times as likely as fatalities.

2.7 Risk Thresholds

Risk is a combined measure of the probability and magnitude of adverse effect. Risk thresholds are a term generally used to designate the levels of risk which are acceptable in certain situations. Possible measures of risk include individual risk, risk expectations, and risk spectra. Individual risk is simply the probability that a given individual will become a casualty as a result of the project over a period of exposure of 1 year. Risk expectation can be described by the use of a risk matrix which relates various discreet levels of likelihood of occurrence and severity of consequences. A risk spectrum gives a continuous relationship between the probability of occurrence and a quantitative measure of the severity of consequences, such as the number of people killed. All three of these measures will be utilized in the assessment of risk under the present study.

2.7.1 Individual Risk Thresholds

Risk acceptability criteria are often based on the premise that the risk being evaluated should not make a substantial addition to the existing risk of everyday life. Table 2.9 lists risk levels associated with a variety of common activities. It should be noted that these activities are also distinguished according to voluntary and involuntary participation. Clearly, people are prepared to accept a higher level

Table 2.6
Constants for Lethal Toxicity Probit Equation

SUBSTANCE	a (ppm)	b (ppm)	n (min)
Ammonia	-35.9	1.85	2.00
Benzene	-109.78	5.3	2.00
Carbon Monoxide	-37.98	3.7	1.00
Chlorine	-8.29	0.92	2.00
Hydrogen cyanide	-29.42	3.008	1.43
Hydrogen Sulphide	-31.42	3.008	1.43
Methyl isocyanate	-5.642	1.637	0.653
Sulphur dioxide	-15.67	2.10	1.00

Table 2.7
Transformation of Probits to Lethality Percentages

%	0	2	4	6	8
0	--	2.95	3.25	3.45	3.59
10	3.72	3.82	3.92	4.01	4.08
20	4.16	4.23	4.29	4.36	4.42
30	4.48	4.53	4.59	4.64	4.69
40	4.75	4.80	4.85	4.90	4.95
50	5.00	5.05	5.10	5.15	5.20
60	5.25	5.31	5.36	5.41	5.47
70	5.52	5.58	5.64	5.71	5.77
80	5.84	5.92	5.99	6.08	6.18
90	6.28	6.41	6.55	6.75	7.05
99	7.33	7.41	7.46	7.65	7.88

Table 2.8
Acute H_2S Lethality Criteria

DISCRIPTION	C (ppm)	DURATION (min)	PROBABILITY OF LETHALITY
IDLH (new)	100	30	0%
ERPG-3	100	60	1%
IDLH(old)	300	30	5%
ERCB L50	700-1000	5	50%

Table 2.9
Common Individual Risks of Casualty

CAUSE*		INDIVIDUAL RISK PER MILLION (per year)
Motor Vehicle Accidents (total)	V	240.0
Home Accidents	V	110.0
Falls	V	62.0
Motor Vehicle Pedestrian Collisions	V	42.0
Drowning	V	36.0
Fires	I	28.0
Inhalation and Ingestion of Objects	I	15.0
Firearms	V	10.0
Accidental Poisoning:	I	
Gases and Vapors		7.7
Solids and Liquids		6.0
(Not drugs or medicaments)		
Electrocution	I	5.3
Tornadoes	I	0.6
Floods	I	0.6
Lightning	I	0.5
Tropical Cyclones and Hurricanes	I	0.3
Bites and Stings by Venomous Animals and Insects	I	0.2

* V denotes "Voluntary"; I, "Involuntary"

of risk from voluntary activities from which they derive a direct benefit (such as driving), and a lower level from involuntary risks such as living next to a gas plant, which give no immediately identifiable direct benefit. An increase of 1% or more in the individual risk of death, due to a specific hazardous activity, is the basis of many criteria of unacceptable or intolerable risk. Acceptable or tolerable risk criteria are a factor of 10 to 100 lower than those for unacceptable risks. In an area where risk lies between unacceptable and acceptable levels, risk reduction is desirable.

Tolerable or acceptable risk levels will vary with the benefits and costs. In between the unacceptable risk level and the acceptable risk level is the area where risks may or may not be tolerable depending on the situation. Risk in the grey area is generally acceptable only if all reasonably practical measures have already been taken to reduce it.

Individual risk is often expressed in terms of an annual probability of death for the exposed person or Individual Specific Risk (ISR). An annual probability (or chance) of death of 1 in 1,000,000 (or 10^6 per year) is often taken as a tolerable level. An annual probability of death of 1 in 10,000 (or 10^4 per year) is considered unacceptable.

In Canada, The Major Industrial Accident Council of Canada (MIACC) developed the risk acceptability criteria presented in Figure 2.9. Similar criteria are cited for the U.S. and several Western European countries [11, 52]. These criteria are reflected in terms of allowable land-uses for specified levels of individual risk. This approach implicitly provides a guideline for allowable societal risk in one simple statement. An annual individual fatality risk of 1 in 10,000 (or 10^{-4}) from the presence of a facility is considered unacceptable for a member of the general public, and the area defined by this risk contour is called the exclusion zone. A risk of less than 1 in 1,000,000 (or 10^{-6}) is considered negligible, and the use of land beyond this risk contour is not restricted by the presence of the facility.

2.7.2 *Risk Matrix Thresholds*

Figure 2.10 illustrates the Santa Barbara risk matrix [45]. The risk matrix is a semi-quantitative display of the severity and frequency of different adverse consequences with the areas of increasing significance in terms of risk depicted on Figure 2.10. Events within the shaded area are considered significant and must be mitigated. Numerous forms of the risk matrix have been used worldwide, based on the same principles as the County of Santa Barbara risk matrix.

Table 2.10 summarizes the criticality and frequency classifications that are given in the margins of the risk matrix given in Figure 2.10 together with a qualitative description for the frequency categories.

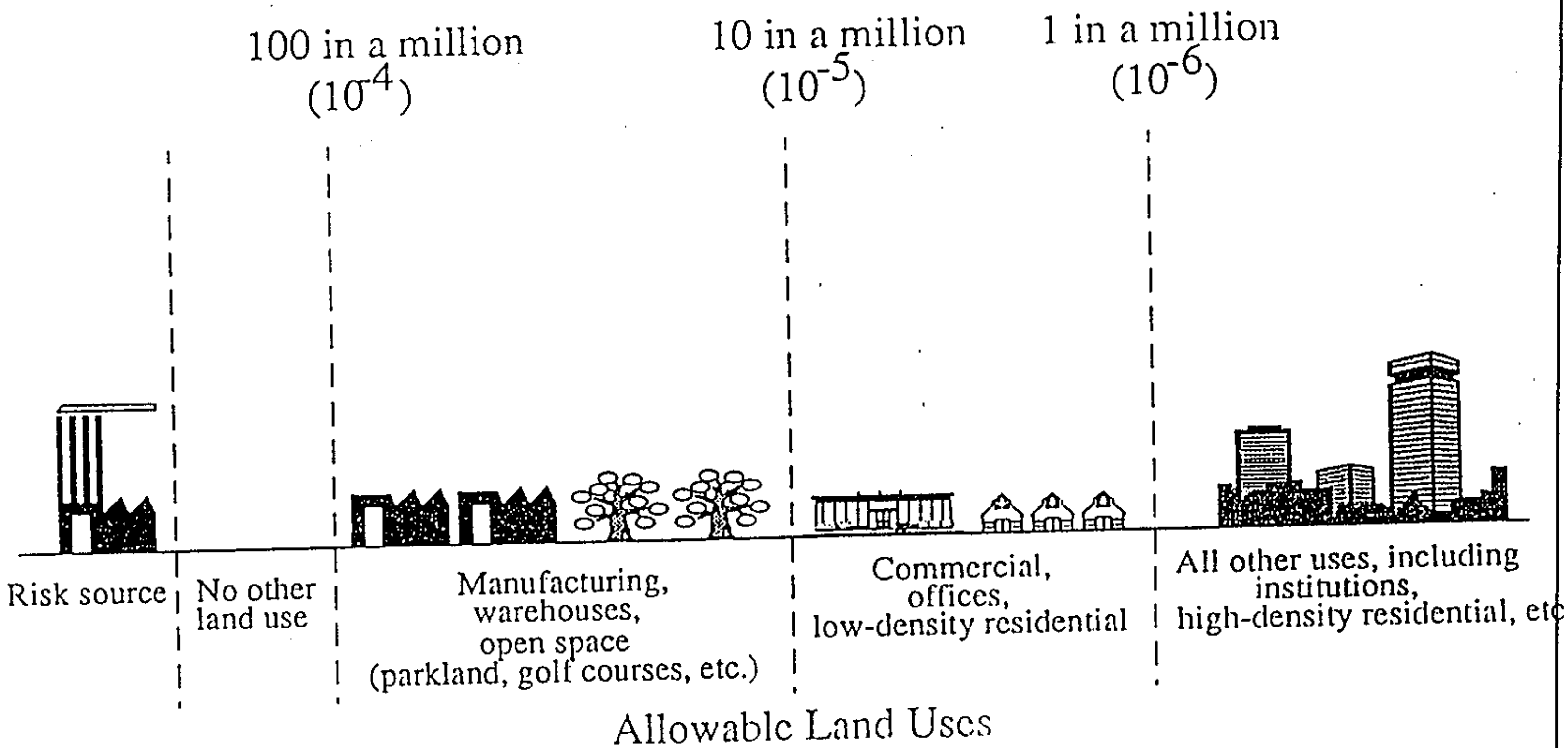

Figure 2.9
ISR Risk Acceptability Criteria

FREQUENCY OF OCCURRENCE	SEVERITY OF CONSEQUENCE				
	Negligible: No significant risk to the public, with no minor injuries; less than 10 barrels spilled.	Minor: Small level of public risk, with at most a few minor injuries; 10-238 barrels spilled.	Major: Major level of public risk with up to 10 severe injuries; 238 - 2380 barrels spilled.	Severe: Severe public risk with up to 100 severe injuries or up to 10 fatalities; 2380 to 357,142 barrels spilled.	Disastrous: Disastrous public risk involving more than 100 severe injuries or more than 10 fatalities; greater than 357,142 barrels spilled.
Frequent: Greater than once a year.					
Likely: Between once a year and once in one hundred years.					
Unlikely: Between once in a hundred and once in ten thousand years.					
Rare: Between once in ten thousand years and once in a million years.					
Extraordinary: Less than once in one million years.					

DIRECTION OF INCREASING SIGNIFICANCE

County defined as significant impacts.

Source: County of Santa Barbara Department of Resource Management, Environmental Thresholds & Guidelines Manual, Amended 1990; Shell Hercules Platform EIR, 1983.

Figure 2.10
Santa Barbara Risk Matrix

Table 2.10
Criticality and Frequency Classifications

CLASSIFICATION	DESCRIPTION OF PUBLIC SAFETY HAZARD
Negligible	No significant risk to the public, with no minor injuries.
Minor	Small level of public risk, with at most a few minor injuries.
Major	Major level of public risk with up to 10 severe injuries
Severe	Severe public risk with up to 100 severe injuries or up to 10 fatalities.
Disastrous	Disastrous public risk involving more than 100 severe injuries or more than 10 fatalities.

TYPE	FREQUENCY	DESCRIPTION
Extraordinary	Less than once in one million years	An event whose occurrence is extremely unlikely.
Rare	Between once in ten thousand years and once in one million years	An event which almost certainly would not occur during the project lifetime.
Unlikely	Between once in a hundred and once in ten thousand years	An event which is not expected during the project lifetime
Likely	Between once a year and once in one hundred years	An event which probably would occur during the project lifetime.
Frequent	Greater than once a year	An event which would occur more than once a year on average.

The risk matrix is being phased out in favor of the risk spectrum or profile in the County of Santa Barbara.

2.7.3 Risk Spectra

The discussion of risk spectra and choice of risk spectrum thresholds given herein is based on the Santa Barbara County Policy Report [45].

Risk spectrum thresholds [8, 11] employ quantitative measures of societal risk to indicate whether the annual probability of expected fatalities or serious injuries is significant of not. Both unmitigated risk estimates and the effectiveness of options to mitigate significant risk should be tested against the threshold. If a proposed project exposes the public to significantly high risks despite all feasible measures to mitigate the impact, then approval of the project requires a statement of overriding considerations, adopted by the approving authority and supported by substantial evidence in the record. Upon project approval, the risk estimates should be adjusted and charted on the thresholds to reflect the risk accurately, based on accepted mitigation, for future land-use planning and permitting purposes.

As described below, these thresholds should not function as the sole determinants of significance for public safety impacts. Rather, they must be used in concert with applicable community policy, regulation, and guidelines to address other qualitative factors specific to the project which also help determine the significance of risk. For example, highly sensitive land uses (e.g., hospitals or schools) are generally given greater protection from hazardous situations overall. Also, long-term significant risks (e.g., natural gas production) generally are treated more conservatively than relatively short-term risks (e.g., natural gas exploration).

The thresholds for public fatalities and injuries are given in Figures 2.11 and 2.12 respectively. They require quantitative risk analysis to determine the total societal risk attributable to the full set of possible accidents that can occur from the operation of a hazardous facility or undertaking of an activity that involves handling of hazardous materials. The analysis must consider both the significance of the risk and the beneficial effect of mitigation. It must also comply with community guidelines for risk assessment to ensure compatibility with the thresholds and consistency over time. When these thresholds are applied to proposed development in proximity to an existing hazardous operation, the risk measurement must be adjusted to reflect reductions in risk due to mitigation or to reflect societal risk from a newly proposed development.

These thresholds refine previous, quantitative thresholds by employing the entire risk spectrum of a project and they refine the qualitative character of previous thresholds (risk matrices) by employing quantitative factors into the determination of significance. The thresholds provide three zones - Intolerable, Grey, and Insignificant - for guiding the determination of significance or insignificance

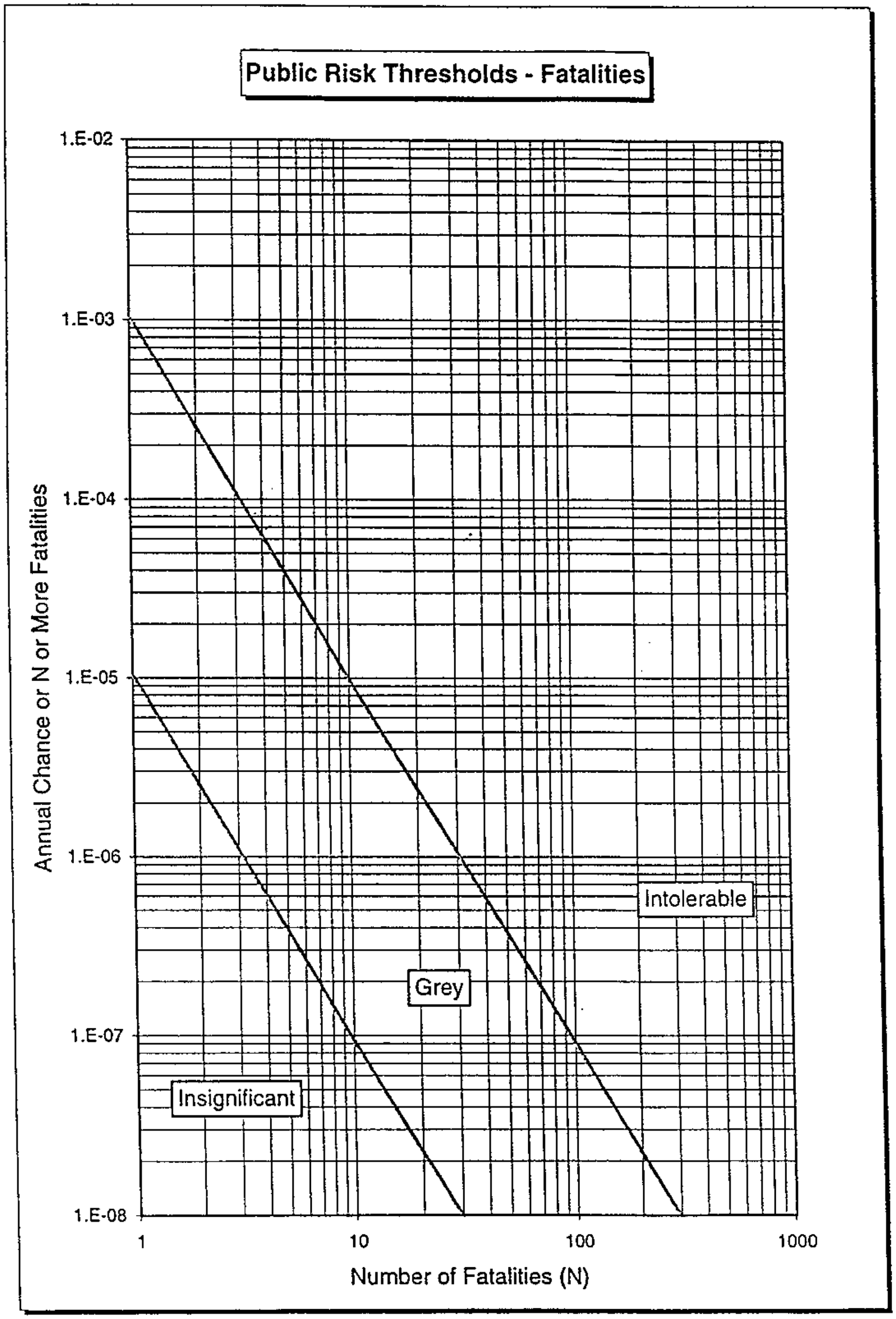

Figure 2.11
Santa Barbara Public Fatality Risk Threshold

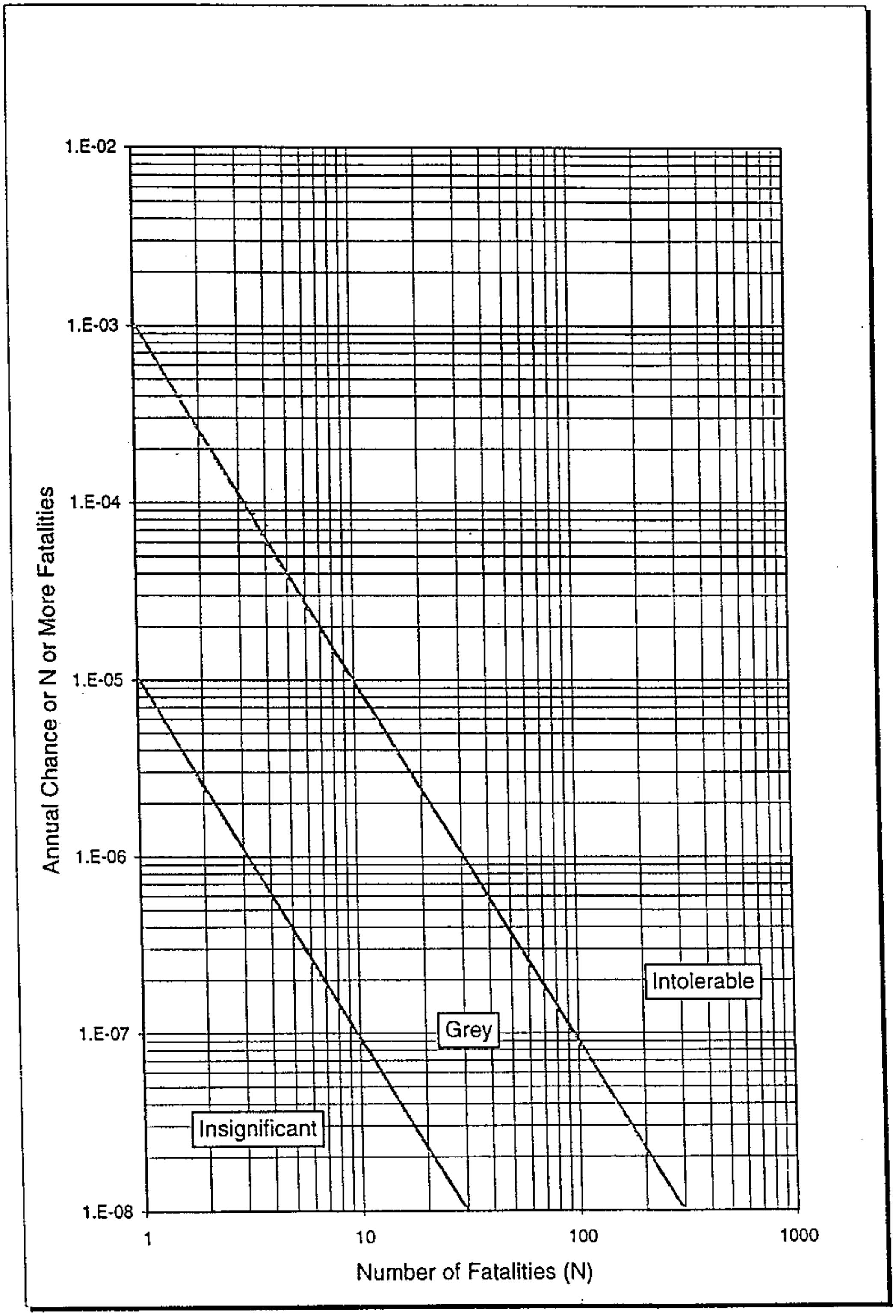

Figure 2.12
Santa Barbara Public Injury Risk Threshold

based on the estimated probability and consequences of an accident. Risk analysis is based on best available data and modelling techniques but still requires informed assumptions to compensate for gaps in data, shortfalls in modelling, and our ability to predict future outcomes with 100% accuracy. Given the unavoidable margin of error associated with any projection, the grey zone represents an area where caution is recommended, particularly considering the presence or absence of relevant qualitative factors; meanwhile, the overall goal should remain focused on maximizing public safety, using feasible mitigation to achieve a risk spectrum that falls solely within the insignificant zone.

2.8 Background on Chronic Risks from H_2S

Twenty-one scientific studies were reviewed to identify the human health effects from exposure to low hydrogen sulphide (H_2S) emissions. The results of these studies are summarized in Table 2.11. The majority of the scientific studies to date focus on the human health effects from acute exposure, which is high H_2S concentrations over a short period of time (see Table 2.11). In general, these studies have concluded that H_2S is toxic at very high exposure concentrations (greater than 500 ppm), depending on the exposure period. Death can result in humans exposed to H_2S at concentrations greater than 1,000 ppm, when exposed to H_2S for less than 1 hour.

Ten of the 21 scientific studies reviewed provide some information on the human health effects from exposure to low H_2S concentrations. Five of the studies found that H_2S does not constitute an important hazard to human health from chronic exposure to very low H_2S concentrations (<10 ppm) (see Table 2.11, Hosking, 1983; Smith; Milby; Young; National Institute for Occupational Safety and Health, 1977). The studies also found that repeated exposure to low concentrations of H_2S does not result in any cumulative based health effects. In addition, there is no evidence that low levels of H_2S can negatively effect a pregnant woman, or the development of the baby.

The other five studies found conflicting public health information from exposure to low H_2S concentrations (see Table 2.11, Haggard, 1925; Richardson, 1995; Skrjny; Reiffenstein; Sainsbury; Roth, 1996; Guidotti, 1994; Hannah, Roth, 1990). These studies identify a number of potential health effects from low H_2S concentrations (20 to 100 ppm), such as: loss of sleep, potential headaches, nausea, blurred vision, reduced lung function, reduced brain function and cardiac arrhythmia. However, it should be noted that H_2S concentrations in these studies were higher that the five previous studies that found no chronic effects from low H_2S concentrations.

With regard to odor, the odor thresholds for H_2S is approximately 0.1 ppm, and therefore, concentrations below 3 ppm would be noticeable to any exposed individual. Concentrations as high as 3 ppm may be considered offensive and may result in a public nuisance.

Table 2.11
Summary of Studies Regarding H_2S Exposure

#	TITLE	AUTHOR	DATE	DESCRIPTION	CONCLUSIONS
1	A Search for the Scientific Literature for Evidence of the Effects of Low Concentrations of Hydrogen Sulphide on Human Populations	David J. Hosking	July, 1983	In 1982 a large area of Alberta, Canada recorded H_2S concentrations of 3 ppm or less for a period of weeks. Many complaints were made by members of the public that they experienced adverse health effects. This study summarizes existing literature on the potential health effects from chronic exposure to low-level H_2	The literature review can be summed up as follows: • The existence of a clinical syndrome of "chronic hydrogen sulfide poisoning" is uncertain • There is no evidence that H_2S is a cumulative poison in man • There is very limited information on the effects of low dose exposure in the community setting. • Includes tables summarizing results of reviews previously conducted by other sources.
2	The Toxicology of Hydrogen Sulfide with Particular Reference to the Effects of Long-Term, Low-Level Exposure	Roger P. Smith		This study provides a brief history of the toxicology of hydrogen sulphide, including a summary of what is known about the human health effects of hydrogen sulphide largely as inferred from studies on laboratory animals.	• The bulk of the evidence indicates that hydrogen sulfide is a gas of high acute toxicity, but one with no tendency to produce life-threatening cumulative or chronic effects. • The gas is well known to have a low persistence in the environment, do to the fact that it reacts rapidly with heavy metals in water and soil, and tends to be dissipated rapidly in the atmosphere where it is quickly oxidized to sulfate.
3	A Review of and Comments on Concerns Raised Regarding the Health Effects of Hydrogen Sulfide and the AMOCO Dome Brazeau Blowout	Thomas H. Milby		Study was conducted to explain the numerous complaints fielded from the public as a result of the Amoco Dome Brazeau Blowout, and subsequent ambient H_2S concentrations	• Among conclusions is the idea that, "... the role of the media as a stimulus to social contagion also may have been considerable. Certain members of the medical and media communities release public statements which create paranoia with the public". • The general perception among U.S. scientists is that H_2S in very low concentrations (<3 ppm) does not constitute an important hazard to health. • Studies conducted on animals indicated that H_2S is not toxic to the reproductive process in low doses. Humans exposed to lethal concentrations showed no adverse reproductive effects. • No evidence that low levels of H_2S negatively affects a pregnant woman.
4	Study Trip to	Murray R.		Study of an area which is exposed	• Studies of the area show that birth defect rates and illness rates

Table 2.11
Summary of Studies Regarding H_2S Exposure

#	TITLE	AUTHOR	DATE	DESCRIPTION	CONCLUSIONS
	Rotorua, New Zealand	Young		to low level concentration of H_2S. These levels are often higher than recommended occupational levels of H_2S exposure in North America, yet the citizens have not shown any adverse health effects.	are similar to those of an area with similar demographics, but without the constant presence of H_2S.
5	Criteria for a Recommended Standard... Occupational Exposure to Hydrogen Sulfide	National Institute for Occupational Safety and Health	May, 1977	This study describes the effects of acute exposure on humans and chronic occupational exposure to H_2S	• 70% of workers exposed to H_2S in their daily work, often at 20 ppm or more, complained of fatigue, lack of initiative, decreased libido, loss of appetite, headache, irritability, poor memory, anxiety, etc. • Acute exposures to hydrogen sulfide at higher concentrations were associated with signs of cerebral and extrapyramidal damage, facial paralysis, prolonged reaction time, absent or abnormal reflexes at both cranial and spinal nerve levels, poor memory, depression, epiletic-like seizure. • No evidence of chronic or cumulative effects from H_2S exposure.
6	Report on H_2S Toxicity	Ad Hoc Committee	August, 1988	After well blow out and subsequent H_2S release, an Ad Hoc Committee was developed to evaluate: 1. To assess the scientific evidence for low level acute, subacute, and chronic effects of H_2S on humans in the range 0 to 100 ppm, and especially the 0 to 20 ppm range. 2. To clarify the issue of the effects of low levels of H_2S on sensitive individuals.	• Consists mainly of examples of acute exposure of humans to H_2S, tests done on varying species of animals, and of effects olfactory • Factors other than H_2S itself, may be responsible for hypersusceptibility of a small proportion of the population, including, mixed-exposure with other chemicals at the same time, pre-exposure to mixed medications, alcohol, or drugs, diseases and/or physiological conditions. • States that individuals who may be expected to show increased susceptibility to H_2S exposure include: –Individuals with eye/respiratory problems –Individuals with severe enemia –Individuals with lower resistance to bacterial infections
7	The Toxicology of Hydrogen Sulphide	Dr. Howard W.	March, 1925	This article provides a general background of the toxicology of H_2S.	• Hydrogen sulphide is both extremely toxic and also irritant. It causes severe local irritation of the eyes and may induce pulmonary edema. The more severe irritant effects are, however, usually obscured by the symptoms of acute systematic

Table 2.11
Summary of Studies Regarding H_2S Exposure

#	TITLE	AUTHOR	DATE	DESCRIPTION	CONCLUSIONS
		Haggard			poisoning. • Prolonged exposure to low concentrations of hydrogen sulphide is generally believed to result in a chronic form of poisoning. This is characterized by local irritation of the eyes and the respiratory tract, cold sweats, digestive disturbances, headache, and in some cases, skin eruption. Although these symptoms are somewhat indefinite, there appears to be little question that the repeated and prolonged inhalation of H_2S in concentration as low as 100 ppm may cause local irritation and depression of the nervous system.
8	The Influence of Hydrogen Sulphide Upon Respiration	Dr. Howard W. Haggard	July, 1922	A brief description of H_2S influences the respiratory function	• Sulphides in small amounts in the blood stream are oxidized. • Hydrogen sulphide causes systematic poisoning whenever the concentration inhaled is sufficient to maintain in the blood an amount of the unoxidized gas great enough to exert a pharmacologic action.
9	Technical Information for Problem Spills	Environmental Canada - Environmental Protection Service	July, 198`	This report contains tables, listing results from experimental exposure of H_2S on humans. In addition, it contains a brief section on the effects of H_2S on humans.	Hydrogen sulphide is an acute poison and acts as an enzyme inhibitor. At concentration in the range 500 to 1000 ppm, it acts primarily as a systematic poison, causing unconsciousness and death through respiratory paralysis. At concentrations below 500 ppm, it acts as an eye and respiratory irritant. No reports associating hydrogen sulphide in air with carcinogenesis, mutagenesis, or teratogenesis were found in the literature.

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Table 2.11
Summary of Studies Regarding H_2S Exposure

#	TITLE	AUTHOR	DATE	DESCRIPTION	CONCLUSIONS
11	Gases in Agricultural Slurry Stores	J.A. Groves and P.A. Ellwood	Sept., 1990	The evaluation of gases during the handling of animal slurry was investigated at five sites. Particular attention was paid to the mixing and emptying operations since it is when performing these that personnel are most likely to be at risk of exposure to H_2S.	• The main hazard was found to be high transient concentrations of hydrogen sulphide presenting in some cases a serious acute toxicity problem. • Time-weighted average exposure did not generally indicate any long-term exposure risk. • High concentrations (up to 141 ppm) were found in slurry pits • Higher transient concentrations (up to 541 ppm) was a feature of the slatted system.
12	Concentration-Time Interactions in Hydrogen Sulphide Toxicity in Rats	M. Prior, A. Sharma, S. Yong, and A. Lopez	July, 1987	Concentration-time iterations were investigated in young male and female Sprague-Dawley, Long Evans and Fischer-344 rats exposed to hydrogen sulphide for two, four or six hours.	• Higher concentrations caused more rat deaths, with no significant difference in the duration of exposure. • Changes in rat weight were significant; increasing with concentration, higher in males than in females, different among strains, and affected by duration of exposure. • All rats of all strains dying had severe pulmonary edema.
13	Acute and Subchronic Toxicity Studies of Rats Exposed to Vapors of Methyl Mercaptan and Other Reduced-Sulfur Compounds	M. Tansy, F. Kendall, J. Fantasia, W. Landin, R. Oberly, W. Sherman	1981	Acute inhalation experiments were conducted to determine 24-hour LC50 values for adult Sprague-Dawley rats of both sexes exposed to vapors of methyl mercaptan and other reduced-S compounds for 4-hour.	• The American Conference of Government Industrial Hygienists states that the acute toxicity of methyl mercaptan is "similar to, but less than, that of hydrogen sulfide or of the same magnitude".
14	Low Concentrations of Hydrogen Sulphide Alter Monoamine Levels in the Developing	B. Skrajny, R. Hannah, S. Roth	1992	This study evaluated the levels of serotonin and norepinephrine in the developing rat cerebellum and frontal cortex following chronic exposure to 20 and 75 ppm H_2S during perinatal development.	• Exposure to 75 ppm H_2S during development of rat central nervous system results in increased serotonin and norepinephrine levels in both the cerebellum and the frontal cortex. • In humans, exposure to similar concentrations results in eye irritation within several minutes and respiratory tract irritation in 30 minutes. • Repeated exposures to H_2S are usually necessary to produce

Table 2.11
Summary of Studies Regarding H_2S Exposure

#	TITLE	AUTHOR	DATE	DESCRIPTION	CONCLUSIONS
	Rat Central Nervous System				neurological symptoms, such as mental depression, irritability, poor memory, and fatigue.
15	Respiratory Effects of Chronic Hydrogen Sulfide Exposure	David Richardson	1995	A cross-sectional study investigated whether the exposure of sewer workers to hydrogen sulfide (H_2S) was associated with reduced lung function.	• This study found evidence that chronic low level exposure to H_2S may be associated with reduced lung function
16	Effects of repeated Exposures of Hydrogen Sulphide on Rat Hippocampal EEG	B. Skrajny, R. Reiffenstein, R. Sainsbury, S. Roth	1996	The effects of low levels of H_2S on electroencephalographic (EEG) activity in the hippocampus and neocortex were invetigated on the freely moving rat (Sprague-Dawley type). Rats were exposed to H_2S (25, 50, 75, or 100 ppm) for 3 h/day; data was collected during the final 10 minutes of each exposure period.	• The effects were found to be highly significant at all concentrations within subjects. • Neocortical EEG and LIA (Large Amplitude Irregular Activity) were unaffected. • The results demonstrated that repeated exposure to low levels of H_2S can produce cumulative changes in hippocampal function and suggests selectivity of action of this toxicant.
17	Brain Damage Caused by Hydrogen Sulfide: A Follow-Up Study of Six Patients	B. Tvedt, K. Skyberg, O. Aaserud, A. Hobbesland, T. Mathiesen	1991	This study provides a description of six patients who lost consciousness due to H_2S poisoning.	• The symptoms varied from anosmia in the patient with the shortest but highest exposure to delayed neurological deterioration in the patient with the longest exposure. • The two patients with the most serious symptoms developed pulmonary edema, which may have prolonged the hypoxia. • The five patients who had been unconscious in H_2S atmosphere from 5 to 20 minutes showed persisting impairment during subsequent neurological and neuropsychological re-examination. • Memory and motor function were most affected.
18	Sulfide Toxicity: Mechanical Ventilation and Hypotension Determine Survival Rate	R. Baldelli, F. Green, R. Auer	1993	This study sought to determine whether sulfide can directly kill central nervous system neurons. Ventilated and unventilated rats were studied to allow administration of higher doses of sulfide and to facilitate	• It was concluded that very-high doses of sulfide did not produce cerebral necrosis by a direct histrtoxic effect.

Table 2.11
Summary of Studies Regarding H_2S Exposure

#	TITLE	AUTHOR	DATE	DESCRIPTION	CONCLUSIONS
	and Brain Necrosis			physiological monitoring.	
9	Occupational Exposure to hydrogen Sulfide in the Sour Gas Industry: Some Unresolved Issues	Tee Guidotti	1994	This study provides a description of the unresolved issues regarding the H_2S exposure and potential health concerns.	• The acute effects of exposure to H_2S are well recognized, but accurate exposure-response data are limited to acutely lethal effects, even in animal studies • Odor followed by olfactory paralysis and keroto-njunctivitis are the characteristic effects of H_2S at lower concentrations. • Pulmonary edema is also a well-recognized acute effect of H_2S toxicity. Human studies of sublethal exposure with satisfactory exposure assessment are almost nonexistent. • There are indications, poorly documented at present, of other chronic health problems associated with H_2S exposure including neurotoxicity, cardiac arrhythmia, and chronic eye irritation, but not cancer.
10	Chronic Exposure to Low Concentrations of Hydrogen Sulfide Produces Abnormal Growth in Developing Cerebellar Purkinje Cells	R. Hannah and S. Roth	1990	In this study, the dendritic fields of developing cerebellar Purkinje cells were analyzed to determine the effects of chronic exposure to low concentrations of H_2S during development.	• Treatment with two concentrations (20 to 50 ppm) of H_2S produced severe alterations in the architecture and growth characteristics of the Purkinje cell dendritic fields. • These findings suggest that developing neurons exposed to low concentrations of H_2S are at risk of severe deficits.
11	A Critical Review of the Literature on Hydrogen Sulfide	R. Beauchamp, J. Bus, J. Popp, C. Boreiko, D. Andejelkovich	1984	This study provides a detailed description on hydrogen sulfide toxicity.	• Hydrogen sulfide has been demonstrated to be toxic to a wide variety of animal species. The lethal concentrations have been adequately determined in laboratory experiments although actual concentrations are unknown in accidental human cases of toxic exposures. • The carcinogenic, teratogenic, and reproductive effects of H_2S gas have not been studied. A long-term chronic study of sodium sulfide, which may have physiological effects similar to those of H_2S, produced results. • H_2S gas is highly toxic and can be rapidly fatal. It is both an irritant and asphyxiant. • It affects the nervous system and may cause paralysis of the respiratory center which usually results in death.

CHAPTER 3

HAZARD AND FREQUENCY ANALYSIS

3.1 General Description of Hazard and Frequency Analysis

The first substantial step in risk analysis is the definition of hazard scenarios. What can go wrong? Typical hazard scenarios include the release of a flammable gas due to the rupture of a vessel, a traffic accident involving the uncontrolled impact of a tanker truck against or by another vehicle, or a spill of gasoline or crude oil at a loading terminal due to the accidental severance of a loading hose. Many of these hazard scenarios can be characterizes by the initial conditions of the accident including the impact energy or amount of fluid released and the duration of the release. In the characterization of hazard scenarios, the first significant step in the risk analysis, is a semi-quantitative step involving the qualitative characterization of the hazard scenario or initiating accident and a quantitative characterization of its most important parameters such as impact energy, amount of fluid released, and duration.

When will it happen? How often? The next step of the risk analysis, the frequency analysis, involves an estimation of the likelihood of occurrence of each of the different types of hazard scenarios identified. In risk analysis, it is customary to characterize frequencies of occurrence either on an annual basis, or on an incident basis. An example of an annual frequency of occurrence is 10 major spills per 100 years. An example of an event frequency of occurrence is that in 10% of tanker traffic accidents, a spill of the cargo fluid occurs. These frequencies of occurrence are generally based on empirical data available to the risk analyst and, generally, to the public. Empirical data sources on accident or accidental release frequencies include industry sources, public sources [21, 50], and results of other risk analyses in the public domain [4, 7].

When the frequency for the type of event being studied is not directly available from the data, it can be obtained utilizing analytical techniques such as fault tree analysis [2, 8]. In fault tree analysis, the frequency of occurrence of an event under study can be derived by considering the probabilistic relationships of more basic events that lead to its occurrence. Fortunately, for the current analysis, most of the frequencies required for the risk analysis are obtainable from publicly accessible empirical data. Naturally, the frequencies publicly available have to be adapted to the specific conditions and configurations of facilities under study. For example, although representative failure frequencies for all of the components of the production process facility are available, it is necessary to combine these frequencies to obtain an estimate of the likelihood of a failure of **any** part of the process facility. This process is described and documented subsequently.

3.2 Release Sizes

The range of release sizes possible in an accidental release from the pipeline or process facility spans a full spectrum of release sizes from a small puncture to a full pipe bore severance or vessel rupture. In order to adequately characterize the spectrum of release sizes, the following representative flammable fluid accidental release orifice sizes summarized in Table 3.1 have been selected:

- Leak - ¼" diameter orifice
- Hole - 1" diameter orifice
- Rupture - 6" diameter orifice

In addition, in the case of a full pipeline rupture, the release can be predominately from one of the ruptured segments, if the other is relatively short, or from both segments in the instance that the rupture occurs near the center of the pipeline segment. In this work, it has been postulated that if the middle third of the segment fails, a double rupture scenario is modelled. When the outer third on either end fails, only single rupture behavior for this segment is modelled.

3.3 Gas Composition

The typical gas composition for the process gas in the current project was obtained from chromatograph analysis of results and which have been simplified to give the typical gas composition shown in Table 3.2. In addition, of course, a component of hydrogen sulphide (H_2S) of the maximum permissible level of 40 ppm or 0.004% (4 - 1,000's of a percent) were included in the modelling.

3.4 Hazard Scenario Nomenclature

Because there was a large number of hazard scenarios, each having a relatively lengthy generic description, a code has been developed to characterize each hazard scenario uniquely. The code is best explained through illustration for a typical hazard scenario such as **HB-T-P-H-N** where:

- The first two letters identify this project as Hermosa Beach
- The second letter, in this case T, identifies phase of the project, Test Phase. In other characterizations, P stands for Production Phase, and E stands for existing facilities
- The next letter, in this case H, characterizes the size of the release, in this case a hole. L, R, and DR stand for leak, rupture, and double rupture, respectively.
- A final letter, which does not begin to appear in the scenarios until the consequence analysis part of the risk analysis process begins (Chapter 4), characterizes the conditions of the release, in this case N, signifying night. The other two principal conditions are D, for day, and W, for worst case.

Table 3.1
Release Size Characterization

SCENARIO TYPE	DESCRIPTION
Leak	• ¼" diameter opening
Hole	• 1" diameter opening
Rupture	• 6" diameter opening, or • Guillotine type failure of pipeline occurring within the first and last sections along the length of the pipeline
Double Rupture	• Guillotine type failure of pipeline occurring within the middle section along the length of the pipeline

Table 3.2
Typical Gas Composition

COMPONENT	MOLE FRACTION (%)
Oxygen	0.01
Carbon Dioxide	4.14
Nitrogen	0.01
Methane	93.61
Ethane	1.86
Propane	0.09
i - Butane	0.10
n - Butane	0.07
i - Pentane	0.04
n - Pentane	0.00
Hexane	0.09
TOTAL	**100.00**

3.5 Test Phase Hazard and Frequency Analysis

The test phase consists of four principal physical components capable of posing hazards to the public:

- Well drilling and production operations
- Oil and gas processing
- Oil storage
- Oil trucking

Table 3.3 shows the hazard scenarios selected to represent the range of hazards posed by these four components. The frequency of well blowouts has been estimated through the analysis of data provided by the Department of Conservation of California [19]. Through the analysis of relevant data, it has been concluded that drilling well blowouts may occur at the rate of 3.3×10^{-4} per well drilled, giving the resultant rate for 3 wells of 9.9×10^{-4}. As these 3 wells are proposed to be drilled in the one year of operation of the test phase, this frequency for blowouts associated with 3 drilled wells is also the annual frequency for the blowout scenario.

For the test phase process release, because at this level, the entire process segment was considered to be interconnected but isolatable with emergency shutdown valves (ESDV) at the inlet and outlet, all of the equipment and piping have been included with potential to contribute fluids to the occurrence of an accidental release. Table 3.4 summarizes the equipment and inventory for the test phase, obtained from the piping and instrumentation diagrams [39]. Failure frequencies based on published data [21, 25] for the equipment types as well as the unit frequencies associated with the wells, are summarized in Table 3.5. Equipment for both the test phase and the production phase has been included in the summary of frequencies in order to avoid repetition of the table in the production phase frequency computation description. Table 3.6 summarizes the frequencies for equipment failures associated with the test phase as well as the resultant frequencies for each of the four principal scenarios. The final scenario, HB-T-P-E is associated with a release due to the pressure relief system which results in venting to the flare system. The failure frequency for atmospheric storage vessels, the temporary oil storage tanks onsite is also included in Table 3.5.

Finally, an estimate of the accident frequencies associated with trucks has been generated based on published date [20, 31, 49], giving a casualty related tanker road accident frequency of 9.0×10^{-8}/truck-mile, and an onsite loading major spill accident frequency of 4.0×10^{-5} per trip.

Table 3.7 summarizes the scenarios and their characteristics as well as appropriate frequencies of occurrence for the entire test phase.

3.6 Production Phase Hazard and Frequency Analysis

The principal components of the production phase of the project are as follows:

Table 3.3
Test Phase Hazard Scenarios

SCENARIO	DESCRIPTION
HB-T-W-D-BO	Well blowout while drilling -3 wells
HB-T-P-L	Leak within process unit with inlet and outlet ESDV
HB-T-P-H	Hole within process unit with inlet and outlet ESDV
HB-T-P-R	Rupture within process unit with inlet and outlet ESDV
HB-T-P-E	Emergency release using emergency vent stack
HB-T-TL-A	Tanker truck loading accident
HB-T-TR-A	Tanker truck fatality road accident within ½ mile of site
HB-T-S-H	Oil storage tank failure

Table 3.4
Test Phase Major Equipment Inventory

EQUIPMENT			FLAMMABLE HYDROCARBON DESCRIPTION
COMPONENT	CODE	NUMBER	
a) Pressure Columns (vertical vessels)	C	6	Gas / Oil
b) Pressure Drums (horizontal vessels)	D	1	Gas / Oil
c) Heaters	H	0	
d) Process Piping NPS 4 (average) (Include Valves & Flanges)	PP	800 ft	Gas / Oil
e) Pumps (centrifugal)	Pc	4	Oil
f) Pumps (reciprocating)	Pr	0	
g) Compressors (vane)	Kc	1	Gas
h) Compressors (recip.)	Kr	0	
i) Emergency Vent Stack	EVS	1	Gas
j) Thermal Oxidizer	TO	1	Gas
k) Heat Exchangers	E	0	
l) Air-fin Coolers	AC	0	
m) Wells (oil)	W	3	Gas / Oil
n) Portable Tanks	T	7	Oil
o) Tanker Truck	TT	1	Oil
p) Drilling Rigs	Rd	1	Gas / Oil
q) Service Rigs	Rs	1	Gas / Oil

Table 3.5
Summary of Equipment Failure Frequencies

ITEM	RELEASE TYPE	FREQUENCY	UNITS
Well drilling	Blowout	3.3×10^{-4}	per well
Producing well	Blowout	4.0×10^{-5}	per well-year
Pressure Column (vertical vessel)	Leak	8.9×10^{-5}	per unit-year
	Hole	1.3×10^{-4}	per unit-year
	Rupture	1.5×10^{-5}	per unit-year
Pressure Drum (horizontal vessel)	Leak	8.9×10^{-5}	per unit-year
	Hole	1.3×10^{-4}	per unit-year
	Rupture	1.5×10^{-5}	per unit-year
Heater	Leak	8.7×10^{-4}	per unit-year
	Hole	2.2×10^{-4}	per unit-year
	Rupture	1.0×10^{-4}	per unit-year
Process Piping	Leak	3.5×10^{-6}	per ft-year
	Hole	8.6×10^{-7}	per ft-year
	Rupture	4.0×10^{-7}	per ft-year
Valve	Leak	6.1×10^{-4}	per unit-year
	Hole	1.5×10^{-4}	per unit-year
	Rupture	1.1×10^{-4}	per unit-year
Flange	Leak	3.7×10^{-4}	per unit-year
	Hole	9.8×10^{-5}	per unit-year
	Rupture	3.3×10^{-5}	per unit-year
Pump (centrifugal)	Leak	2.5×10^{-2}	per unit-year
	Hole	1.3×10^{-3}	per unit-year
	Rupture	1.1×10^{-4}	per unit-year
Compressor (centrifugal)	Leak	1.7×10^{-2}	per unit-year
	Hole	8.4×10^{-4}	per unit-year
	Rupture	1.0×10^{-4}	per unit-year
Compressor (reciprocating)	Leak	6.1×10^{-1}	per unit-year
	Hole	3.3×10^{-2}	per unit-year
	Rupture	1.3×10^{-2}	per unit-year

(table continued)

Table 3.5 (continued)
Summary of Equipment Failure Frequencies

ITEM	RELEASE TYPE	FREQUENCY	UNITS
Emergency Vent Stack	Release	1	per unit-year
Thermal Oxidizer	Leak	8.7×10^{-5}	per unit-year
	Hole	2.2×10^{-5}	per unit-year
	Rupture	1.0×10^{-5}	per unit-year
Heat Exchanger (shell side)	Leak	5.8×10^{-3}	per unit-year
	Hole	6.8×10^{-3}	per unit-year
	Rupture	6.8×10^{-3}	per unit-year
Air-Fin Cooler	Leak	3.5×10^{-3}	per unit-year
	Hole	8.6×10^{-4}	per unit-year
	Rupture	4.0×10^{-4}	per unit-year
Tank	Leak	1.5×10^{-2}	per unit-year
	Hole	9.6×10^{-5}	per unit-year
	Rupture	6.0×10^{-6}	per unit-year
Portable Tank	Leak	3.0×10^{-2}	per unit-year
	Hole	1.9×10^{-4}	per unit-year
	Rupture	1.2×10^{-5}	per unit-year
Tanker Truck	Leak	3.5×10^{-3}	per unit-year
	Hole	1.2×10^{-3}	per unit-year
	Rupture	1.2×10^{-3}	per unit-year
Gas Pipeline	Leak	1.0×10^{-3}	per unit-year
	Hole	2.9×10^{-4}	per unit-year
	Rupture	6.8×10^{-5}	per unit-year
	Double Rupture	2.9×10^{-5}	per unit-year
Oil Pipeline	Leak	7.2×10^{-3}	per unit-year
	Hole	2.5×10^{-3}	per unit-year
	Rupture	1.9×10^{-4}	per unit-year

Table 3.6
Test Phase Failure Frequency Estimates for Process Equipment

CASE	PRESSURE VESSELS	PROCESS PIPING (ft)	VALVES / FLANGES	PUMPS (CENTR.)	COMPR. (CENTR.)	EMERG. VENT STACK	THERMAL OXIDIZER	RESULTANT
HB-T-P-L	(7) 6.2×10^{-4}	(800) 2.8×10^{-3}	1.4×10^{-3}	(4) 1.0×10^{-1}	(1) 1.7×10^{-2}		(1) 4.5×10^{-5}	1.2×10^{-1}
HB-T-P-H	(7) 9.1×10^{-4}	(800) 6.9×10^{-4}	3.6×10^{-3}	(4) 5.2×10^{-3}	(1) 8.4×10^{-4}		(1) 5.3×10^{-5}	1.1×10^{-2}
HB-T-P-R	(7) 1.1×10^{-4}	(800) 3.2×10^{-4}	1.9×10^{-3}	(4) 4.0×10^{-4}	(1) 1.0×10^{-4}		(1) 5.3×10^{-5}	2.9×10^{-3}
HB-T-P-E						(1) 1		1.0×10^{0}

Table 3.6
Test Phase Failure Frequency Estimates for Process Equipment

CASE	PRESSURE VESSELS	PROCESS PIPING (ft)	VALVES / FLANGES	PUMPS (CENTR.)	COMPR. (CENTR.)	EMERG. VENT STACK	THERMAL OXIDIZER	RESULTANT
HB-T-P-L	(7) 6.2 x 10^{-4}	(800) 2.8 x 10^{-3}	1.4 x 10^{-3}	(4) 1.0 x 10^{-1}	(1) 1.7 x 10^{-2}		(1) 4.5 x 10^{-5}	1.2 x 10^{-1}
HB-T-P-H	(7) 9.1 x 10^{-4}	(800) 6.9 x 10^{-4}	3.6 x 10^{-3}	(4) 5.2 x 10^{-3}	(1) 8.4 x 10^{-4}		(1) 5.3 x 10^{-5}	1.1 x 10^{-2}
HB-T-P-R	(7) 1.1 x 10^{-4}	(800) 3.2 x 10^{-4}	1.9 x 10^{-3}	(4) 4.0 x 10^{-4}	(1) 1.0 x 10^{-4}		(1) 5.3 x 10^{-5}	2.9 x 10^{-3}
HB-T-P-E						(1) 1		1.0 x 10^{0}

Table 3.7
Test Phase Hazard Scenarios and Frequencies

SCENARIO	DESCRIPTION	CONTENTS	P/T (psia/°F)	MAX RATE (lb/min)	DURATION (min)	FREQUENCY (N/yr)
HB-T-W-D-BO	Well blowout while drilling -3 wells	Gas	65/85	10.8	N/A	9.9×10^{-4}
HB-T-P-L	Leak within process unit with inlet and outlet ESDV	Gas-4080 ft^3	65/85	2.1	581	1.2×10^{-1}
HB-T-P-H	Hole within process unit with inlet and outlet ESDV	Gas-4080 ft^3	65/85	33	36	1.1×10^{-2}
HB-T-P-R	Rupture within process unit with inlet and outlet ESDV	Gas-4080 ft^3	65/85	1181	1	2.9×10^{-3}
HB-T-P-E	Emergency release using emergency vent stack	Gas-4080 ft^3	65/85	131	9	1
HB-T-TL-A	Tanker truck loading accident	Crude oil	atm	10.0	n/a	5.0×10^{-2}
HB-T-TR-A	Tanker truck public fatality road accident within ½ mile of site	Crude oil	atm	-	n/a	1.4×10^{-4}
HB-T-S-H	Oil storage tank failure	Crude oil	atm	-	n/a	2.1×10^{-1}

- Well drilling and production operations
- Oil and gas process equipment
- Oil storage
- Gas pipeline
- Oil pipeline

Table 3.8 summarizes the hazard scenarios associated with each of the principal components described above. The frequency of drilling well blowouts is 3.3×10^{-4} per well drilled, giving the resultant rate for 27 wells of 8.9×10^{-3}. That of well blowouts while producing is 4.0×10^{-5} per well-year, giving the resultant rate for 30 wells of 1.2×10^{-3} per year. The characterization of hazard scenarios is done in a manner similar to that for the test phase. Table 3.9 gives a summary of the principal equipment items, pipelines, and wells associated with the production phase. Based on the unit frequencies described for the test phase, and identified in Table 3.5, a summary of the failure frequencies for process equipment for the production phase shown in Table 3.10.

Table 3.11 shows a summary of the hazard scenarios, their characteristics, and associated frequencies for all components and scenarios for the production phase.

3.7 Existing Facilities

While the existing facilities store a number of hazardous substances on site, the only substance stored with potential offsite effects is the propane. In addition, a substantial amount of vehicle traffic is associated with the existing facilities, and these have been characterized as an additional scenario with the potential for casualties to the public resulting from traffic accidents. Specifically, hazards associated with 50 vehicle round trips within ½ mile of the site have been included. The test phase hazard scenarios, their characteristics, and their frequencies are summarized in Table 3.12.

Table 3.8
Production Phase Hazard Scenarios

SCENARIO	DESCRIPTION
HB-P-W-D-BO	Well blowout while drilling 27 wells - at 10 wells per year
HB-P-W-P-BO	Well blowout during production - 30 wells
HB-P-P-L	Leak within process unit with inlet and outlet blocked-in
HB-P-P-H	Hole within process unit with inlet and outlet blocked-in
HB-P-P-R	Rupture within process unit with inlet and outlet blocked-in
HB-P-PG-L	Leak of gas pipeline
HB-P-PG-H	Hole in gas pipeline
HB-P-PG-R	Rupture of gas pipeline
HB-P-PG-DR	Double rupture of gas pipeline
HB-P-S-L	Storage tank failure
HB-P-PO-L	Leak of oil pipeline
HB-P-PO-H	Hole in oil pipeline
HB-P-PO-R	Rupture of oil pipeline

Table 3.9
Production Phase Major Equipment Inventory

EQUIPMENT			FLAMMABLE HYDROCARBON	
COMPONENT	CODE	NUMBER	DESCRIPTION	CODE
1) PIPELINES				
a) NPS 6 gas pipeline	GP	2500 ft	Process Gas	PG
b) NPS 6 oil pipeline	OP	2500 ft	Process Oil	PO
2) FACILITY SITE				
a) Pressure Columns (vertical vessels)	C	10	Raw Gas / Oil / Process Gas / NGL	RG / OIL / PG / NGL
b) Pressure Drums (horizontal vessels)	D	4	Raw Gas / Oil / Process Gas	RG / OIL / PG / NGL
c) Heaters	H	3	Raw Gas / Oil / Process Gas	RG / OIL / PG
d) Process Piping NPS 4 (average) (Include Valves & Flanges)	PP	1200 ft	Raw Gas / Oil / Process Gas / NGL	RG / OIL / PG / NGL
e) Pumps (centrifugal)	Pc	8	Oil	OIL
f) Pumps (reciprocating)	Pr	0		
g) Compressors (vane)	Kc	1	Gas	GAS
h) Compressors (recip.)	Kr	1	Process Gas	PG
i) Thermal Oxidizer	TO	1	Gas	GAS
j) Heat Exchangers	E	1	Process Gas	PG
k) Air-Fin Coolers	AC	3	Process Gas	PG
l) Wells (production)	W	30	Gas / Oil	GAS / OIL
m) Tanks	T	3	Oil	OIL
n) Drilling Rigs	Rd	1	Gas / Oil	GAS / OIL
o) Service Rigs	Rs	1	Gas / Oil	GAS / OIL

Table 3.10
Production Phase Failure Frequency Estimates for Process Equipment

CASE	PRESSURE VESSELS	HEATER	PROCESS PIPING (ft)	VALVES / FLANGES	PUMPS (CENTR.)	COMPR. (CENTR.)	COMPR. (RECIP.)	THERM. OXID.	HEAT EXCH.	AIR FIN COOLERS	RESULT.
HB-P-P-L	(14) 1.2×10^{-3}	(3) 2.6×10^{-3}	(1200) 4.2×10^{-3}	3.9×10^{-2}	(8) 2.0×10^{-1}	(1) 1.7×10^{-2}	(1) 6.1×10^{-1}	(1) 8.7×10^{-5}	(1) 5.8×10^{-3}	(3) 1.0×10^{-2}	8.9×10^{-1}
HB-P-P-H	(14) 1.8×10^{-4}	(3) 6.6×10^{-4}	(1200) 1.0×10^{-3}	9.9×10^{-3}	(8) 1.0×10^{-2}	(1) 8.4×10^{-4}	(1) 3.3×10^{-2}	(1) 2.2×10^{-5}	(1) 6.8×10^{-3}	(3) 2.6×10^{-3}	6.5×10^{-2}
HB-P-P-R	(14) 2.1×10^{-4}	(3) 3.0×10^{-4}	(1200) 4.8×10^{-4}	5.7×10^{-3}	(8) 8.8×10^{-4}	(1) 1.0×10^{-4}	(1) 1.3×10^{-2}	(1) 1.0×10^{-5}	(1) 6.8×10^{-3}	(3) 1.2×10^{-3}	2.9×10^{-2}

Table 3.11
Production Phase Hazard Scenarios and Frequencies

SCENARIO	DESCRIPTION	CONTENTS	P/T (psia/°F)	MAX RATE (lb/min)	DURATION (min)	FREQUENCY (N/yr)
HB-P-W-D-BO	Well blowout while drilling - 27 wells over three years	Gas	65/85	10.8	N/A	5.0×10^{-3}
HB-P-W-P-BO	Well blowout during production - 30 wells	Gas	65/85	10.8	N/A	1.47×10^{-3}
HB-P-P-L	Leak within process unit with inlet and outlet blocked-in	Gas	65/85	2.7	360	8.9×10^{-1}
HB-P-P-H	Hole within process unit with inlet and outlet blocked-in	Gas	65/85	44	167	6.5×10^{-2}
HB-P-P-R	Rupture within process unit with inlet and outlet blocked-in	Gas	65/85	1570	4.6	2.9×10^{-2}
HB-P-PG-L	Leak of gas pipeline	Gas	120/62	3.9	60	5.0×10^{-4}
HB-P-PG-H	Hole in gas pipeline	Gas	120/62	62	3.2	1.5×10^{-4}
HB-P-PG-R	Rupture of gas pipeline	Gas	120/62	914	0.2	3.4×10^{-5}
HB-P-PG-DR	Double rupture of gas pipeline	Gas	120/62	1828	0.1	1.5×10^{-5}
HB-P-S-L	Storage tank failure	Gas	atm	-	-	4.5×10^{-2}
HB-P-PO-L	Leak of oil pipeline	Gas	-	-	-	3.6×10^{-3}
HB-P-PO-H	Hole in oil pipeline	Gas	-	-	-	1.3×10^{-3}
HB-P-PO-R	Rupture of oil pipeline	Gas	-	-	-	1.0×10^{-4}

Table 3.12
Existing Facilities Hazard Scenarios and Frequencies

SCENARIO	DESCRIPTION	CONTENTS	P/T (psia/°F)	MAX RATE (lb/min)	DURATION (min)	FREQUENCY (N/yr)
HB-X-L	Leak of propane vessel	Propane	200/65	6.6	5.0	1.0×10^{-4}
HB-X-H	Hole in propane vessel	Propane	200/65	105	1.6	1.5×10^{-5}
HB-X-R	Rupture of propane vessel	Propane	200/65	946	0.02	4.0×10^{-6}
HB-X-T	Vehicle public fatality road accident within ½ mile of site	-	-	-	-	1.0×10^{-4}

CHAPTER 4

CONSEQUENCE ANALYSIS

4.1 General Description of Consequence and Risk Analysis

What happens after the initial accidental release? What consequences evolve? Fire, explosions, toxic clouds? What are their relative chances of occurrence? These questions are answered through consequence analysis.

The primary components of consequence analysis are source and dispersion, fire and explosion, and effect or damage models. Source and dispersion models provide quantitative information on release rates and vapour cloud concentrations or spill characteristics and geometries. The ground level concentrations of toxic components of a gas cloud are used as basis for toxic hazard evaluation. Fire and explosion models convert the geometric and concentration data into hazard potentials such as thermal radiation and explosion overpressure levels. Effect or damage criteria are applied to incident-specific results to estimate casualty levels for workers or the public. Additional accuracy can be added by including consideration of mitigating factors such as sheltering, evacuation, protective gear, which reduce the magnitude of potential effects for the incidents considered.

A combination of the results of consequence analysis with frequencies of releases and their probable behavior within the situational context (e.g. probability of ignition in an urban setting) together with appropriate lethality criteria and population distributions leads to the quantification of risks. Various measures of risk may be utilized, ranging from annual risk to specific individuals (ISR) to total project risk spectra characterizing fatality or injury expectations over the full life of the project.

4.1.1 Consequence Event Overview

A schematic of the evolution of consequences associated with potential hazard scenarios for a flammable, toxic hydrocarbon release is presented in Figure 4.1. As may be seen, the hazard scenarios begin with the release of a flammable hydrocarbon which can be a gas, liquid, or a mixture of both. Liquid releases have been differentiated into high vapour pressure NGLs and low vapour pressure condensates because each class of liquid hydrocarbon behaves differently when released to the atmosphere. Following the release, the hazard scenario schematic shows releases which do not ignite but can result in toxic or environmental hazards. Finally, if the flammable hydrocarbon ignites, different types of fires or explosions can occur.

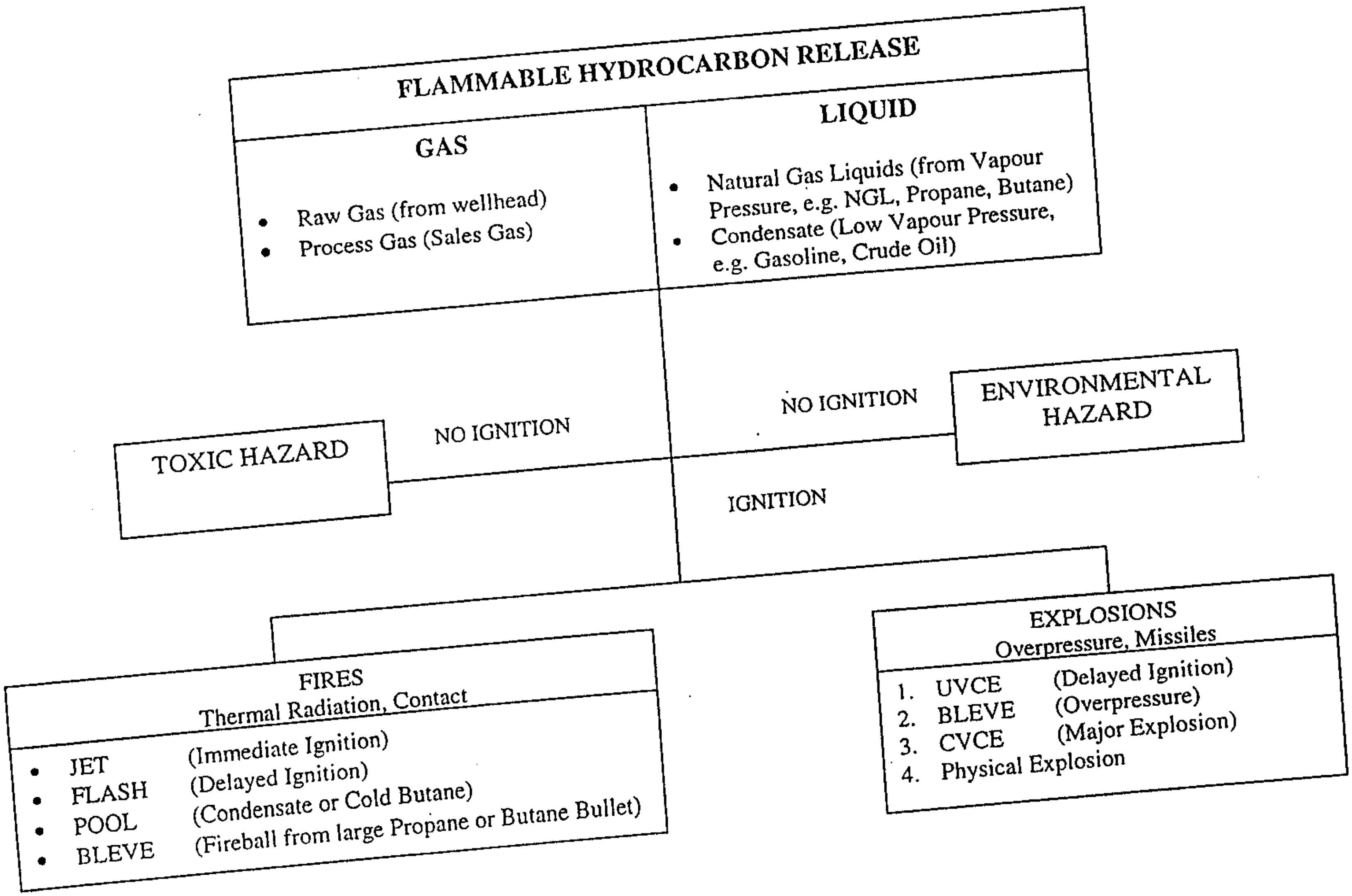
FLAMMABLE HYDROCARBON RELEASE
GAS
• Raw Gas (from wellhead)
• Process Gas (Sales Gas)
LIQUID
• Natural Gas Liquids (from Vapour Pressure, e.g. NGL, Propane, Butane)
• Condensate (Low Vapour Pressure, e.g. Gasoline, Crude Oil)
TOXIC HAZARD
NO IGNITION
NO IGNITION
ENVIRONMENTAL HAZARD
IGNITION
FIRES
Thermal Radiation, Contact
• JET (Immediate Ignition)
• FLASH (Delayed Ignition)
• POOL (Condensate or Cold Butane)
• BLEVE (Fireball from large Propane or Butane Bullet)
EXPLOSIONS
Overpressure, Missiles
1. UVCE (Delayed Ignition)
2. BLEVE (Overpressure)
3. CVCE (Major Explosion)
4. Physical Explosion

Figure 4.1

[illegible]

4.1.2 Analysis of Consequence Evolution Using Event Trees

Event trees are networks which illustrate and characterize the evolution of consequences from a given event. They are the opposite of fault trees, which illustrate and characterize the convergence of events leading to a given resultant. A typical event tree showing possible outcomes of a flammable hydrocarbon release is shown in Figure 4.2. As may be seen, the trunk of the event tree on the left side gives the initiating event, the occurrence of an accidental release, and its probability of occurrence for representative release sizes. The numbers are hypothetical. Following this initial event, moving toward the right, a series of bifurcations show alternative consequences together with their relative probability of occurrence given as a fraction.

On the far right side is given the Ratio of Occurrence (ROO) for each of the possible outcomes. The ratio of occurrence was obtained by sequentially multiplying the conditional probabilities of occurrence along the path leading to the outcome under consideration. Clearly, these ratios should add to unity. Multiplication of the ROO for any outcome by the frequency of the initiating event gives the frequency of that outcome. Thus, for example, the frequency of occurrence of a jet fire from a rupture (R) is given as 10^{-4}/year x .12 or 1.2 x 10^{-4}/year or approximately once in 10,000 years.

4.1.3 Damage Criteria

Quantitative measures of acute damage criteria were given in Chapter 2. As a summary, the following effect levels are used here:

- Flash fire flame boundary
- Jet fire thermal isopleths of 2, 4, and 8 kW/ft^2
- Explosion overpressure levels of 0.3, 1.0, and 3.0 psi
- Acute toxic H_2S GLC of 100 ppm for 30 min. (IDLH-new)

4.1.4 Consequence Modelling Process

Modelling of source, dispersion, and fire and explosion characteristics of the releases described in the previous chapter was accomplished utilizing a multi-purpose hazard and consequence analysis computer program called TRACE [44].

TRACE is a Windows 95/NT based multipurpose chemical release hazard and consequence evaluation model. Because of its state-of-art visual basic features in a Windows environment with full graphics capability the model is efficient and highly productive in the hands of a knowledgeable modeller. Its repertoire includes the following capabilities:

- Estimating the discharge rate and duration of a gas or liquid release from a vessel or pipeline

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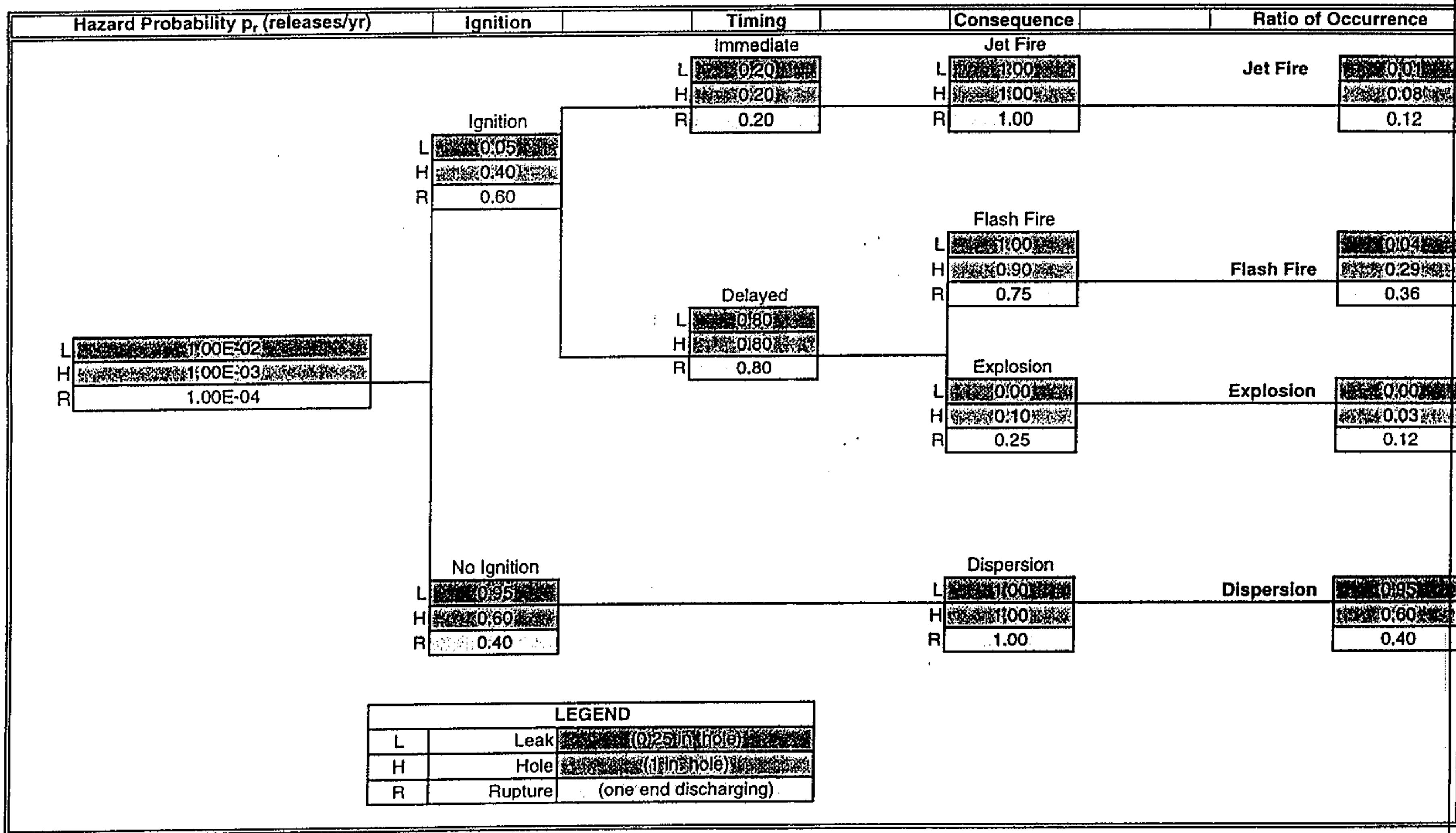


Figure 4.2
Typical Event Tree

BERCHA GROUP

- Estimates the size of any liquid pools that may form on the ground or within the offshore facility
- The rate at which a liquid pool will evaporate or boil and the duration of these phenomena until the point in time that the pool is depleted
- The size of the downwind hazard zone within the facility topology or on the sea for given wind and atmospheric parameters
- The thermal radiation hazards resulting from an ignition of a flammable or combustible pool of liquid
- The size of the downwind area that may be subjected to flammable, explosive, or toxic concentrations of gases or vapours in air due to the release of a gas or vapour
- The maximum weight of potentially explosive gas or vapour in air that occurs during a release incident.
- The consequences of an explosion arising from the internal overpressurization of a sealed or inadequately vented tank due to external heating or internal reaction
- The consequences of an explosion arising from ignition of a true explosive material in the solid or liquid state.
- Explosion modelling by both TNO multi-energy and Baker Strehlow Methodologies
- Full dispersion modelling capability including inertia, buoyancy, and multicomponent gas or fluid mixtures
- Isopleths for selected damage criteria for toxic, thermal, or overpressure effects
- Risk evaluation for specified population distributions

4.1.5 Consequence Model Results

The modelling tools utilized for the assessment of the immediate consequences of flammable hydrocarbon releases were used to quantify the following principal hazard parameters:

- Downwind distances and widths of multicomponent gas cloud ground level concentrations (GLC), as well as associated vertical and horizontal sections.
- Downwind distance and width of various upper and lower flammability limits and associated thermal radiation levels upon ignitions
- Radii of a range of overpressure levels (1 to 3 psi) associated with uncontained vapour cloud explosions
- Length and width of jet fires and associated thermal radiation levels
- Diameters of fireballs and associated ranges of harmful thermal radiation levels

4.2 Selection of Representative Atmospheric Conditions

The dispersion behavior of a gas release is dependent on atmospheric conditions prevailing during the release. Specifically, the geometry of the vapour cloud concentration depends on the wind direction and velocity and the prevailing atmospheric stability class. Atmospheric stability classes are categorized on a scale of 1 to 7, or the letters A to G, ranging from the most unstable for 1 or A to the most stable for 7 or G. In consonance with this, wind direction and intensity data are reported for each of the stability classes as well as in summaries for the unstable (A, B, C) and stable (E, F, G) classes.

For the present study, three representative conditions were considered and the consequence analysis was carried out accordingly. These representative conditions are as follows:

- Unstable (Classes A, B, and C) with a mean wind speed of 3 m/s
- Stable (Classes E, F, and G) with a mean wind speed of 2 m/s
- Worst case (Class G) with a mean wind speed determined through sensitivity analysis for each characteristic release size

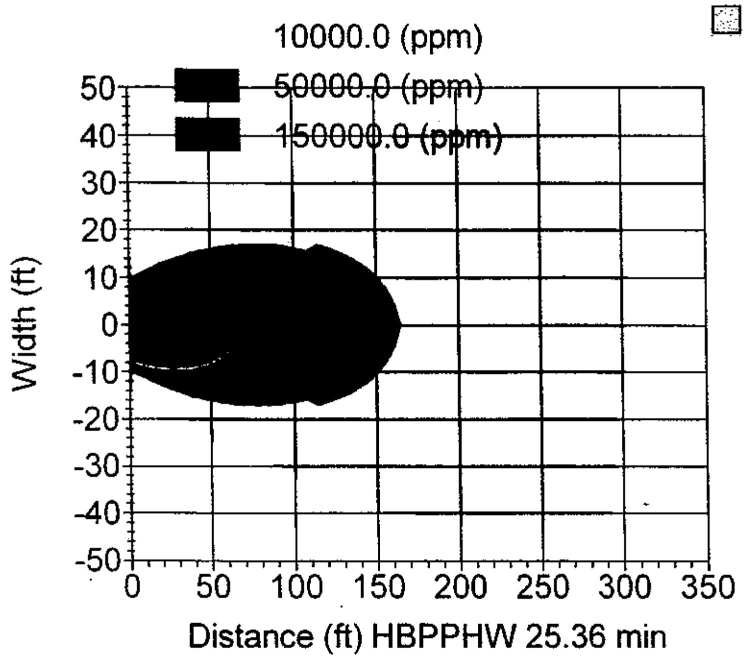
For the purposes of the present study, the atmospheric worst case was deemed to be the atmospheric condition conducive to the highest ground level concentration over the largest distance from the sources for each of the characteristic release sizes. This worst case condition was assessed by studying the dispersion patterns for each of the characteristic release sizes for a range of wind velocities between 0 and 1 m/s for the most stable atmospheric class (Class G). Table 4.1 summarizes the results of these sensitivity studies for each of the characteristic release scenarios. The worst case condition for each case is highlighted. It can be seen that for the leak and hole releases, the worst case wind velocity is 0.05 m/s, or almost still air. While, for the rupture conditions, a higher wind velocity of 0.25 m/s was identified as that associated with the worst case or largest ground level concentration footprint conditions. As indicated above, the table only gives the salient results of the sensitivity analysis. Figure 4.3 shows examples of the graphic output from the TRACE program showing the full vertical profile and horizontal plan of dispersion isopleth for the worst case Hole conditions at 25.36 minutes. The dispersion isopleth modelled here is that from a horizontal, ground level jet release of a multicomponent gas mixture characteristic of the process gas from the Hermosa Beach Oil Project.

For subsequent steps in the risk analysis, it is also necessary to estimate the probability of occurrence associated with the worst case condition as well as the representative stable and unstable conditions. Figure 4.4 shows the cumulative probability distribution function for wind intensity between 0 and 2 m/s, estimated by plotting the wind intensity data for Redondo Beach for the Class G most stable conditions. From this CDF, it follows that the probability of wind speeds less than 0.1 m/s is approximately 10%, and that of wind speeds between 0.1 and 0.2 m/s is also approximately 10%.

Table 4.1
Summary of Meteorology Sensitivity Study

CASE	STAB. CLASS	WIND v (m/s)	TIME OF MAX FOOTPRINT (min)	SIZE (ft) 50000 ppm	
				LENGTH	WIDTH
Rupture HB-P-P-R-W	G	2.5	1.08	120	13
		2.0	1.25	14	14
		1.0	1.08	220	25
		0.5	2.17	260	30
		0.25	**4.34**	**280**	**50**
		0.10	4.34	170	60
		0.05	5.43	140	75
Hole HB-P-P-H-W	G	2.5	23.43	110	1.7
		2.0	39.30	110	2.5
		1.0	23.43	120	3.0
		0.5	23.45	95	5
		0.25	23.53	70	7
		0.10	16.24	110	12
		0.05	**25.36**	**160**	**16**
Leak HB-P-P-H-W	G			SIZE (ft) 10,000 ppm[1]	
				L	W
		3.0	5.0	0	0
		2.0	5.0	30	1.6
		0.25	5.0	50	4.6
		0.05	**10.0**	**100**	**10**

[1] A GLC of 50,000 ppm does not occur for the leak.



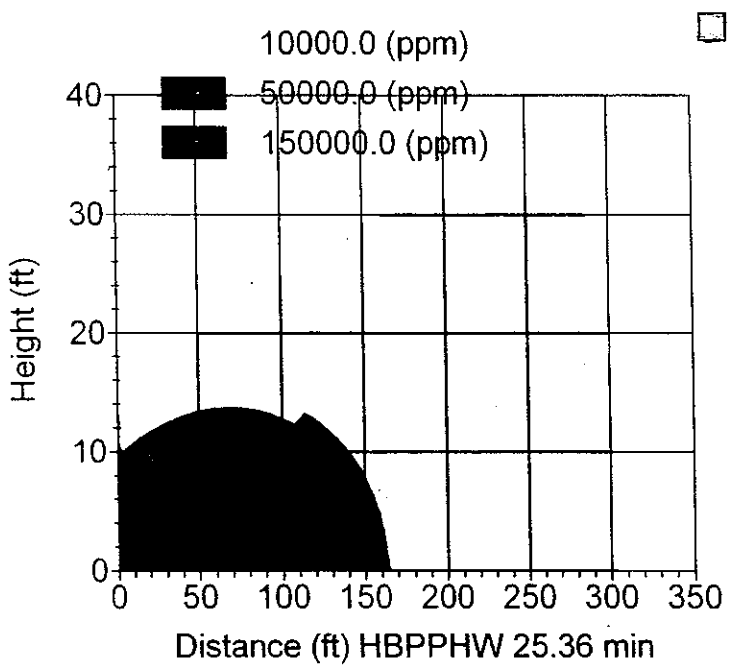


Figure 4.3
Examples of TRACE Program Output

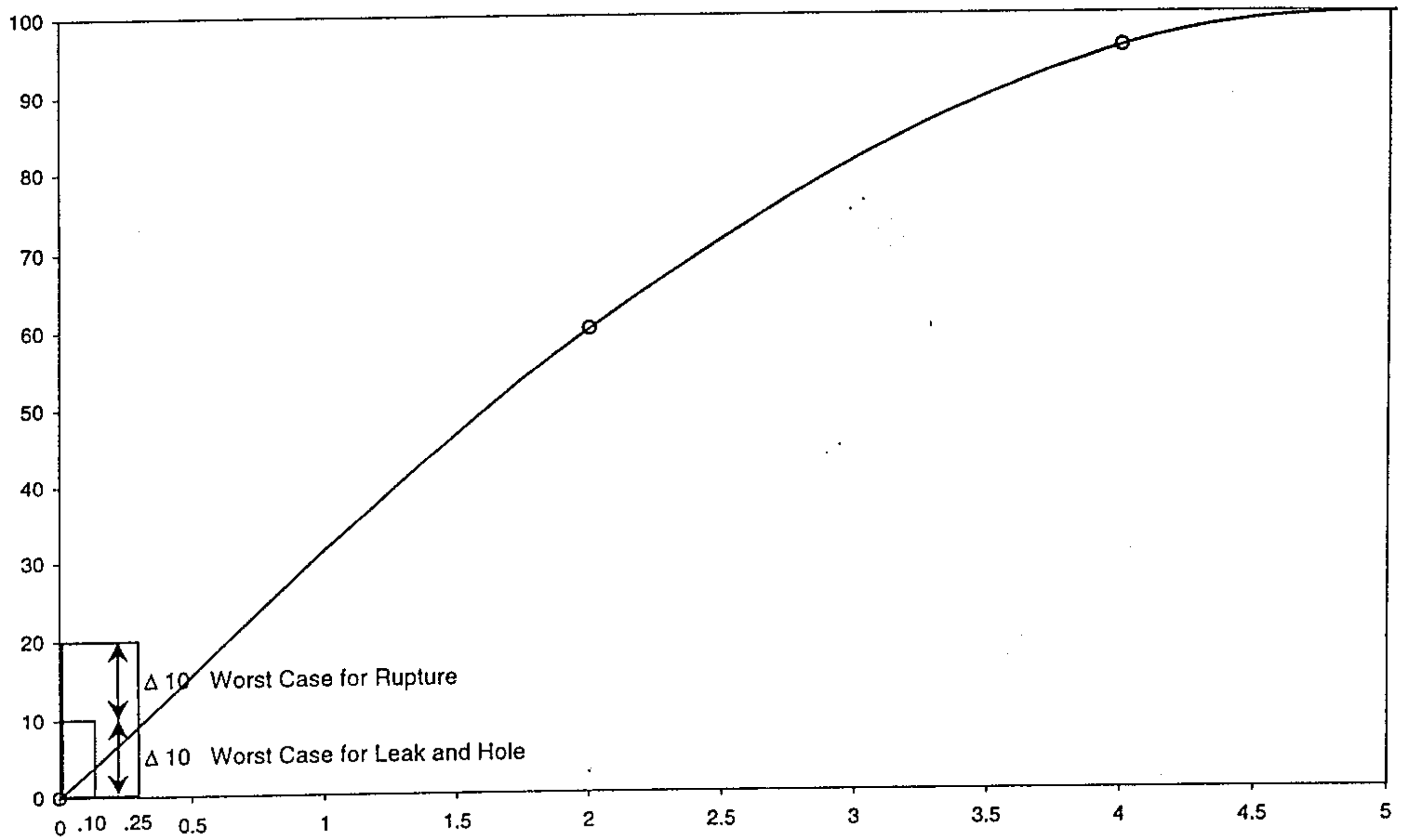


Figure 4.4
Wind Velocity CDF for Class G Stability

In the probability analysis discussed in Chapter 5, the worst case was accordingly taken to occur 10% of the time while the balance of the time was equally distributed between stable (night) and unstable (day) conditions.

4.3 Effects of Topography and Buoyancy

The risk assessment described in this report was largely carried out on the basis of the most conservative release type, which gives the highest and most extended ground level concentrations. This release type is a jet or blowdown release in a horizontal direction at ground level. In fact, the majority of the releases associated with the process facilities are likely to be somewhat elevated above ground level, generally up to several feet, since the process piping and equipment are usually installed on supports to maintain them above the grade.

When a horizontal jet release of a gas lighter than air (such as the current multicomponent mixture which is approximately ½ the density of air) occurs from an elevated source above the ground, the effects of buoyancy are much more pronounced than for the case of ground level releases. Typical elevated releases for the process phase were modelled and compared to ground level releases for the leak, hole, and rupture, respectively, as shown in Figure 4.5, 4.6, and 4.7.

By considering that these releases could occur in the easterly direction, the direction of a gradual rise in the terrain, the effects of topography can be graphically viewed by comparing the release geometry to the topographic cross-section superimposed on each of the release vertical profiles. As can be seen, the release rise for the elevated source is steep enough that topography is unlikely to result in an accentuation of the ground level concentrations. For the ground level horizontal releases, similarly, the vertical concentration isopleths are high and steep enough as they approach the ground that the variation in topography experienced on the maximum gradient side (east) are also unlikely to significantly alter the results.

4.4 Test Phase Consequence Analysis

4.4.1 Test Phase Consequence Evolution Event Trees

Figure 4.8 shows the consequence evolution event tree associated with releases from the test phase process component and wells. As may be seen, the event tree gives the initial release frequency for leaks, holes, and ruptures, and as described in Section 4.1.2, gives the evolution of consequences moving from left to right, ultimately providing the Ratio of Occurrence (ROO) of each of the possible outcomes of the release. These values of ROO are utilized subsequently in the risk analysis described in Chapter 5 to obtain the next measures of risk associated with each of the release scenarios.

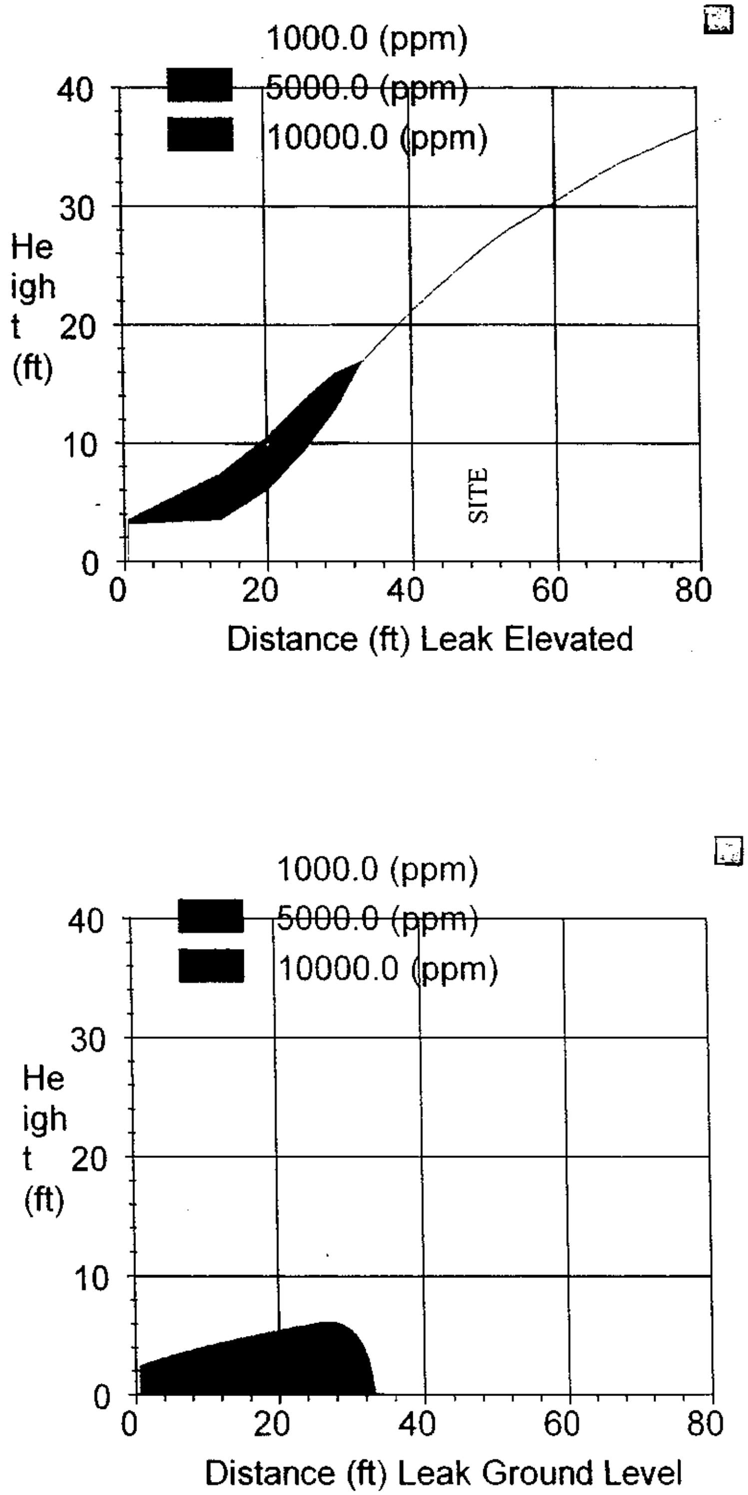
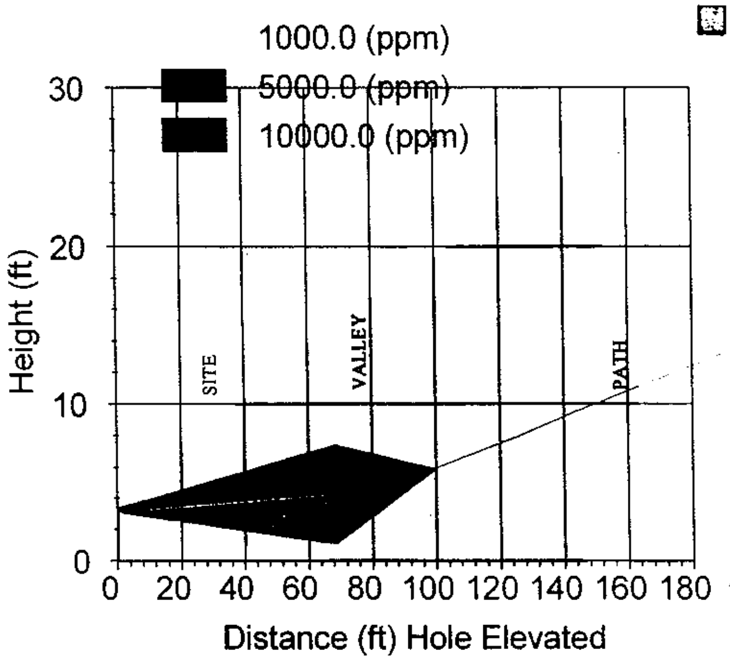


Figure 4.5
Elevated and Ground Level Release Profiles for Leak



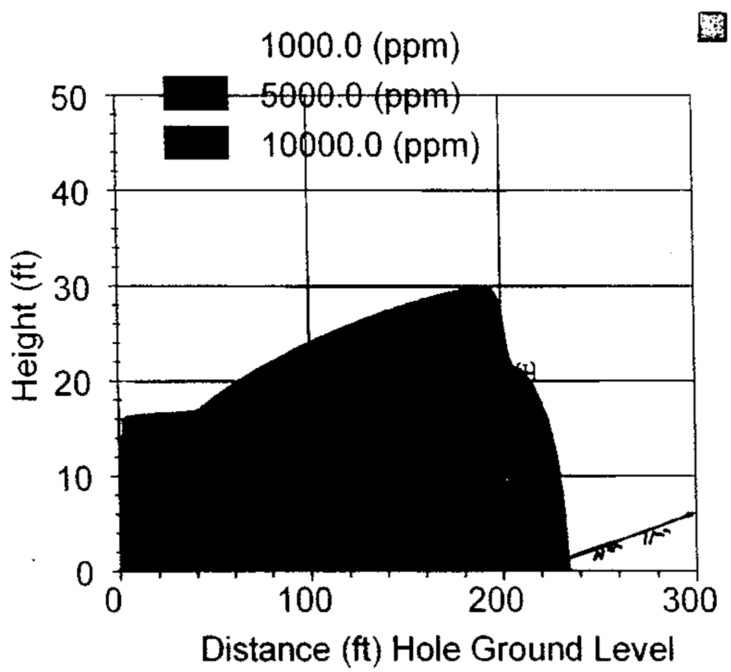
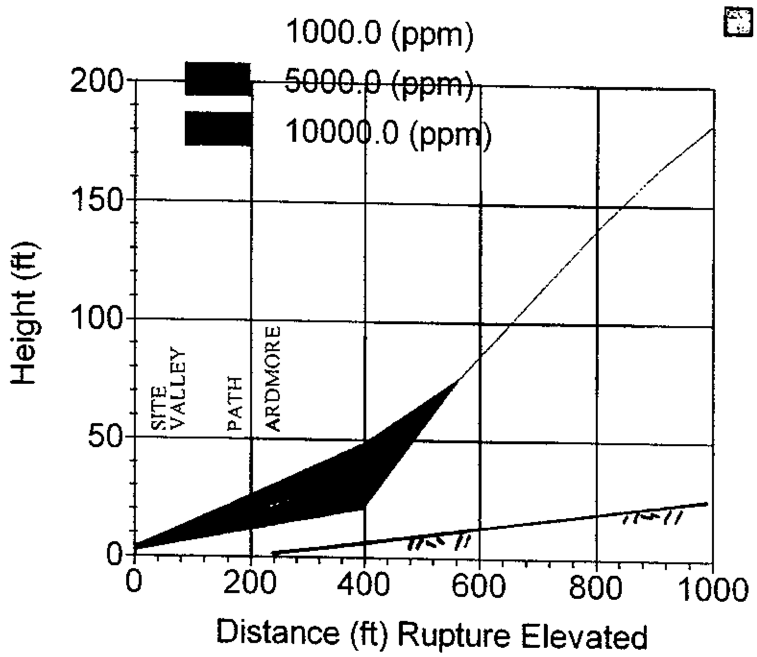


Figure 4.6
Elevated and Ground Level Release Profiles for Hole



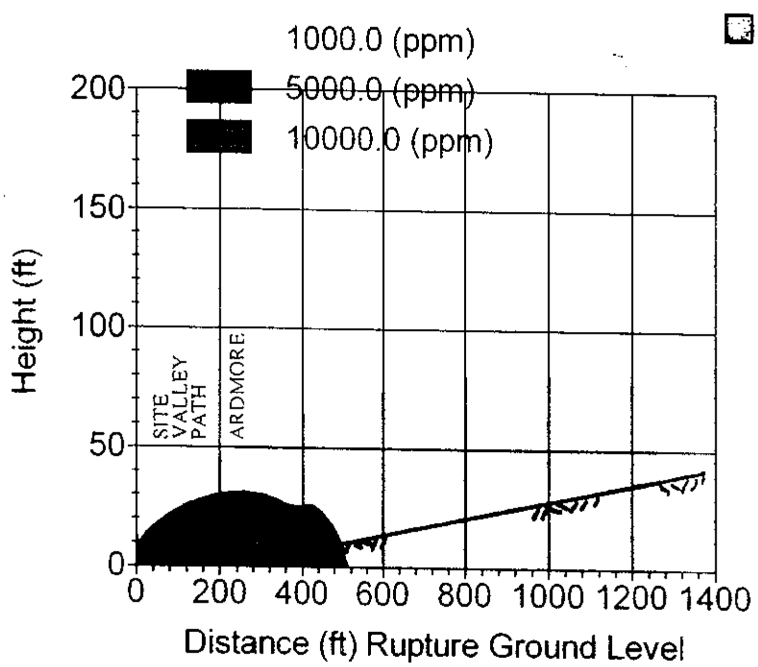


Figure 4.7
Elevated and Ground Level Release Profiles for Rupture

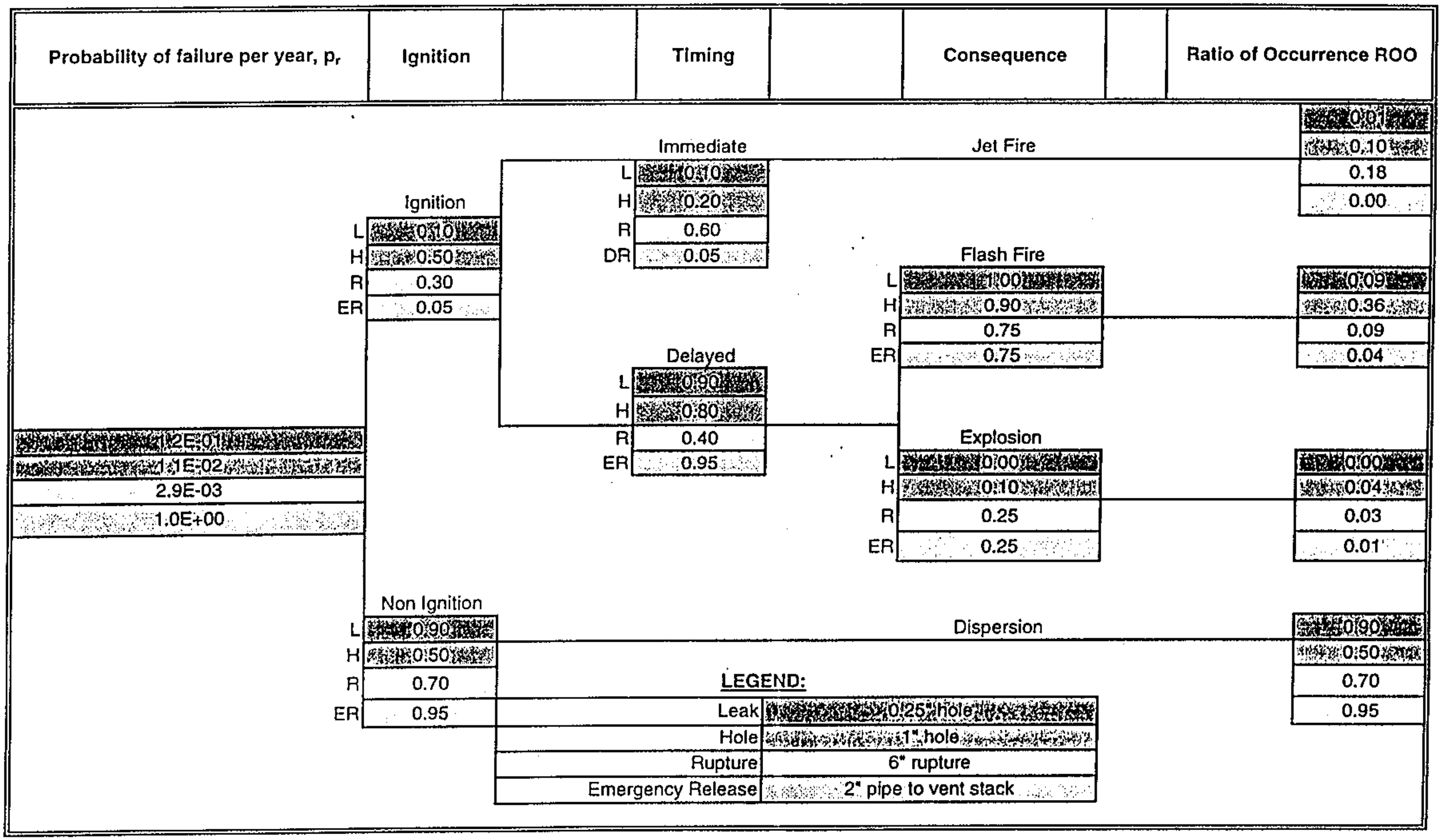


Figure 4.8
Event Tree - Process - Test Phase

4.4.2 Consequence Model Results

As indicated earlier, the consequence model is a multi-purpose physical modelling tool capable of estimating time-dependent liquid or gaseous (or both) releases into the environment. The model provides both tabular and graphic outputs as illustrated in Figure 4.9, 4.10, and 4.11, and Table 4.2. The salient results of the modelling of the key release scenario outcomes for the test phase are summarized in Table 4.3. As may be seen, for each of the scenarios and designated atmospheric conditions, the isopleths for flash fires, jet fires, and explosion overpressures are given. In addition, a weighted average value of these distances is also given primarily to provide perspective on the average expectation associated with each scenario. The precise distances and associated probabilities, however, are used in the actual calculations to be described in Chapter 5. The consequence modelling results, from left to right, can be characterized as follows for Table 4.3:

- N, is the scenario number
- The scenario code description as described in Section 3.4
- The release type specification in terms of release orifice
- Process volume, pressure, and temperature in the release segment
- The duration of the release from the time it occurs until the segment reaches atmospheric pressure
- The maximum release rate which occurs at the initiation of the release
- The meteorology and its relative probability in percent associated with each of the scenarios modelled
- The maximum thermal isopleth distance for flash fires, which occur in a downwind direction from the facility
- The maximum isopleth distance for different thermal isopleths for jet fires which can occur in any direction, depending on the release orientation
- The maximum explosion overpressure isopleth distance for 3 different overpressure levels from the epicenter which is located downwind of the release as the explosion occurs from the ignition of a vapour cloud which moves in the direction of the wind
- The entries for the table were generally obtained directly from the isopleth plots, for example, the HB-P-P-H-D flash fire thermal radiation isopleth illustrated in Figure 4.12

4.5 Production Phase Consequence Model Results

4.5.1 Production Phase Consequence Evolution Event Trees

Figure 4.13 shows the consequence evolution event tree for the production phase pipeline. The event tree for the production phase process facilities is the same as that in Figure 4.5 for the test phase process facilities.

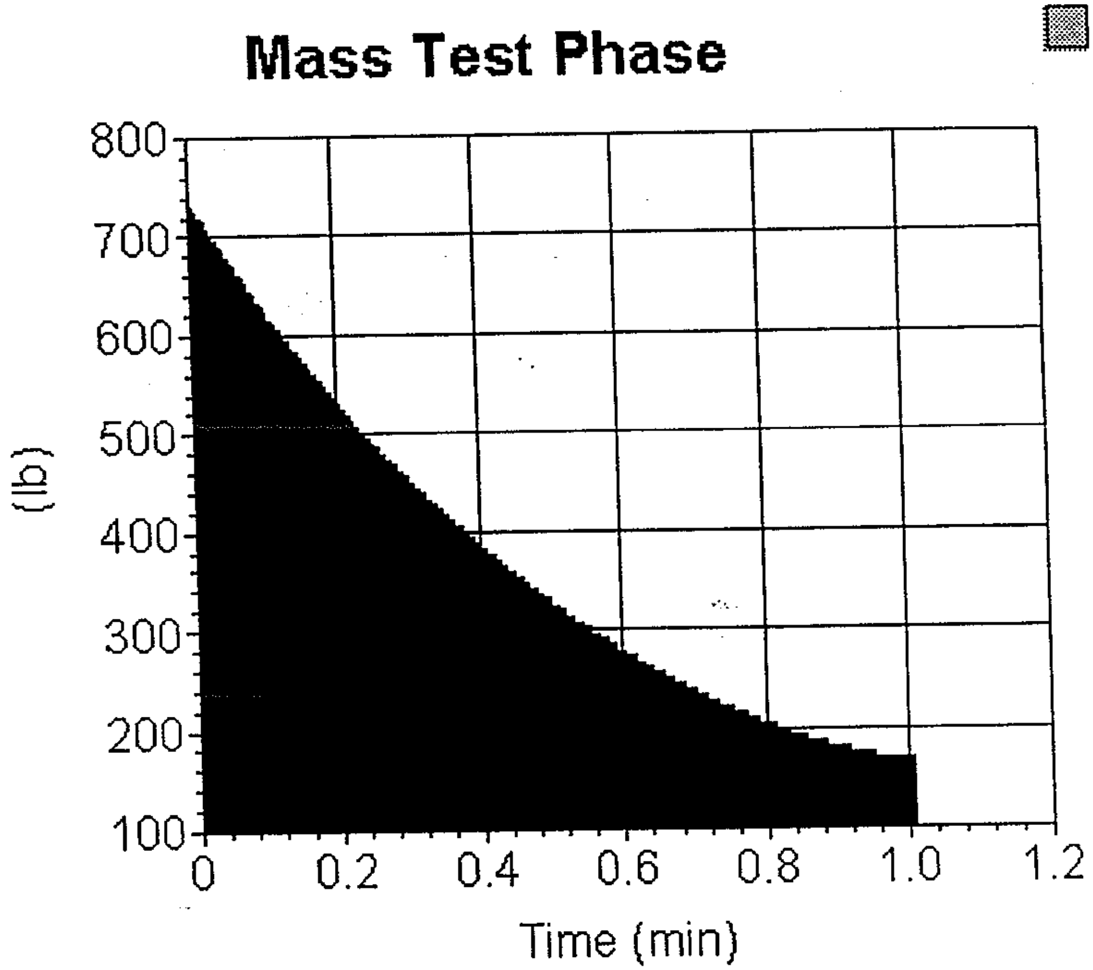


Figure 4.9
Tank Mass Blowdown Graph

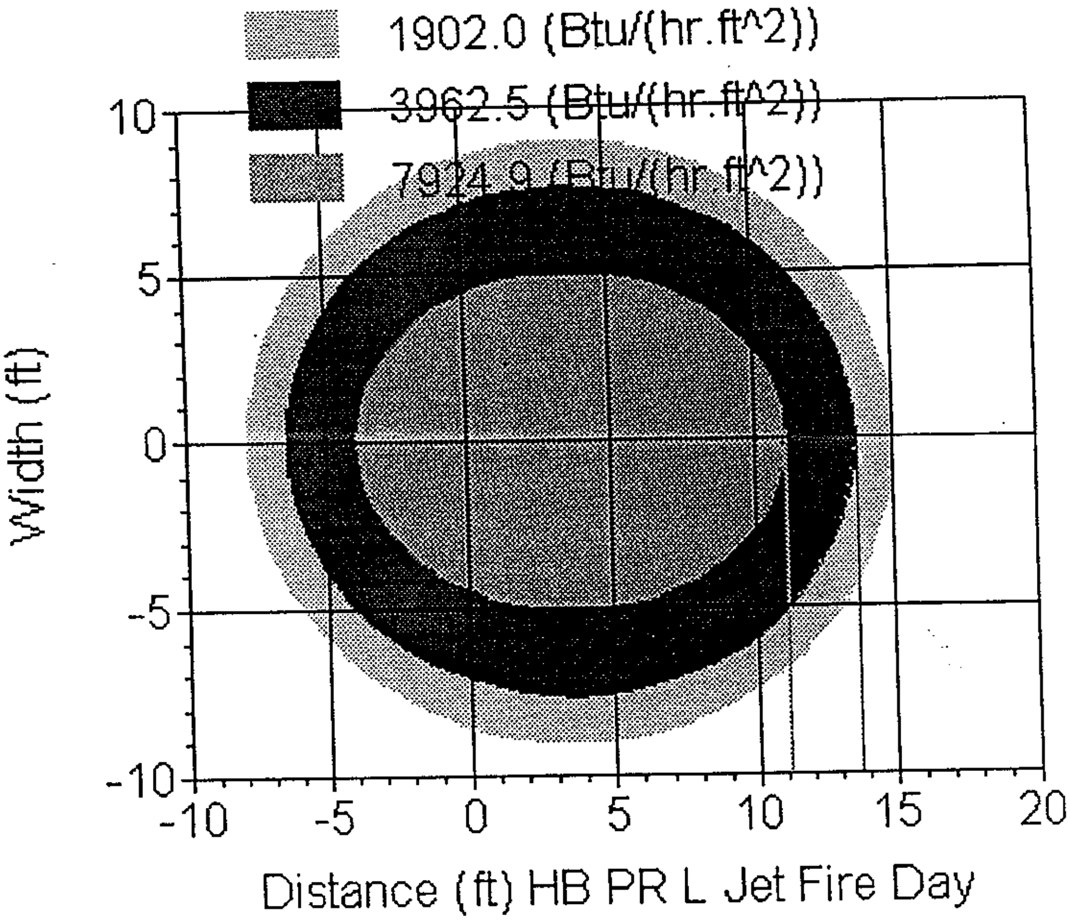


Figure 4.10
Thermal Radiation Isopleths for Jet Fire

HB T H Release Day

Study

Description	HB T H Release Day
Notes	Type your notes here
Created On	5:45:54 PM
Revised On	10:40:03 AM
Scenario selected for this study	HB T H
Meteorology selected for this study	Hermosa Beach Day
Isopleth limits selected for this study	Hermosa Beach Methane Limits
Simulation time	Let the program decide (Automatic)
Model flash fire	Yes
Model vapor cloud explosion	Yes
Time of ignition	240.0 (s)
Surface radiation intensity	53889.6 (Btu/(hr.ft^2))

Summary of source characteristics

Scenario type	Tank
Release duration	3600.0 (min)
Padding pressure	14.7 (psi)
Type of release	Transient
Release stream condition	Gas
Maximum release rate	32.8 (lb/min)
Release duration	36.3 (min)
Occurance of flash	No
Pool formation	No
Evaluate dispersion isopleths at height	0.0 (ft)
Averaging time	0.2 (min)
Meander time	0.2 (min)

Concentration

Isopleth limit (ppm)	Maximum isopleth distance (ft)	Maximum isopleth half width (ft)
10000.0	213.3	1.6
50000.0	213.3	1.3
150000.0	213.3	1.0

Default Receptor

Downwind distance (ft)	Peak meander concentration (ppm)	Dose (ppm-min)	Exposure time (min)
0.0	999993.5	2907789.0	36.4
0.0	999993.5	2907789.0	36.4
0.0	999993.5	2907789.0	36.4
0.0	999993.5	2907789.0	36.4
0.0	999993.5	2907789.0	36.4
0.0	999993.5	2907789.0	36.4
0.0	999993.5	2907789.0	36.4
0.0	999993.5	2907789.0	36.4

Figure 4.11
Typical TRACE Tabular Output

Table 4.2
Tabular Output for Explosion Overpressures

Explosion - Centerline values

Distance (ft)	Overpressure (psi)	Impulse (psi-min)
52.0	0.9	0.002
83.4	0.7	0.001
114.8	0.5	0.001
146.1	0.4	0.001
177.5	0.3	0.001
208.8	0.3	0.001
240.2	0.2	0.001
271.6	0.2	0.001
302.9	0.2	0.0005
334.3	0.2	0.0004
365.7	0.2	0.0004
397.0	0.1	0.0004
428.4	0.1	0.0003
459.8	0.1	0.0003
491.1	0.1	0.0003
522.5	0.1	0.0003
553.9	0.1	0.0003
585.2	0.1	0.0003
616.6	0.1	0.0002
648.0	0.1	0.0002
679.3	0.1	0.0002
710.7	0.1	0.0002
742.0	0.1	0.0002
773.4	0.1	0.0002
804.8	0.1	0.0002
836.1	0.1	0.0002
867.5	0.1	0.0002
898.9	0.1	0.0002
930.2	0.1	0.0002
961.6	0.1	0.0002
993.0	0.1	0.0002
1024.3	0.1	0.0001
1055.7	0.1	0.0001
1087.1	0.1	0.0001
1118.4	0.1	0.0001
1149.8	0.1	0.0001
1181.2	0.1	0.0001
1212.5	0.05	0.0001
1243.9	0.05	0.0001
1275.2	0.05	0.0001
1306.6	0.05	0.0001
1338.0	0.04	0.0001
1369.3	0.04	0.0001
1400.7	0.04	0.0001
1432.1	0.04	0.0001
1463.4	0.04	0.0001
1494.8	0.04	0.0001
1526.2	0.04	0.0001
1557.5	0.04	0.0001

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Table 4.3
Summary of Consequence Modelling Results

N	Scenario	Release Type	V [ft³] p [psi] T [°F]	Release [min]	Max Release Rate [lb/min]	Meteorology		Max Isopleth Distance [ft] Flash Fire, Thermal Radiation [Btu / hr ft²]			Max Isopleth Distance [ft] Jet Fire, Thermal Radiation [Btu / hr ft²]			Max Isopleth Distance [ft] Explosion Overpressure [psi]		
						Class	%	1902.0	3962.5	7924.9	1902.0	3962.5	7924.9	0.3	1.0	3.0
1	HB-P-PG-L-D	Leak 1/4" Dia	260 120 62	50.9	3.9	B	45	4.5	2.1	1	10.9	10.4	9.3	0	0	0
2	HB-P-PG-L-N					F	45	5.5	2.6	1.3	11.7	11	9.7	0	0	0
3	HB-P-PG-L-W					W	10	49.1	46.6	45.1	14.4	13.2	11.1	0	0	0
						Average		9.4	6.8	5.5	11.6	11.0	9.7	0.0	0.0	0.0
4	HB-P-PG-H-D	Hole 1" Dia		3.2	62.4	B	45	7.7	3.6	2.6	35.1	31.8	28.5	0	0	0
5	HB-P-PG-H-N					F	45	39.9	27.1	23.1	37.9	34.5	31.2	0	0	0
6	HB-P-PG-H-W					W	10	102.6	74.2	54.5	47.8	44.1	40.2	0	0	0
						Average		31.7	21.2	17.0	37.6	34.2	30.9	0.0	0.0	0.0
7	HB-P-PG-R-D	Rupture 3.83" Dia		0.2	914.1	B	45	132.5	75.1	45.1	116.1	103.9	94.8	100.8	0	0
8	HB-P-PG-R-N					F	45	132.8	80	55.2	124.9	112.7	103.4	100.8	0	0
9	HB-P-PG-R-W					W	10	132.8	80	65.2	124.9	112.7	103.4	100.8	0	0
						Average		132.7	77.8	50.7	120.9	108.7	99.5	100.8	0.0	0.0
10	HB-P-PG-D-D	Double Rupture 5.41" Dia Eq.Hole		0.1	1827.7	B	45	132	74.6	44.6	162.1	144.6	131.9	100.8	0	0
11	HB-P-PG-D-N					F	45	127.6	75.6	52.4	174.4	156.7	144.1	100.8	0	0
12	HB-P-PG-D-W					W	10	127.6	75.6	52.4	174.4	156.7	144.1	100.8	0	0
						Average		129.6	75.2	48.9	168.9	151.3	138.6	100.8	0.0	0.0
13	HB-T-W-D-BO-D	Well Blowout	n/a 64.7 85	n/a	10.8	B	45	12.5	6	3	41	37	30	0	0	0
14	HB-T-W-D-BO-N					F	45	19	18	18	42	38	31	0	0	0
15	HB-T-W-D-BO-W					W	10	122.2	116.5	113	48.6	42.9	32.1	0	0	0
						Average		26.4	22.5	20.8	42.2	38.0	30.7	0.0	0.0	0.0
16	HB-T-P-L-D	Leak 1/4" Dia	4080 64.7 85	581.6	2.1	B	45	4.5	2.1	1	15	13.5	10.2	0	0	0
17	HB-T-P-L-N					F	45	5.5	2.8	1.3	15.5	13.5	10	0	0	0
18	HB-T-P-L-W					W	10	43.2	41	39.7	17.2	14.2	10	0	0	0
						Average		8.8	6.3	5.0	15.4	13.6	10.1	0.0	0.0	0.0

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Table 4.3
Summary of Consequence Modelling Results (continued)

N	Scenario	Release Type	V [ft³] p [psi] T [°F]	Release [min]	Max Release Rate [lb/min]	Meteorology Class	%	Max Isopleth Distance [ft] Flash Fire, Thermal Radiation [Btu / hr ft²] 1902.0	3962.5	7924.9	Max Isopleth Distance [ft] Jet Fire, Thermal Radiation [Btu / hr ft²] 1902.0	3962.5	7924.9	Max Isopleth Distance [ft] Explosion Overpressure [psi] 0.3	1.0	3.0
19	HB-T-P-H-D	Hole 1" Dia	4080 64.7 85	36.3	32.8	B	45	47	38	38	31	29	26.5	0	0	0
20	HB-T-P-H-N					F	45	68	65	65	33	31	28	0	0	0
21	HB-T-P-H-W					W	10	121.7	97.2	81	40.8	38.3	33.6	0	0	0
						Average		63.9	56.1	54.5	32.9	30.8	27.9	0.0	0.0	0.0
22	HB-T-P-R-D	Rupture 6" Dia		1	1181	B	45	160	92	51	142	127	117	120	0	0
23	HB-T-P-R-N					F	45	218	142	100	152	138	126	120	0	0
24	HB-T-P-R-W					W	10	231	149.8	113.7	189.7	173.9	161	120	0	0
						Average		193.2	120.3	79.3	151.3	136.6	125.5	120.0	0.0	0.0
25	HB-T-P-E-D	PSV 2" Dia	4080 64.7 85	9.1	131.2	B	45	50	32	23	54	49	44	0	0	0
26	HB-T-P-E-N					F	45	62	43	38	58	53	48	0	0	0
27	HB-T-P-E-W					W	10	180.1	136.6	106.7	72.9	67.9	61.8	0	0	0
						Average		68.4	47.4	38.1	57.7	52.7	47.6	0.0	0.0	0.0
28	HB-P-P-L-D	Leak 1/4" Dia	16200 64.7 85	360	2.7	B	45	5	2.4	1	15	13.8	11	0	0	0
29	HB-P-P-L-N					F	45	6.2	3	1.5	15.5	14	11	0	0	0
30	HB-P-P-L-W					W	10	23.8	16.7	16.6	17.4	14.9	11	0	0	0
						Average		7.4	4.1	2.8	15.5	14.0	11.0	0.0	0.0	0.0
31	HB-P-P-H-D	Hole 1" Dia		167.2	43.6	B	45	13	6	3	46	44	38	0	0	0
32	HB-P-P-H-N					F	45	16	7.5	3.5	49	45	38	0	0	0
33	HB-P-P-H-W					W	10	129.1	102.7	81.1	56.2	50.9	40.6	0	0	0
						Average		26.0	16.3	11.0	48.4	45.1	38.3	0.0	0.0	0.0
34	HB-P-P-R-D	Rupture 6" Dia		4.6	1571	B	45	150	90	55	160	145	130	120	0	0
35	HB-P-P-R-N					F	45	200	155	155	170	156	141	120	0	0
36	HB-P-P-R-W					W	10	317.5	224.3	159.7	208.9	192.2	176.9	120	0	0
						Average		189.3	132.7	110.5	169.4	154.7	139.6	120.0	0.0	0.0

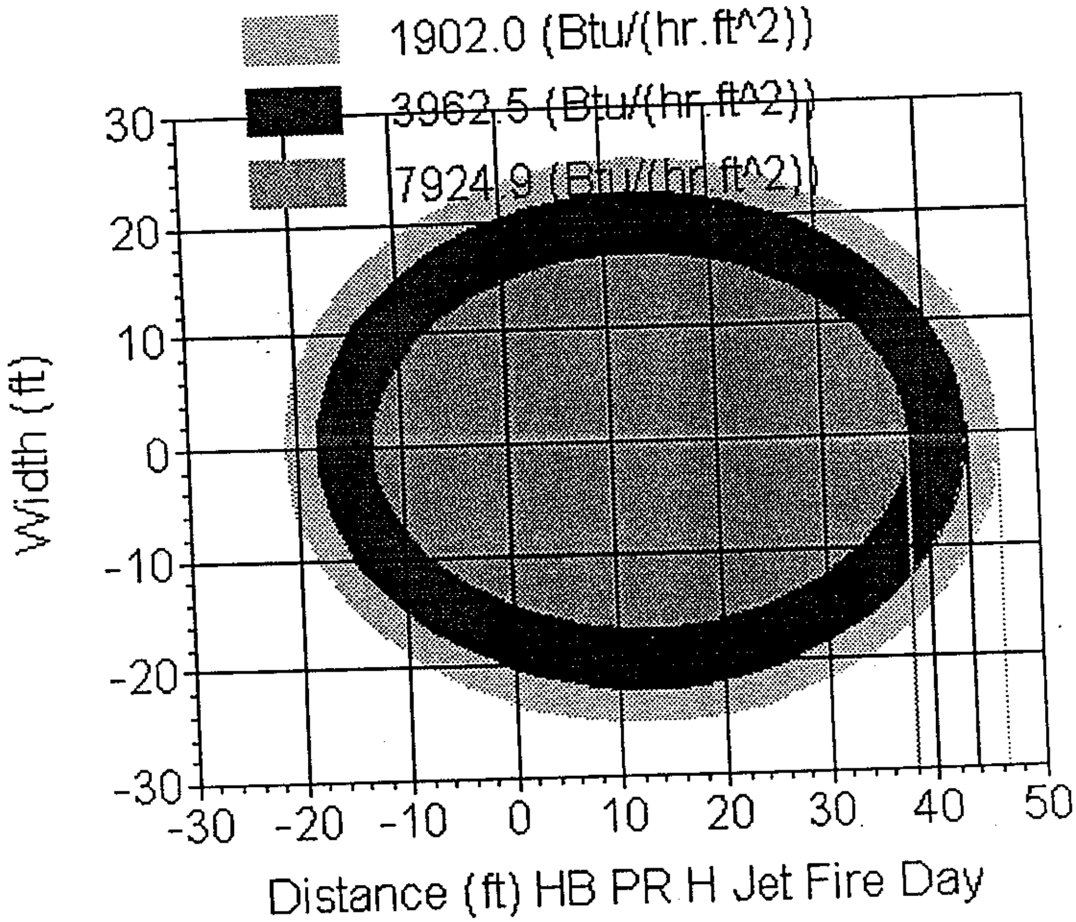

Figure 4.12
Isopleth Plot for HB-P-P-H-W

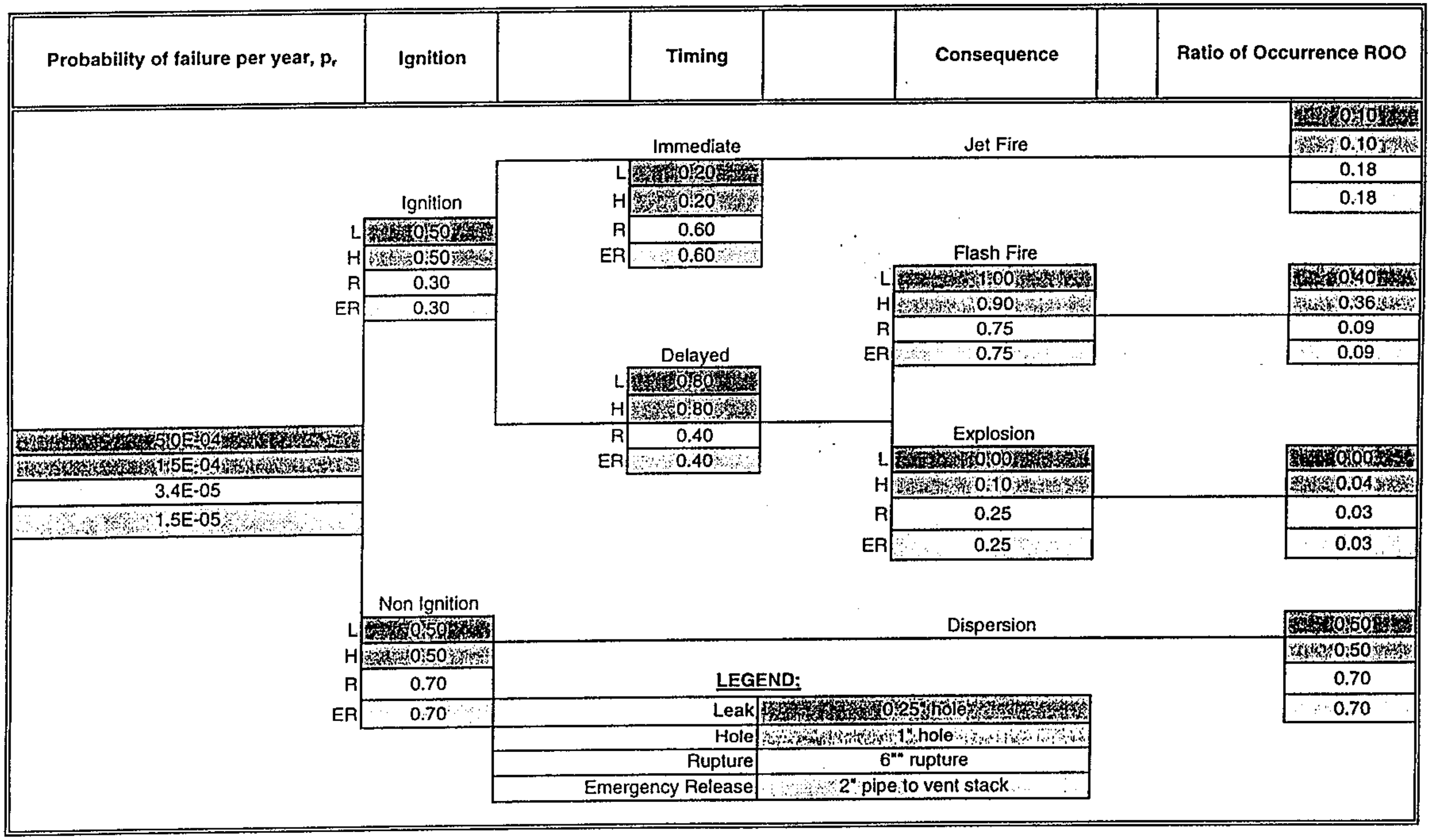

Figure 4.13
Event Tree - Gas Pipeline - Using Point Source Method

4.5.2 Production Phase Consequence Model Results

Table 4.3 summarizes the salient results from the consequence modelling for the production phase. It is in the same format and protocol as the table described in the test phase.

4.6 Existing Facilities

The event tree for the existing facilities consequence evolution is the same as that used for the test and production phase process facilities. The consequence model results for the existing facilities consequence modelling are given in Table 4.4.

4.7 Low-level H_2S Ground Level Concentrations

No acute damage H_2S ground level concentrations were found to occur because the maximum source concentration modelled was 40 ppm, while the minimum acute damage criterion concentration is 100 ppm.

However, low-level H_2S concentrations for leak, hole, and rupture releases were modelled in accordance with the mandate to study these in the present investigation. Table 4.5 summarizes the ground-level concentrations associated with representative stable atmospheric conditions and worst-case conditions for ground-level releases of the multi-component 40 ppm H_2S gas mixture. Figures 4.14, 4.15, and 4.16 illustrate the H_2S concentrations as a function of distance from the source associated with these low-level releases.

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Table 4.4
Summary of Consequence Modelling Results for Existing Facilities

N	Scenario	Release Type	V [ft³] p [psi] T [°F]	Release [min]	Max Release Rate [lb/min]	Meteorology	Max Isopleth Distance [ft] Flash Fire, Thermal Radiation [Btu / hr ft²]			Max Isopleth Distance [ft] Jet Fire, Thermal Radiation [Btu / hr ft²]			Max Isopleth Distance [ft] Explosion Overpressure [psi]		
						Class	1997.1	3962.5	7924.9	1997.1	3962.5	7924.9	0.3	1.0	3.0
1	HB-X-L	Leak 1/4" Dia		5	6.6	F	5	3	1	18	17	15	68	0	0
1	HB-X-H	Hole 1" Dia	67 200 65	1.6	105	F	127	96	77	65	59	55	68	0	0
2	HB-X-R	Rupture 3" Dia		0.02	946	F	127	96	77	175	158	145	68	0	0

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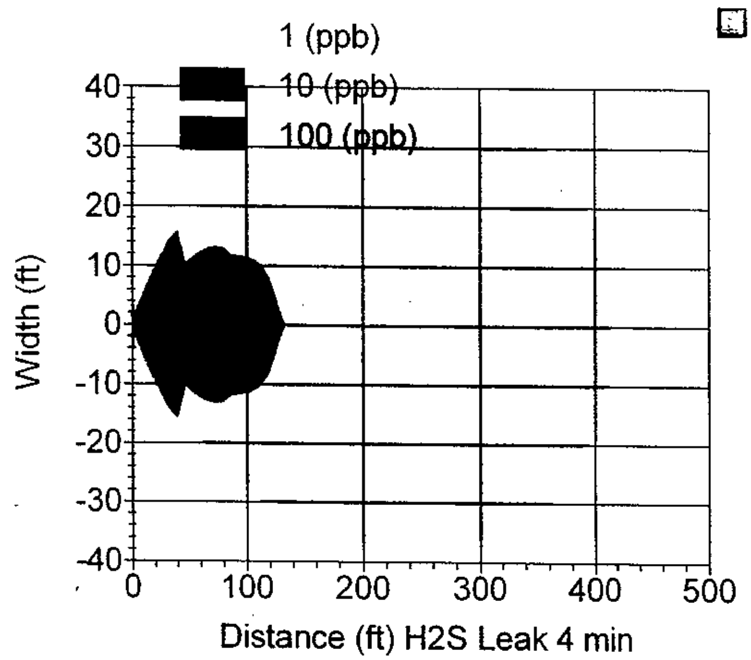
Table 4.5
Summary of H_2S Low Level GLC

Scenario	Release Type	V [ft^3] p [psi] T [^oF]	Release [min]	Max Release Rate [lb/min]	Down-wind Distance to GLC [ft.]		
					1 ppb	10 ppb	100 ppb
HB-P-P-L-LL	Leak 1/4" Dia	16200 64.7 85	360	2.7	420	130	50
HB-P-P-H-LL	Hole 1" Dia	16200 64.7 85	167.2	43.6	1850	530	170
HB-P-P-R-LL	Rupture 6" Dia	16200 64.7 85	4.6	1571	2650	2300	600



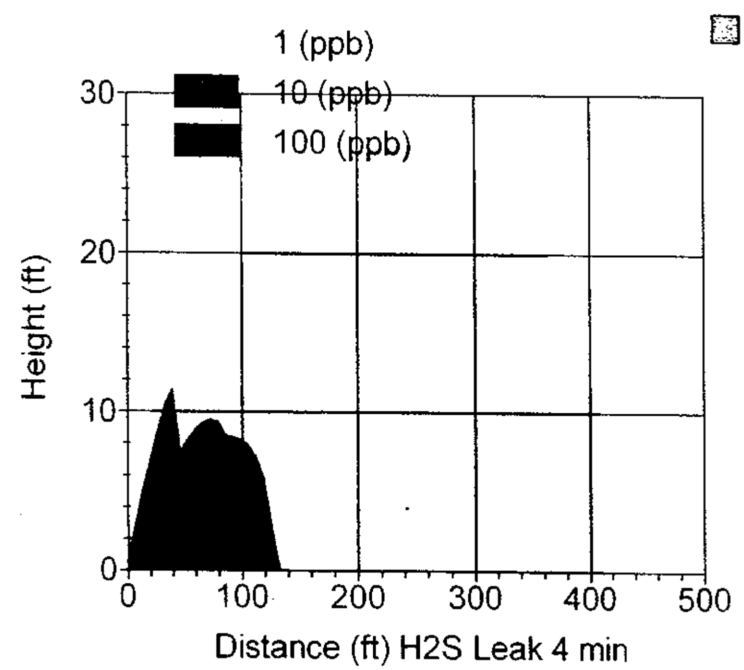
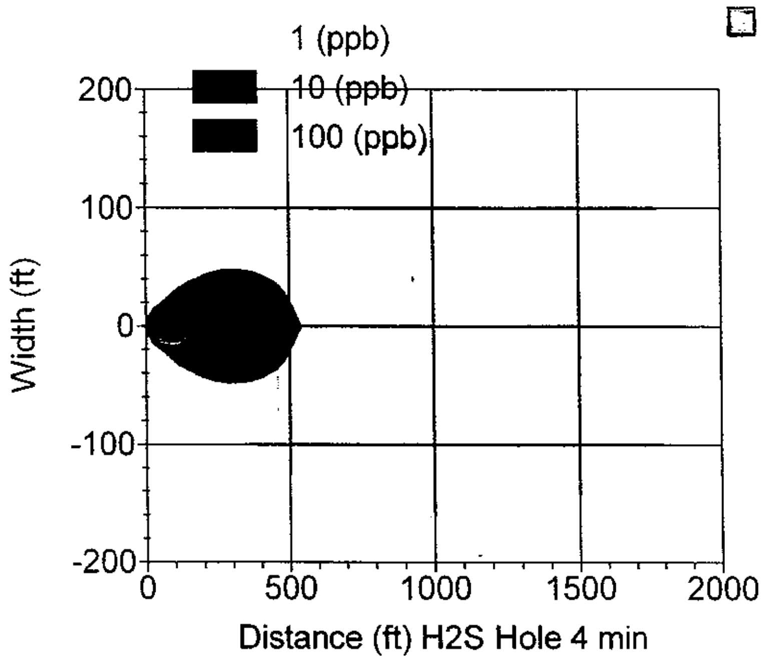


Figure 4.14
H_2S Concentration Plan and Profile for Process Leak



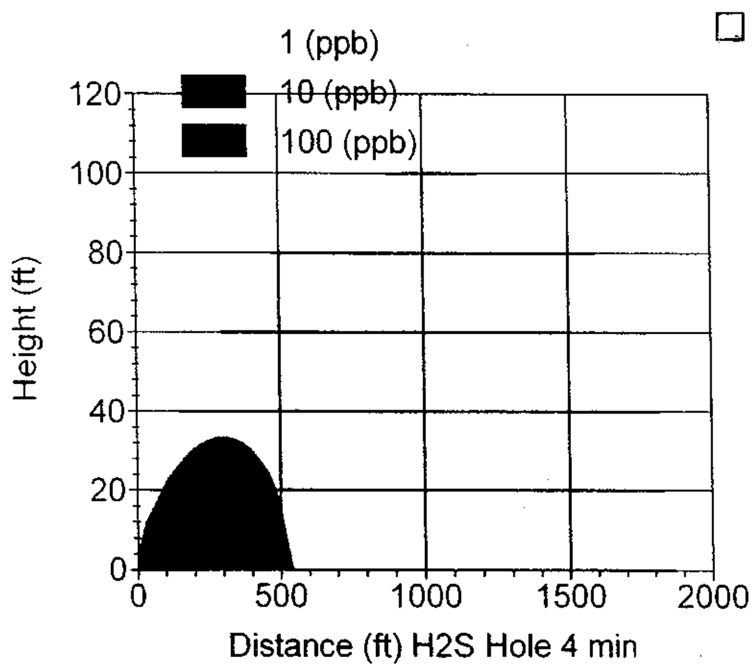


Figure 4.15
H_2S Concentration Plan and Profile for Process Hole

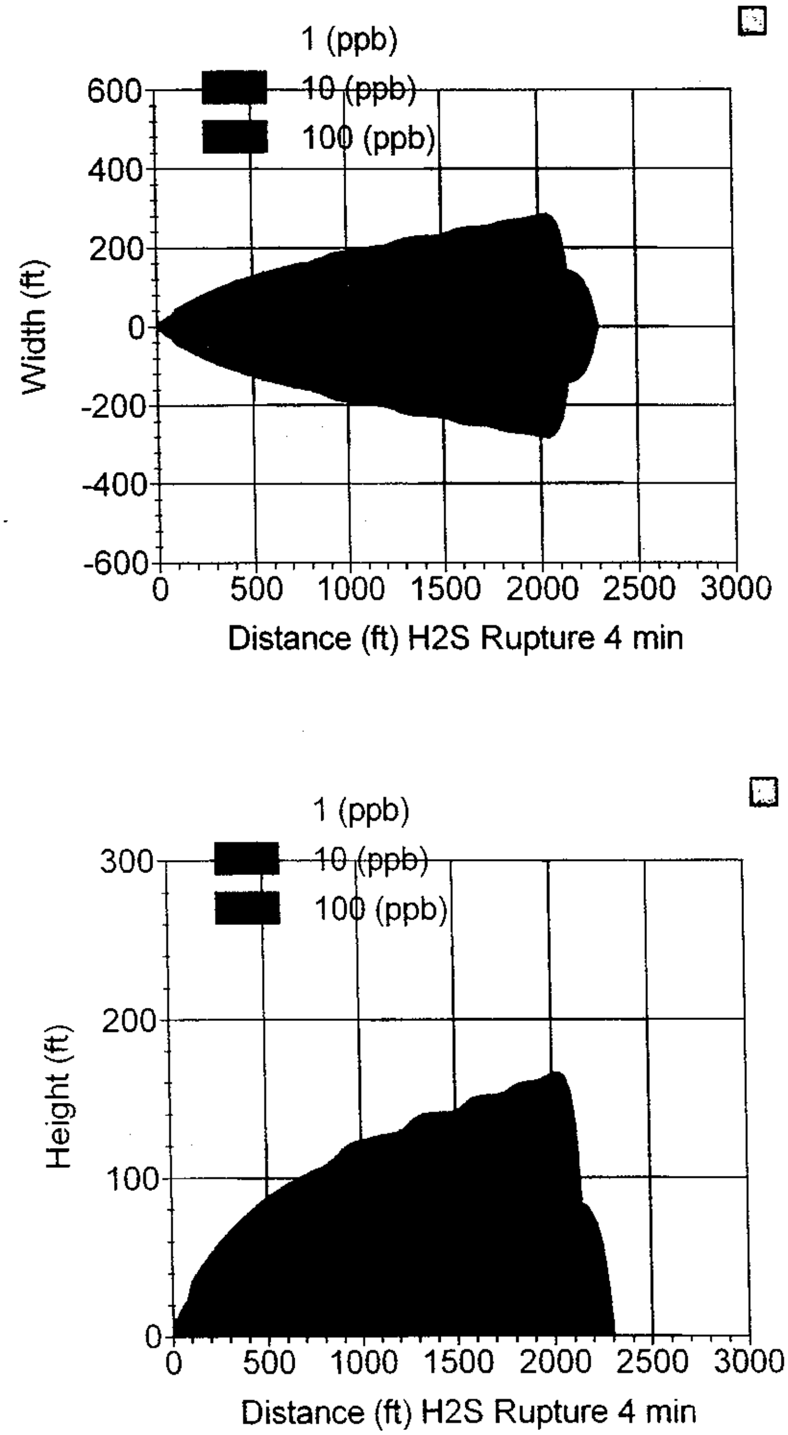


Figure 4.16
H_2S Concentration Plan and Profile for Process Rupture

CHAPTER 5

UNMITIGATED RISK

5.1 Risk Assessment Process

5.1.1 Summary of Risk Assessment Process

The combination of the results of the consequence analysis with the frequencies of releases and their probable behavior as assessed utilizing event trees, together with appropriate lethality criteria and population distributions permits the quantification of risks.

The principal steps in the quantification of risk may be summarized as follows:

- Individual risk assessment
- Definition of risk contours for facilities
- Definition of risk transects for pipelines
- Estimation of outside individual specific risk factors
- Evaluation of individual specific risk
- Evaluation of societal risk

5.1.2 Individual Risk Assessment

Individual risk (IR) for a given location is defined as the probability that a normal adult individual will be killed if that individual remains outdoors continuously (24 hours a day, 365 days per year) at that location for one year. Individual risk, thus defined forms an upper bound to other measures of individual risk such as individual specific risk (ISR) or average individual risk (AIR). Any other measure of individual risk is likely to be lower due to the introduction of mitigating factors such as reduction in time spent at the location, sheltering through indoor time, use of protective gear, or evasive action. The upper bound individual risk quantified herein, however, has the advantage that it is a clearly defined quantity which can be used as a basis for computation of any other measure of specific individual risk without major factoring or manipulation.

Computation of IR was conducted for two different types of sources; namely, point sources and linear sources. Linear sources were represented by the pipelines, while point sources were considered to be associated with the process facilities and wells.

For point sources, the individual risk may be computed as follows:

$$IR_p = P_R \cdot P_S \cdot P_F \cdot P_D \qquad (5.1)$$

where

IR_p	= IR for point source
P_R	= probability of release
P_S	= conditional probability of scenario occurrence (ROO from event trees)
P_F	= probability of fatality
P_D	= probability of hazard occurring in direction D

For linear sources, such as pipelines, on the other hand, the individual risks may be computed by,

$$IR_L = P_R \cdot P_S \cdot P_F \cdot P_D \cdot L_I \qquad (5.2)$$

where,

$$L_I = 2\,(H^2 - X^2)^{1/2} \qquad (5.3)$$

where,

IR_L	= individual risk for a linear source
P_R	= linear failure rate per km year
P_S	= conditional probability of scenario occurrence (ROO)
P_F	= probability of fatality
P_D	= probability of hazard in direction D
L_I	= interaction length of pipeline
H	= extent of hazard footprint from location of release at pipeline
X	= distance to receptor, perpendicular to pipeline centreline

The above formulas were embedded in spreadsheets to generate base data for plotting individual risk transects and contours. Table 5.1 shows the basis of the computation for individual risk contours associated with a typical risk point source exemplified by the process facilities. As may be seen, the computation provides individual risk at different distances, which can then be utilized to generate risk transects in each of the eight compass directions, as shown in Figure 5.1.

Generally, for the case of point sources, risk transects are computed along several directions (8 compass directions) as shown in Figure 5.1 and then combined to generate a plan view of iso-risk contours around a facility, as illustrated in Figure 5.2.

A similar spreadsheet approach, except embedding Equation 5.2 in a spreadsheet, can be used for the computation of individual risk from linear sources. One of the associated computational spreadsheets is illustrated in Table 5.2. This allows for

Table 5.1
Example of IR Calculation for Point Source

Scenario		FLASH FIRE			JET FIRE			EXPLOSION		
Release type		Leak	Hole	Rupture	Leak	Hole	Rupture	Leak	Hole	Rupture
Releases (/year)		8.90E-01	6.50E-02	2.90E-02	8.90E-01	6.50E-02	2.90E-02	8.90E-01	6.50E-02	2.90E-02
P of Scen. occ.		0.09	0.36	0.09	0.01	0.10	0.18	0.00	0.04	0.03
p (/year)		8.01E-02	2.34E-02	2.61E-03	8.90E-03	6.50E-03	5.22E-03	0.00E+00	2.60E-03	8.70E-04
Pf		0.50	0.50	0.50	0.05	0.05	0.05	0.10	0.10	0.10
Directional Probability	N	0.060			0.125			0.125		
	NE	0.260			0.125			0.125		
	E	0.220			0.125			0.125		
	SE	0.060			0.125			0.125		
	S	0.070			0.125			0.125		
	SW	0.070			0.125			0.125		
	W	0.220			0.125			0.125		
	NW	0.040			0.125			0.125		
Haz dist. W (ft)		1	3	55	8	22	50	0	0	0
Haz dist. L (ft)		6	16	200	14	45	155	0	0	0
Individual Risk at L	IR_N	2.40E-03	7.02E-04	7.83E-05	5.56E-05	4.06E-05	3.26E-05	0.00E+00	3.25E-05	1.09E-05
	IR_{NE}	1.04E-02	3.04E-03	3.39E-04	5.56E-05	4.06E-05	3.26E-05	0.00E+00	3.25E-05	1.09E-05
	IR_E	8.81E-03	2.57E-03	2.87E-04	5.56E-05	4.06E-05	3.26E-05	0.00E+00	3.25E-05	1.09E-05
	IR_{SE}	2.40E-03	7.02E-04	7.83E-05	5.56E-05	4.06E-05	3.26E-05	0.00E+00	3.25E-05	1.09E-05
	IR_S	2.80E-03	8.19E-04	9.14E-05	5.56E-05	4.06E-05	3.26E-05	0.00E+00	3.25E-05	1.09E-05
	IR_{SW}	2.80E-03	8.19E-04	9.14E-05	5.56E-05	4.06E-05	3.26E-05	0.00E+00	3.25E-05	1.09E-05
	IR_W	8.81E-03	2.57E-03	2.87E-04	5.56E-05	4.06E-05	3.26E-05	0.00E+00	3.25E-05	1.09E-05
	IR_{NW}	1.60E-03	4.68E-04	5.22E-05	5.56E-05	4.06E-05	3.26E-05	0.00E+00	3.25E-05	1.09E-05

Table 5.1
Example of IR Calculation for Point Source

Scenario		FLASH FIRE			JET FIRE			EXPLOSION		
Release type		Leak	Hole	Rupture	Leak	Hole	Rupture	Leak	Hole	Rupture
Releases (/year)		8.90E-01	6.50E-02	2.90E-02	8.90E-01	6.50E-02	2.90E-02	8.90E-01	6.50E-02	2.90E-02
P of Scen. occ.		0.09	0.36	0.09	0.01	0.10	0.18	0.00	0.04	0.03
p (/year)		8.01E-02	2.34E-02	2.61E-03	8.90E-03	6.50E-03	5.22E-03	0.00E+00	2.60E-03	8.70E-04
Pf		0.50	0.50	0.50	0.05	0.05	0.05	0.10	0.10	0.10
Directional Probability	N	0.060			0.125			0.125		
	NE	0.260			0.125			0.125		
	E	0.220			0.125			0.125		
	SE	0.060			0.125			0.125		
	S	0.070			0.125			0.125		
	SW	0.070			0.125			0.125		
	W	0.220			0.125			0.125		
	NW	0.040			0.125			0.125		
Haz dist. W (ft)		1	3	55	8	22	50	0	0	0
Haz dist. L (ft)		6	16	200	14	45	155	0	0	0
Individual Risk at L	IR_N	2.40E-03	7.02E-04	7.83E-05	5.56E-05	4.06E-05	3.26E-05	0.00E+00	3.25E-05	1.09E-05
	IR_{NE}	1.04E-02	3.04E-03	3.39E-04	5.56E-05	4.06E-05	3.26E-05	0.00E+00	3.25E-05	1.09E-05
	IR_E	8.81E-03	2.57E-03	2.87E-04	5.56E-05	4.06E-05	3.26E-05	0.00E+00	3.25E-05	1.09E-05
	IR_{SE}	2.40E-03	7.02E-04	7.83E-05	5.56E-05	4.06E-05	3.26E-05	0.00E+00	3.25E-05	1.09E-05
	IR_S	2.80E-03	8.19E-04	9.14E-05	5.56E-05	4.06E-05	3.26E-05	0.00E+00	3.25E-05	1.09E-05
	IR_{SW}	2.80E-03	8.19E-04	9.14E-05	5.56E-05	4.06E-05	3.26E-05	0.00E+00	3.25E-05	1.09E-05
	IR_W	8.81E-03	2.57E-03	2.87E-04	5.56E-05	4.06E-05	3.26E-05	0.00E+00	3.25E-05	1.09E-05
	IR_{NW}	1.60E-03	4.68E-04	5.22E-05	5.56E-05	4.06E-05	3.26E-05	0.00E+00	3.25E-05	1.09E-05

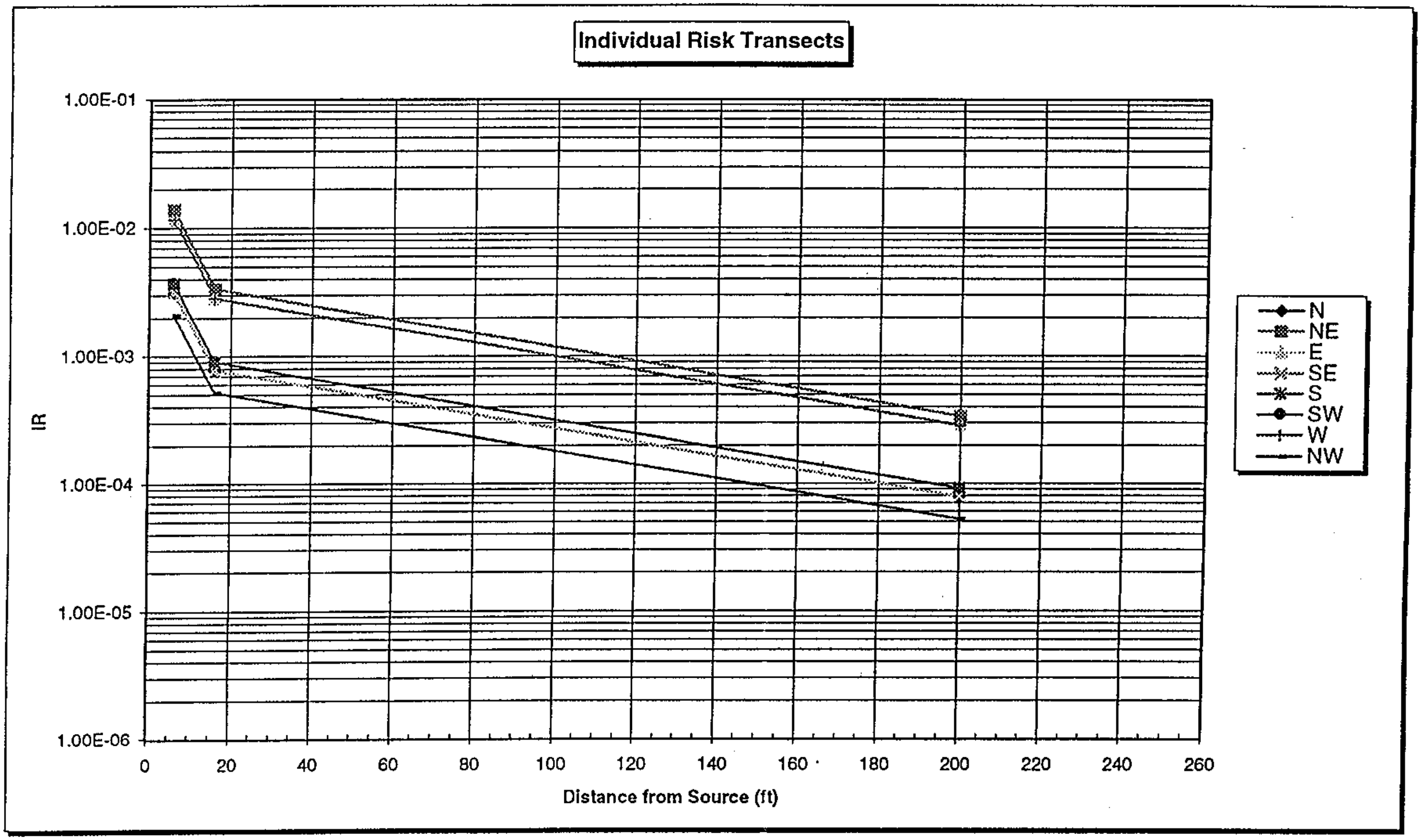


Figure 5.1
Example of Individual Risk Transects for Point Source

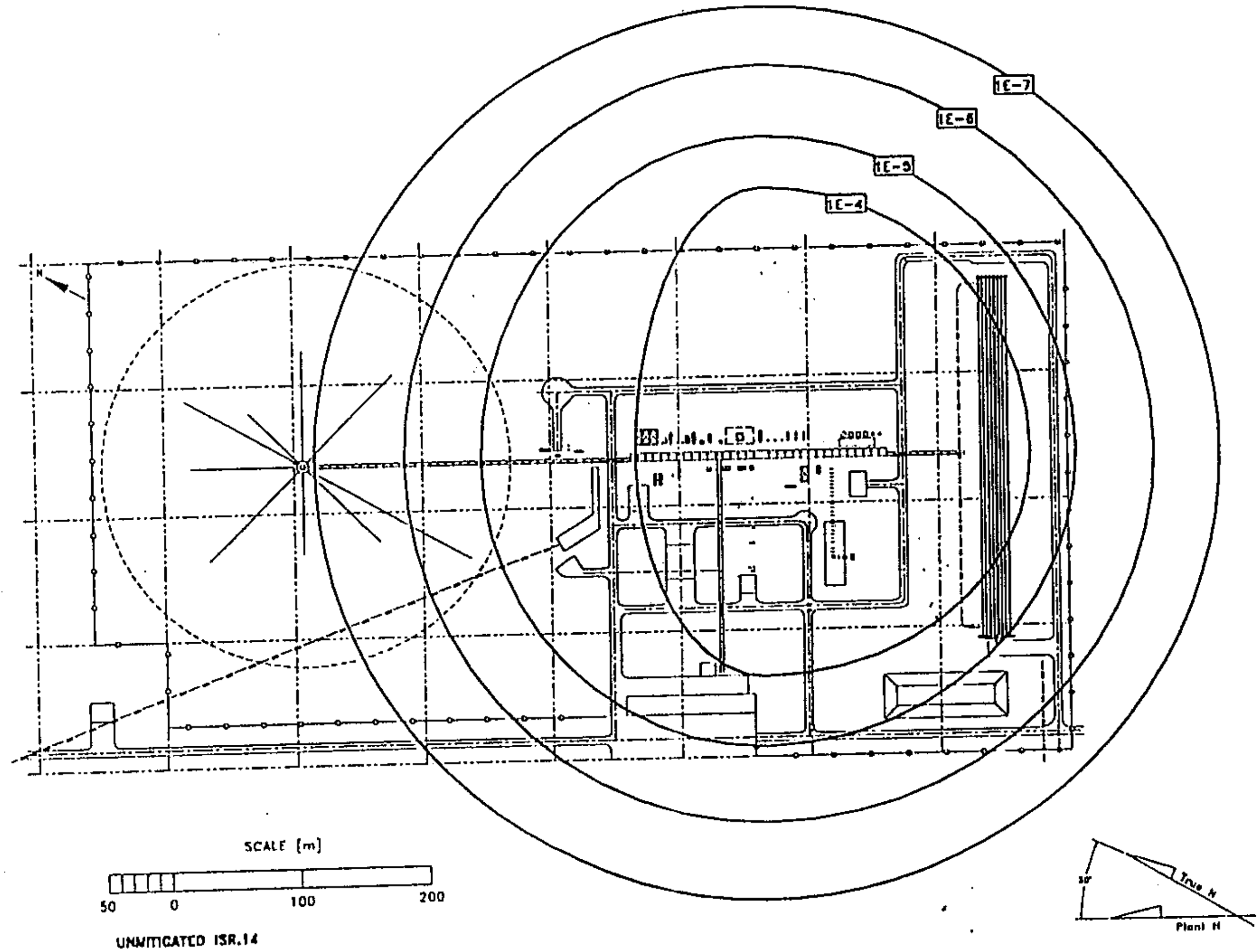


Figure 5.2
Example of Individual Risk Contours

Table 5.2
Example of IR Calculation for Linear Source

SCENARIO	RELEASE TYPE	p_r (/mi - yr)	P_s	$p_r \times P_s$ (/mi - yr)	p_f	H (ft)	INDIVIDUAL ANNUAL RISK AT DISTANCE "x" (ft) (not including "DIRECTIONAL P")									DIRECTIONAL P			
							0	5	10	20	50	75	100	150	200	P_R	P_L	P_U	P_D
GAS RELEASE	Leak	1.05E-03					-	-	-	-	-	-	-	-	-				
	Hole	2.90E-04					-	-	-	-	-	-	-	-	-				
	Rupture	9.66E-05					-	-	-	-	-	-	-	-	-				
	Double Rupture	9.66E-05					-	-	-	-	-	-	-	-	-				
JET FIRE	Leak		0.10	1.05E-04	0.05	10	1.98E-08	1.72E-08	0.00E+00	-	-	-	-	-	-	0.20	0.20	0.30	0.30
	Hole		0.10	2.90E-05	0.05	30	1.65E-08	1.62E-08	1.55E-08	1.23E-08	-	-	-	-	-	0.20	0.20	0.30	0.30
	Rupture		0.18	1.74E-05	0.05	99	3.26E-08	3.26E-08	3.24E-08	3.19E-08	2.81E-08	2.13E-08	-	-	-	0.20	0.20	0.30	0.30
	Double Rupture		0.18	1.74E-05	0.05	138	4.54E-08	4.54E-08	4.53E-08	4.50E-08	4.24E-08	3.81E-08	3.13E-08	-	-	0.20	0.20	0.30	0.30
FLASH FIRE	Leak		0.40	4.18E-04	0.50	1	7.92E-08	-	-	-	-	-	-	-	-	0.42	0.29	0.21	0.08
	Hole		0.36	1.04E-04	0.50	13	2.57E-07	2.37E-07	1.64E-07	-	-	-	-	-	-	0.42	0.29	0.21	0.08
	Rupture		0.09	8.69E-06	0.50	50	8.23E-08	8.19E-08	8.07E-08	7.55E-08	0.00E+00	-	-	-	-	0.42	0.29	0.21	0.08
	Double Rupture		0.09	8.69E-06	0.50	49	8.07E-08	8.03E-08	7.90E-08	7.37E-08	-	-	-	-	-	0.42	0.29	0.21	0.08
EXPLOSION	Leak		0.00	0.00E+00	0.10	0	-	-	-	-	-	-	-	-	-	0.42	0.29	0.21	0.08
	Hole		0.04	1.16E-05	0.10	0	-	-	-	-	-	-	-	-	-	0.42	0.29	0.21	0.08
	Rupture		0.03	2.90E-06	0.10	0	-	-	-	-	-	-	-	-	-	0.42	0.29	0.21	0.08
	Double Rupture		0.03	2.90E-06	0.10	0	-	-	-	-	-	-	-	-	-	0.42	0.29	0.21	0.08
DISPERSION	Leak		0.50	5.23E-04	0.00	0	-	-	-	-	-	-	-	-	-	0.42	0.29	0.21	0.08
	Hole		0.50	1.45E-04	0.00	0	-	-	-	-	-	-	-	-	-	0.42	0.29	0.21	0.08
	Rupture		0.30	2.90E-05	0.00	0	-	-	-	-	-	-	-	-	-	0.42	0.29	0.21	0.08
	Double Rupture		0.30	2.90E-05	0.00	0	-	-	-	-	-	-	-	-	-	0.42	0.29	0.21	0.08
TOTALS							6.14E-07	5.11E-07	4.17E-07	2.38E-07	7.05E-08	5.94E-08	3.13E-08	0.00E+00	0.00E+00				

calculation of individual risk at various distances for each of the consequence sub-scenarios defined in the event tree associated with the pipeline.

For the linear sources, the appropriate representation of risk is a risk transect, showing the variation in IR with the distance on either side of the pipeline, as illustrated in Figure 5.3.

In the balance of this chapter, and in the chapter on resultant risk, the resultant risk contours and transects are shown for each facility type.

5.1.3 Societal Risk Calculations

The societal or group risk results are represented as risk spectra. As indicated earlier, a risk spectrum is a graph of the frequency of occurrence and the number of individuals involved in the occurrence, with the frequency given on the vertical axis and the number of individuals on the horizontal axis. Specifically, the graph represents the probability than N or more (or at least N) individuals will become casualties in any given situation.

The data for the construction of the risk spectrum is obtained by combining the iso-risk contours (risk isopleths) with actual population distributions together with their appropriate dwell time and outdoor exposure factors (combined as the OISR factors defined earlier). Essentially, to construct a risk spectrum each of the octants (for eight wind directions) is analyzed to assess the number of individuals exposed within each successive contour, commencing with the outermost or lowest probability contour. These data are then sorted according to groups associated with the same number of individuals, their frequencies are added to give a summary frequency for each group of equal number and the probabilities are accumulated beginning with the greatest number of people, N. Again, only the resultant risk spectra appropriate to each facility group and component are given in the balance of this chapter.

5.1.4 Unmitigated and Mitigated Risks

For the subject project, very specific risk mitigation measures have been proposed to reduce risks. These specific risk mitigation measures are the concrete block and sound attenuation walls which will be present during the test and production phase. In order to show the efficacy of these risk mitigation measures, it is important to assess the risks without considering the effects of the mitigation measures. The results of such a risk assessment are terms the unmitigated risks. In effect, however, the unmitigated risk does have the more generic risk mitigation measures described in the next chapter and considered to be industry standard. Thus, in the context of the present project, unmitigated risk means the risks without considering the effect of the perimeter walls; mitigated risks are those which give consideration to the perimeter wall effects explicitly.

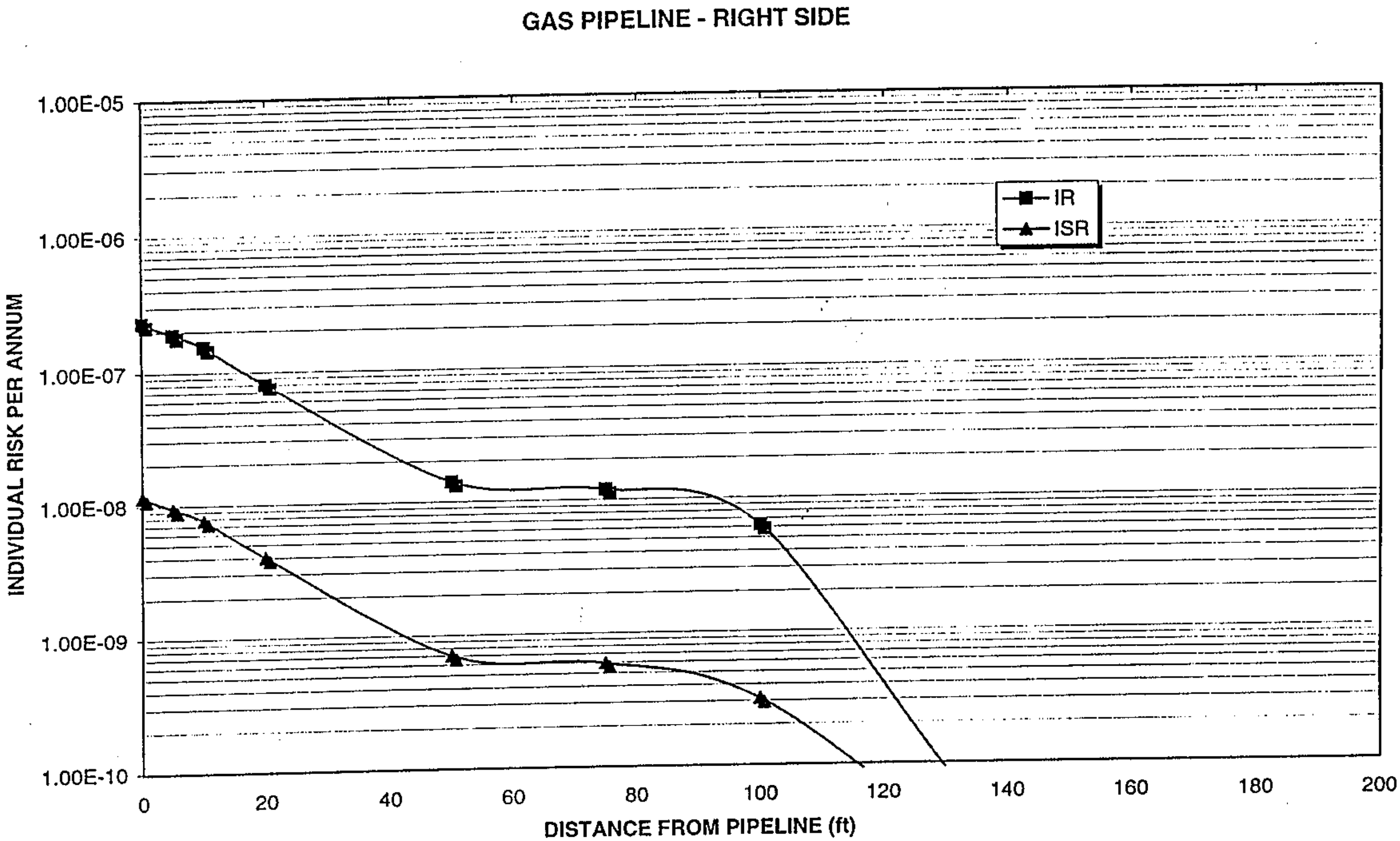


Figure 5.3
Example of Risk Transect for Linear Source

Unmitigated and mitigated risks, however, include consideration of generic, industry standard mitigation for similar facilities.

5.2 Test Phase - Unmitigated Risks

5.2.1 Individual Risk Assessment

The risk isopleths or iso-risk contours for individuals for the three atmospheric conditions considered for the test phase are shown in Figures 5.4, 5.5, and 5.6. Figure 5.4 shows the individual risk contours for the unstable atmospheric condition considered to be representative of daytime conditions while Figure 5.5 shows that representative of nighttime conditions. Figure 5.6, a somewhat larger footprint, is associated with the worst case conditions which have been distributed between both day and night conditions. It is emphasized that the risk contours are representative of the upper bound individual risk, not the individual specific risk. Generally, when the actual exposure of individuals is considered, by multiplying the probabilities by the OISR factor, the risk contour result is reduced by roughly an order of magnitude or to 10% of the value given. It is not feasible to plot the individual specific risk contours because the OISR factor characterizing the population exposure varies from location to location rather than being constant throughout the neighborhood of the project.

The above risk contours include consideration of the well drilling activity and the process activity, and the temporary storage. Trucking is only included in the group risk assessment described in the next section.

5.2.2 Societal Risk Assessment

The risk spectrum for the test phase, giving individual lines for each of the principal components (wells, process, trucking) as well as their integrated total as shown in Figure 5.7. The risk spectrum is shown with the risk thresholds as a background in order to provide a convenient comparison between the unmitigated risk spectrum and the public risk thresholds described earlier.

5.3 Production Phase Unmitigated Risks

5.3.1 Individual Risk Assessment

Figure 5.8, 5.9, and 5.10 show the iso-risk contours giving annual individual risks for the daytime, nighttime, and worst case atmospheric conditions, respectively. These contours include the effects of the well drilling and production wells, process facility, and onsite storage. Figures 5.11 and 5.12 show the individual risk transects associated with the pipeline operations.

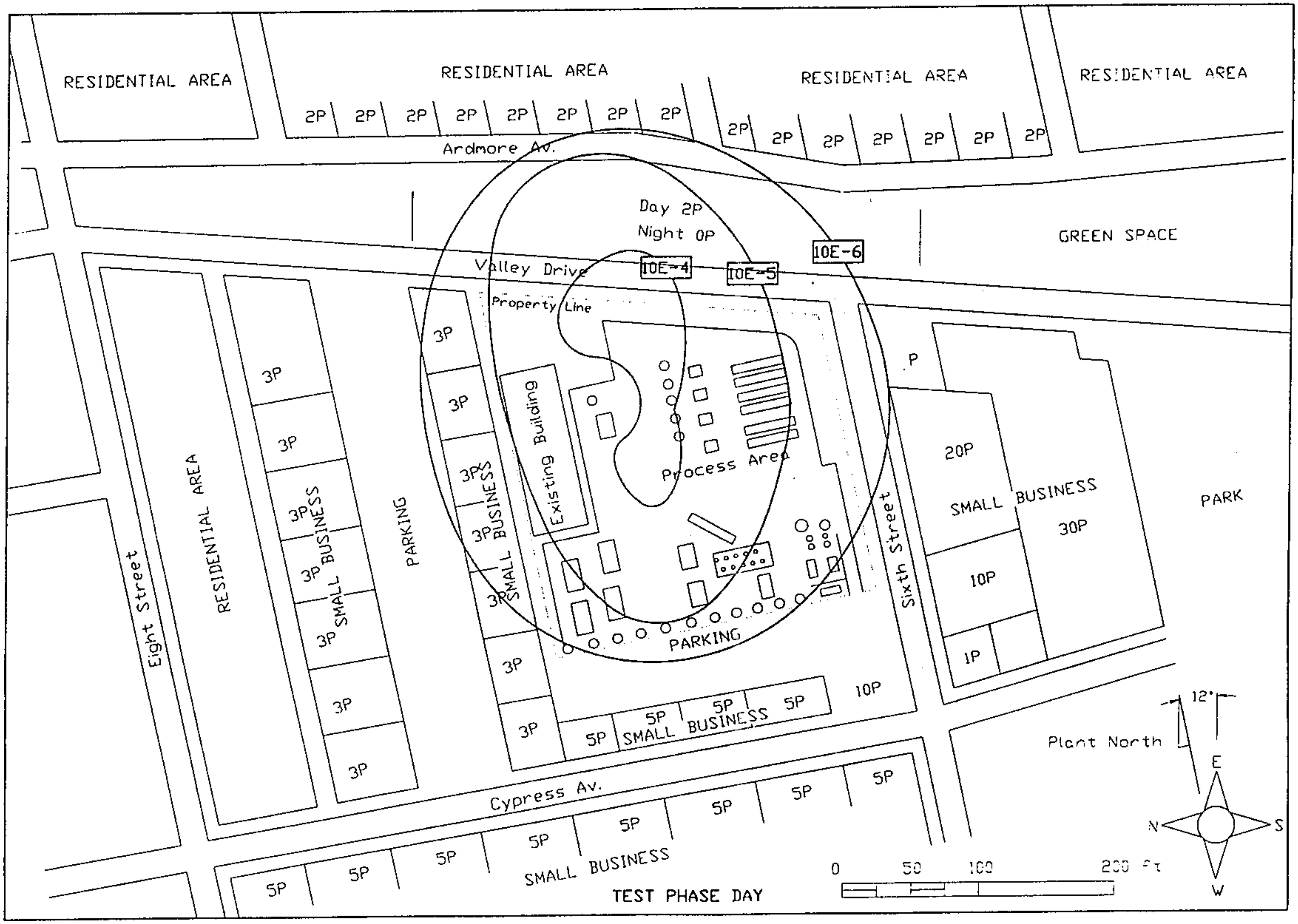


Figure 5.4
IR Contours for Test Phase - Day

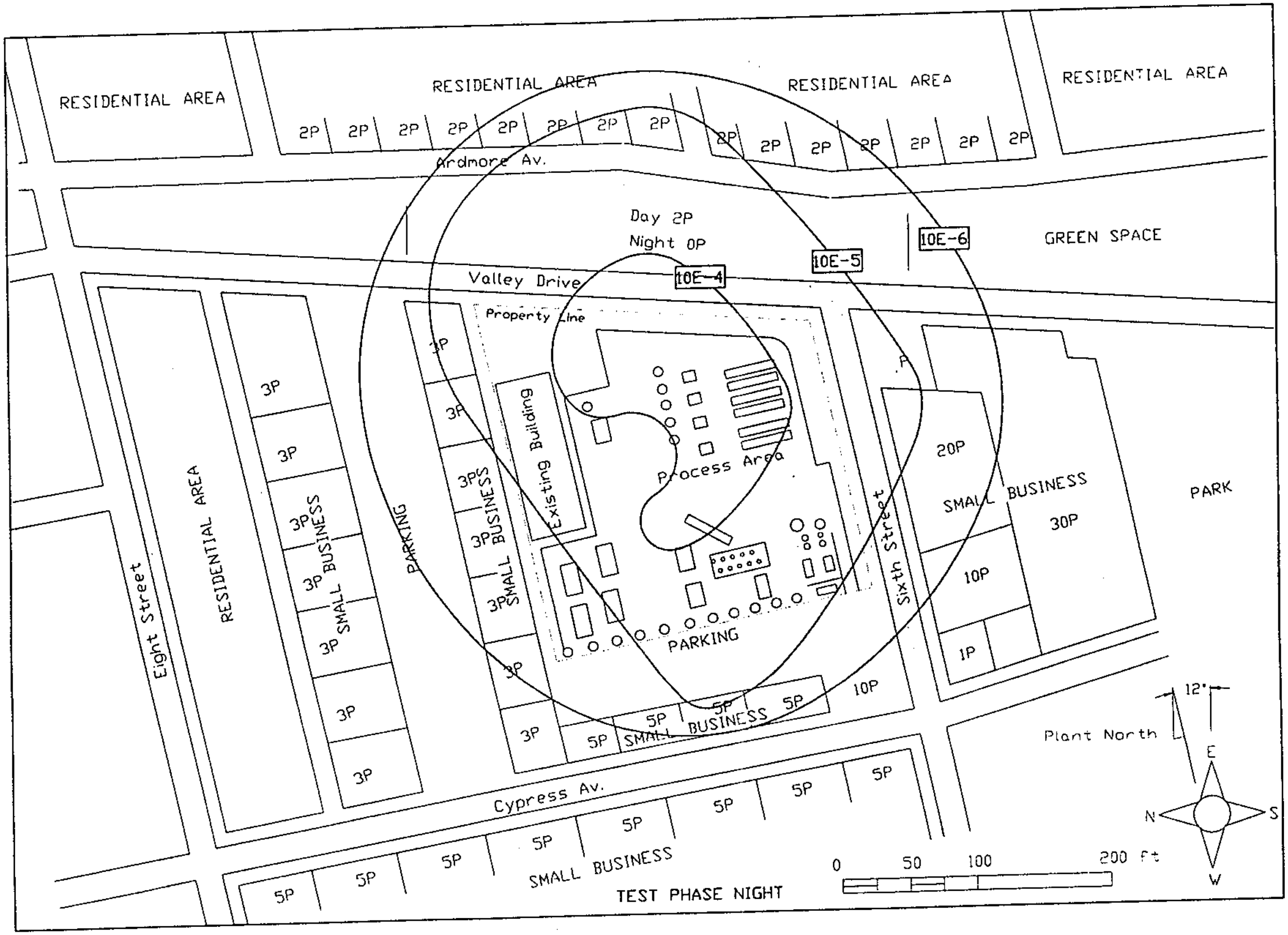


Figure 5.5
IR Contours for Test Phase - Night

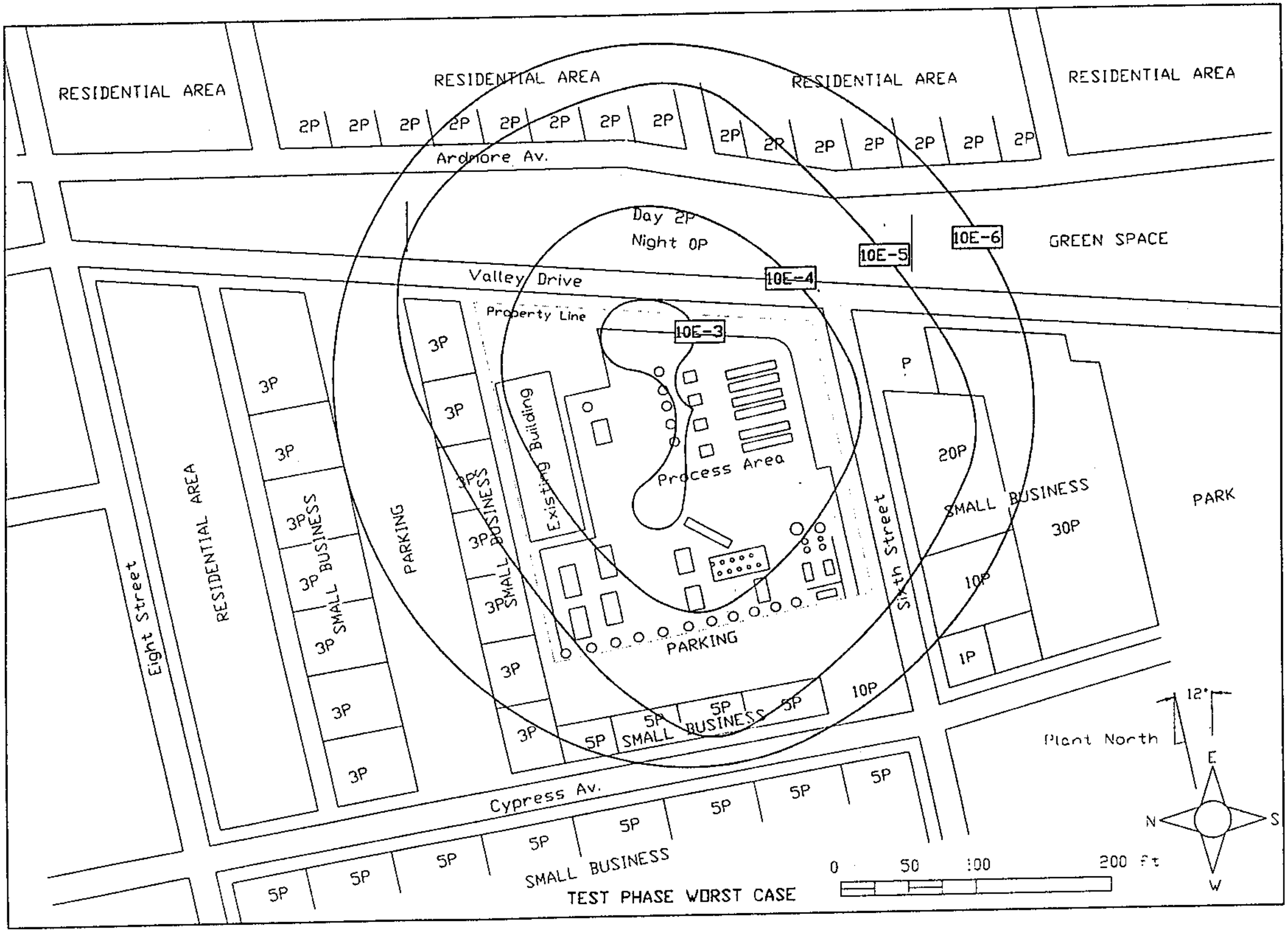


Figure 5.6
IRContours for Test Phase - Worst

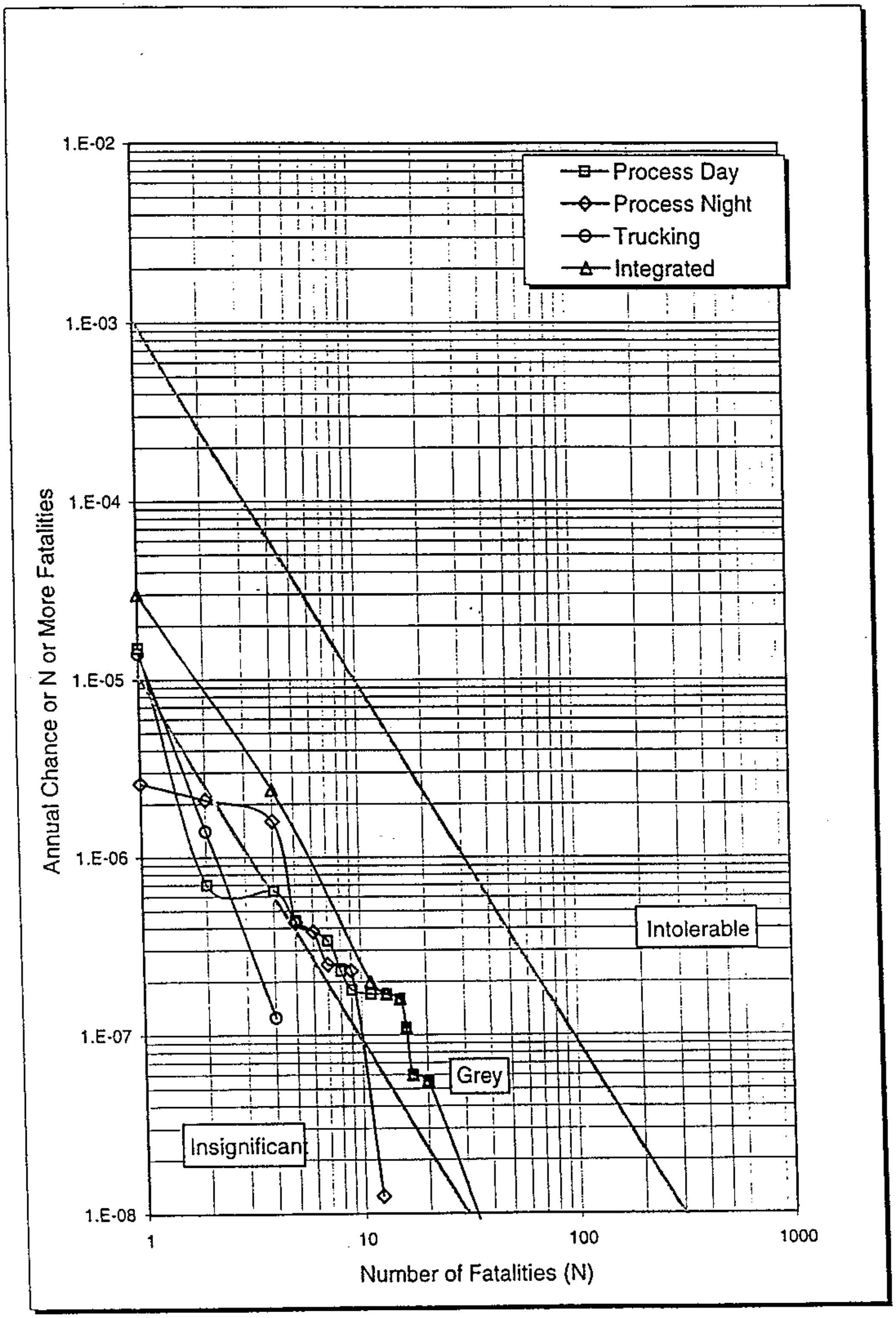


Figure 5.7
Public Risk Spectrum - Test Phase - Process and Trucking - Unmitigated

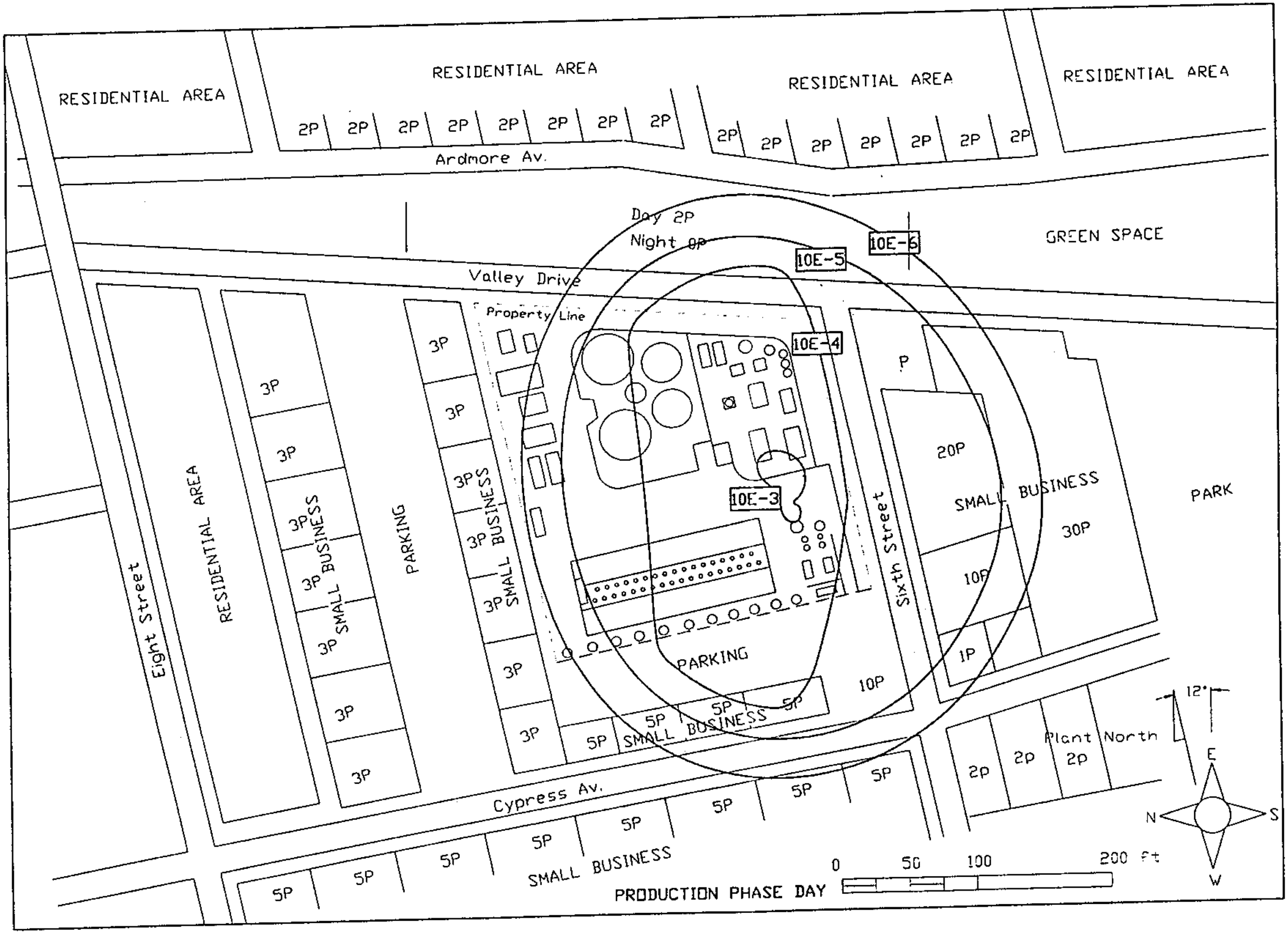


Figure 5.8
IR Contours for Production Phase - Day

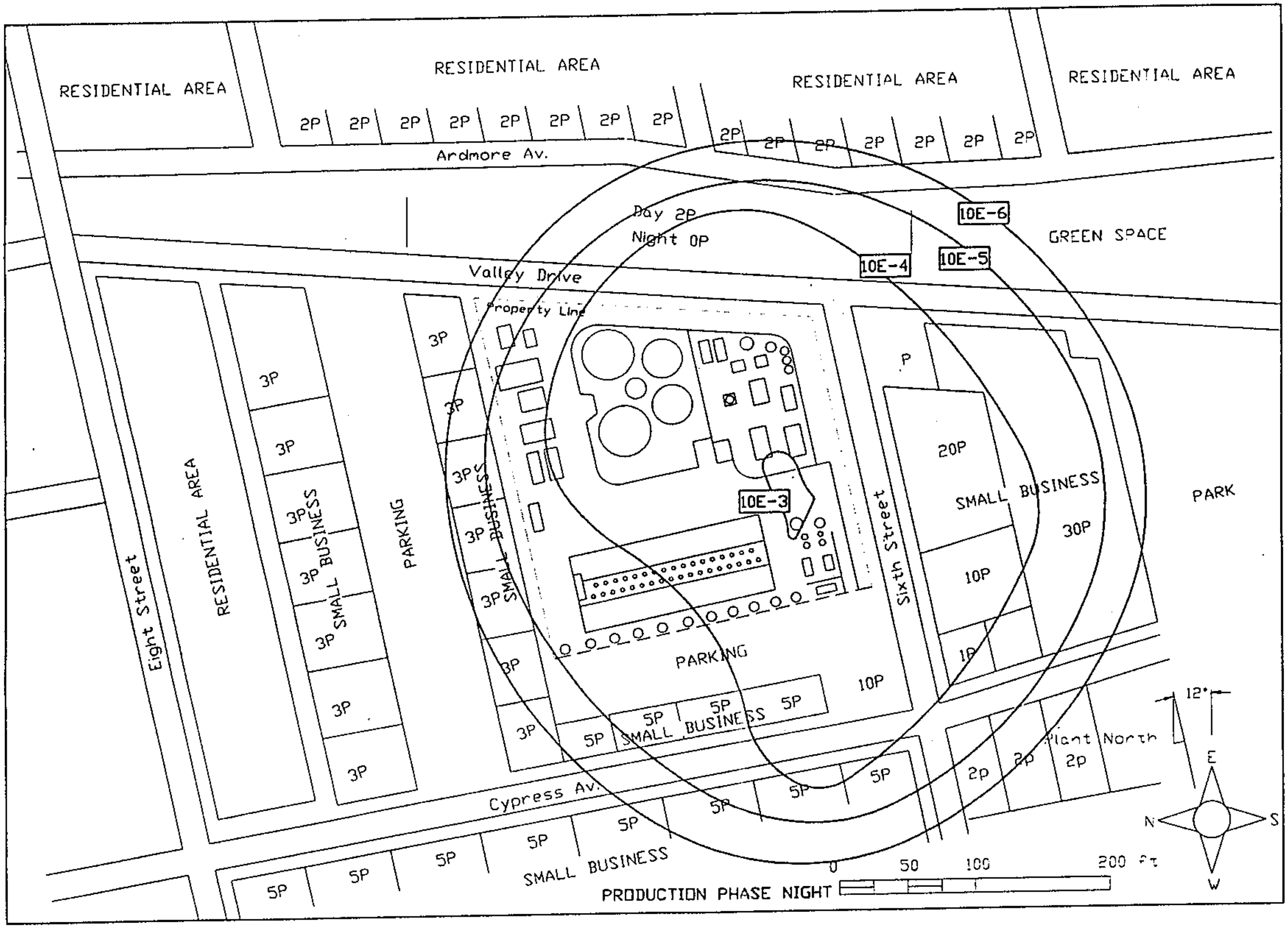


Figure 5.9
IR Contours for Production Phase - Night

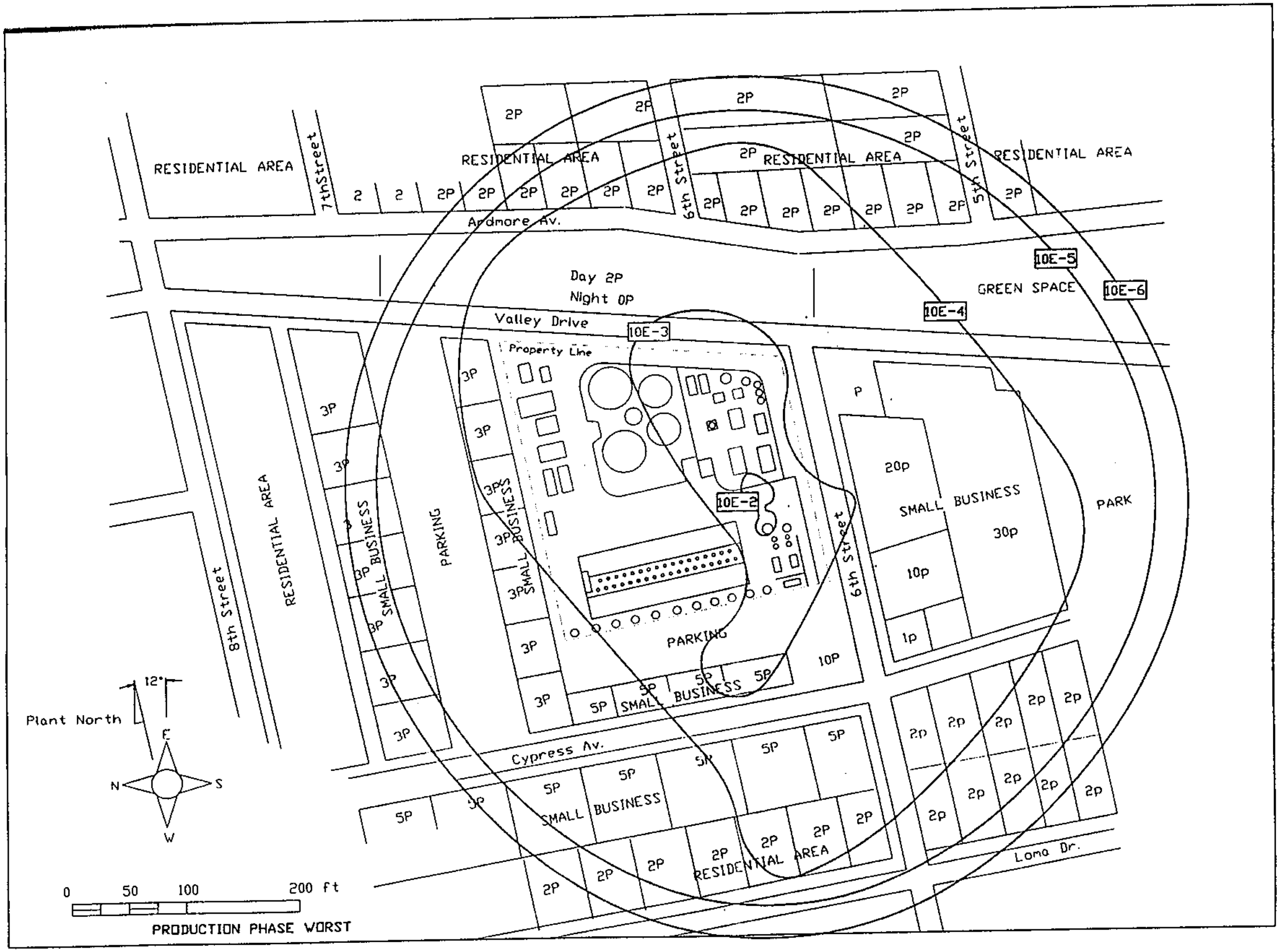


Figure 5.10
IR Contours for Production Phase - Worst

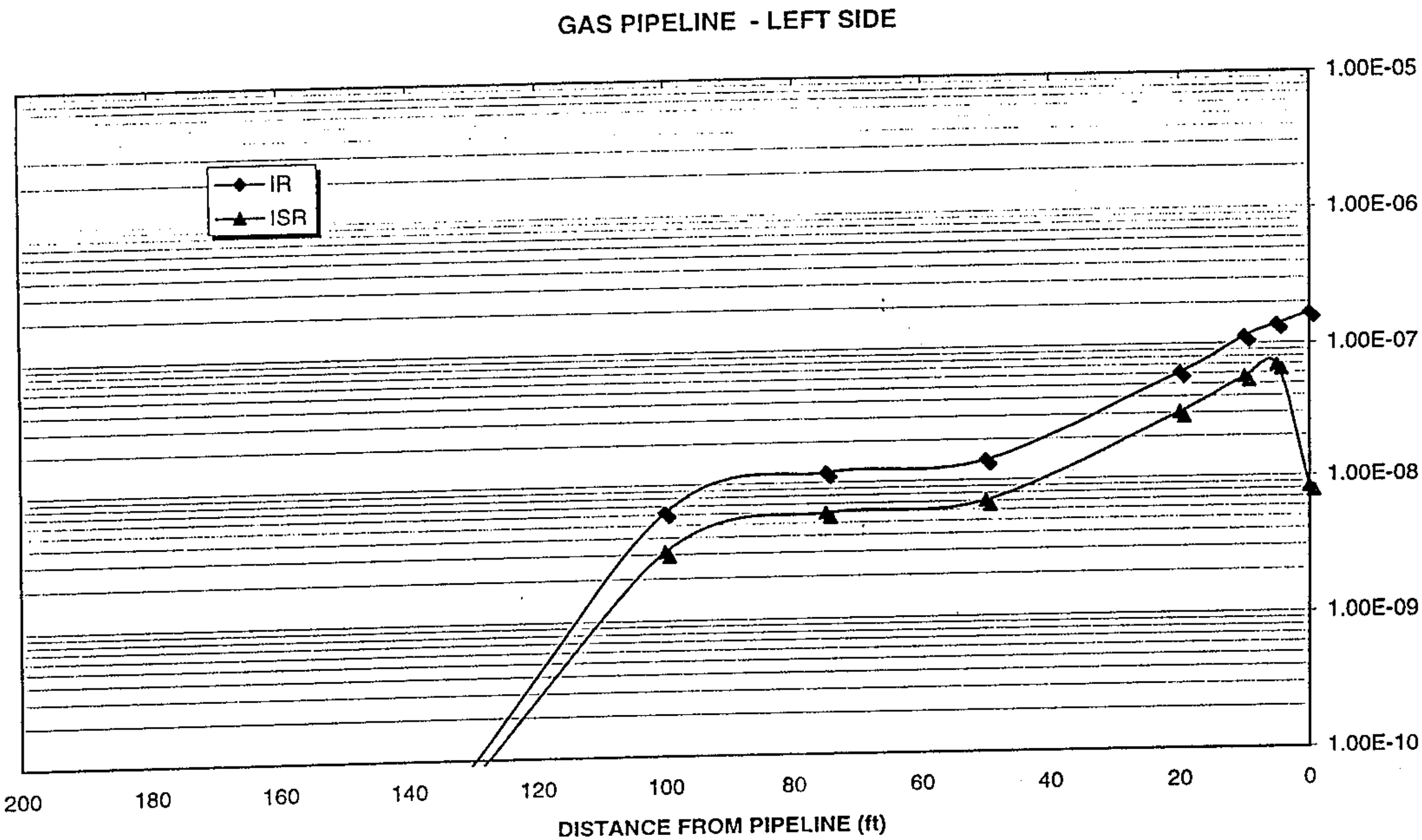


Figure 5.11
Gas Pipeline - Left Transect

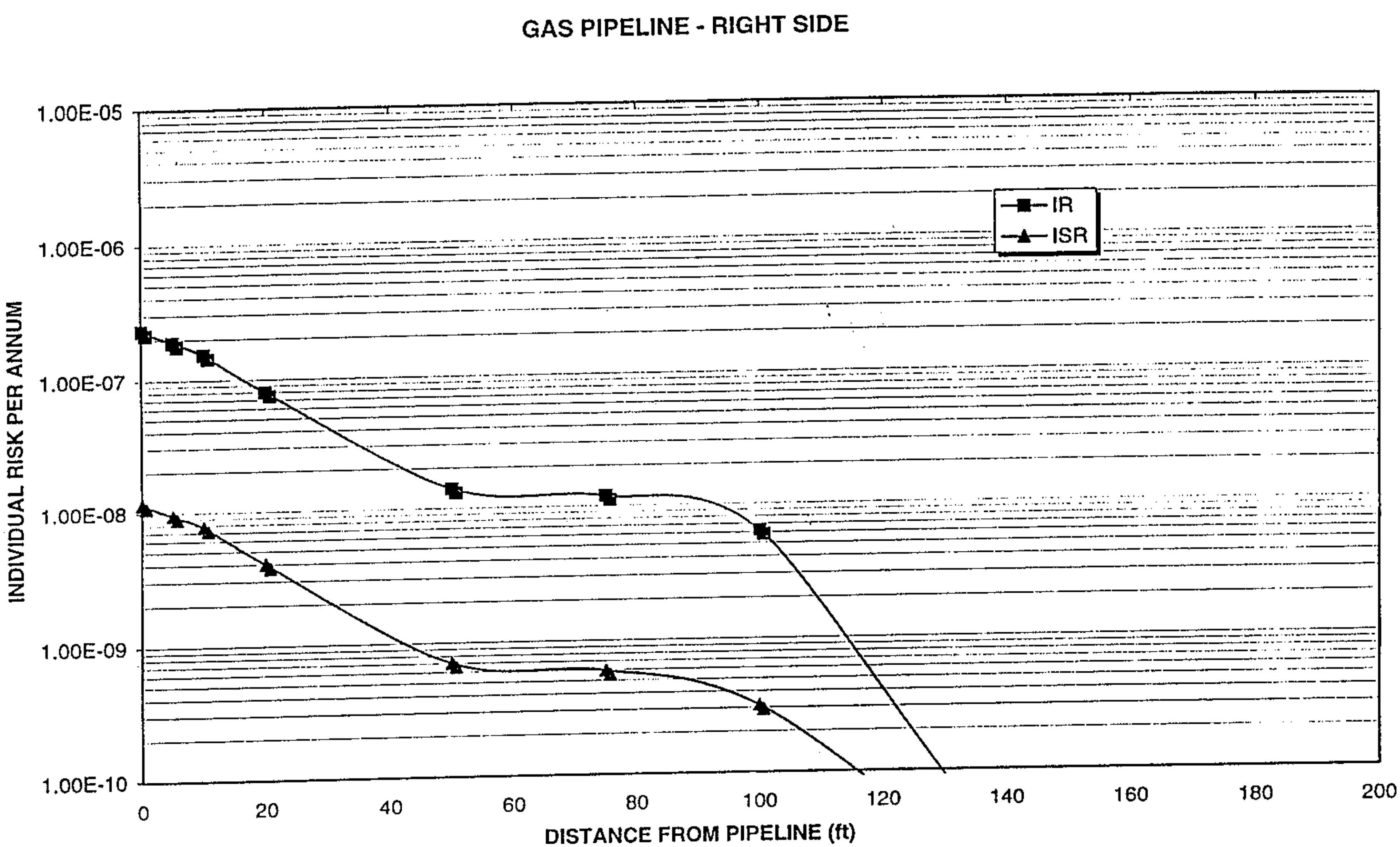


Figure 5.12
Gas Pipeline - Right Transect

5.3.2 Societal Risk Assessment

Figure 5.13 shows the group or societal risk spectrum associated with the production facilities, including the risk profiles for each component as well as the integrated risk profile for the unmitigated production phase risks.

5.4 Existing Facilities

5.4.1 Individual Risk Assessment

Figure 5.14 shows the individual risk contours for the existing facilities. These risk contours are based on the hazardous substances stored onsite and are dominated by the above grade propane hazard.

5.4.2 Group Risk Assessment

Figure 5.15 shows the risk spectrum associated with the existing facilities, including both hazardous materials onsite and traffic activities within ½ mile of the existing site. Individual risk profiles for each of these components are shown as well as the integrated risk profile.

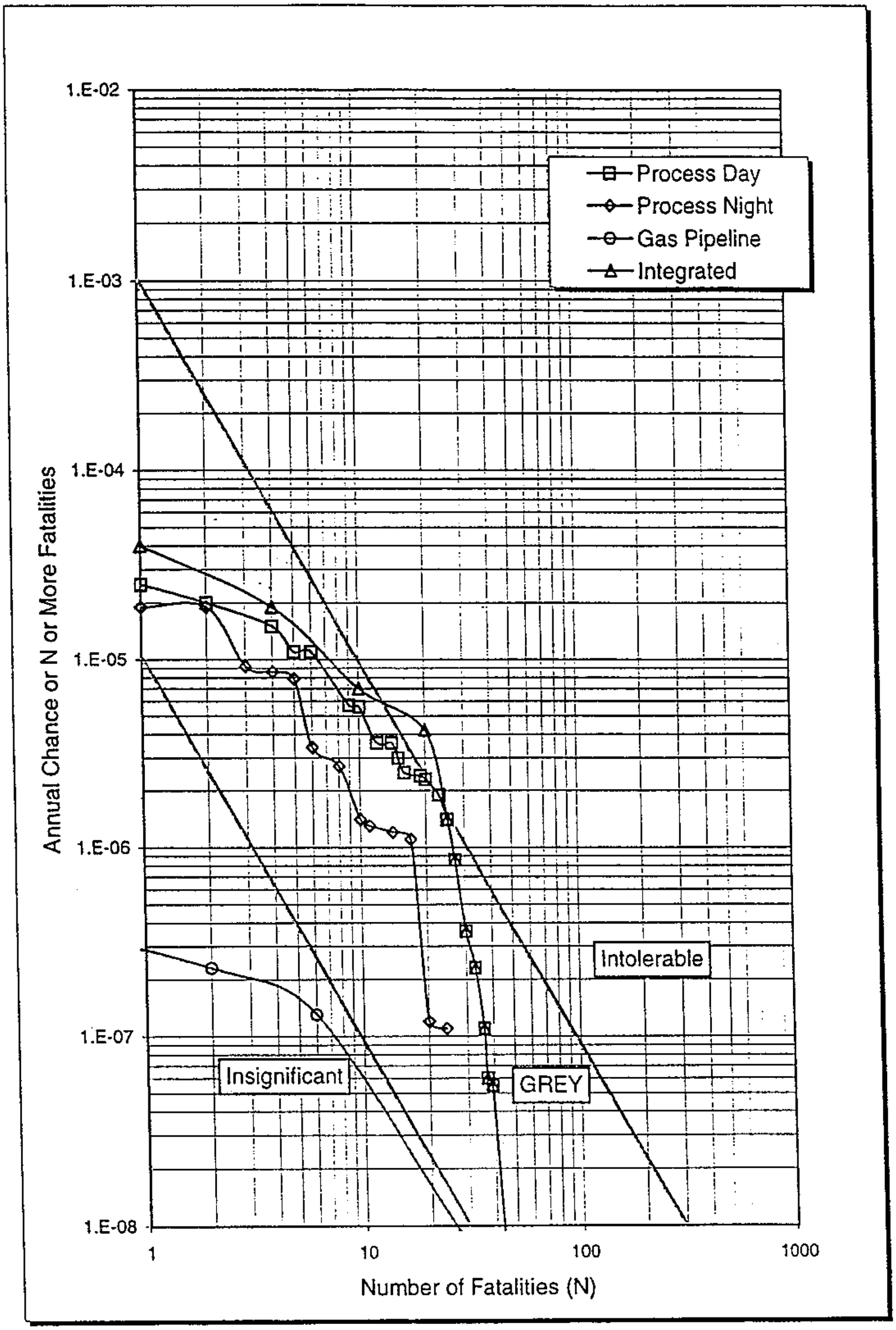


Figure 5.13
Public Risk Spectrum - Production Phase - Process and Gas Pipeline - Unmitigated

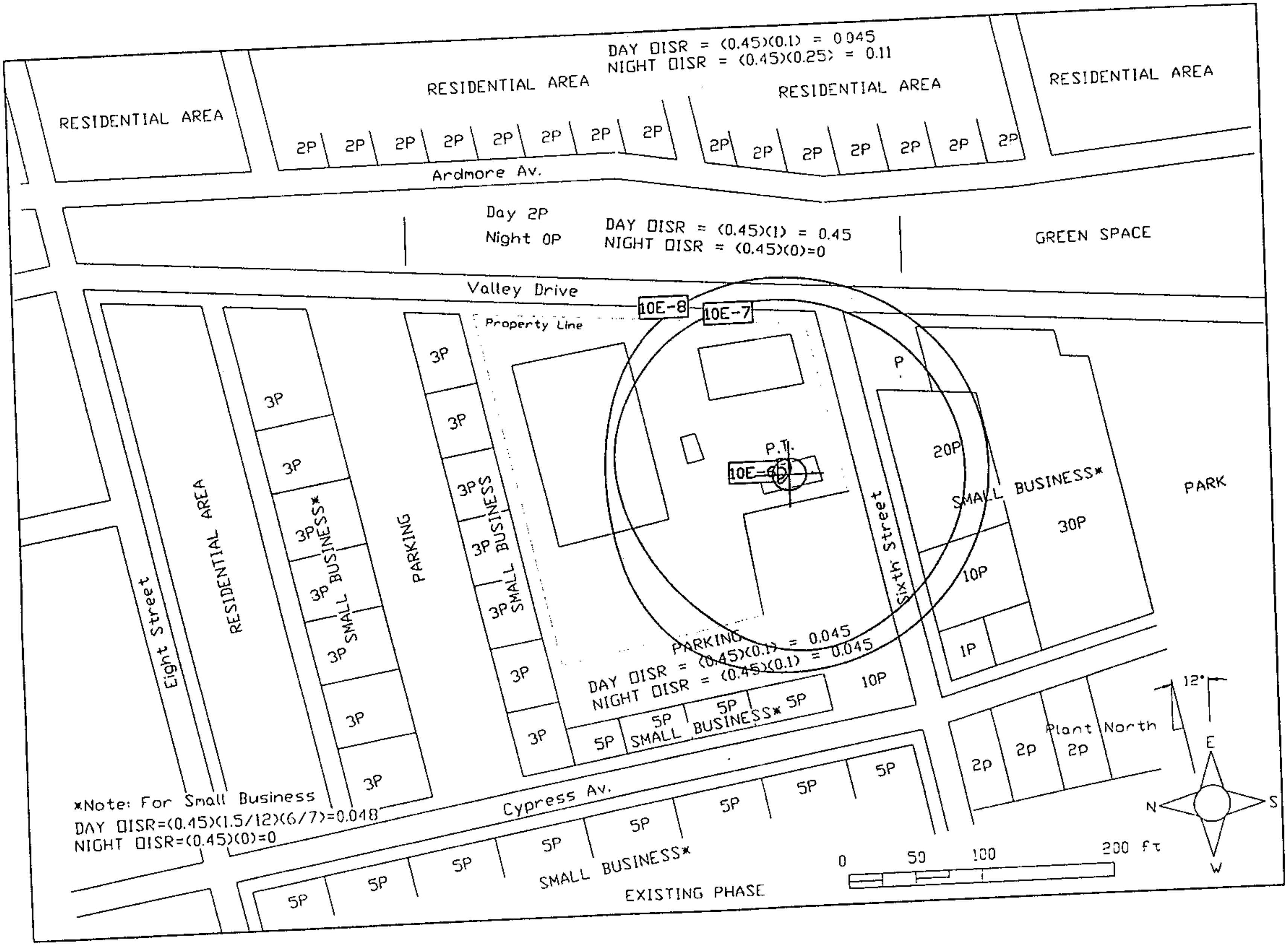


Figure 5.14
IR Contours for Existing Facilities

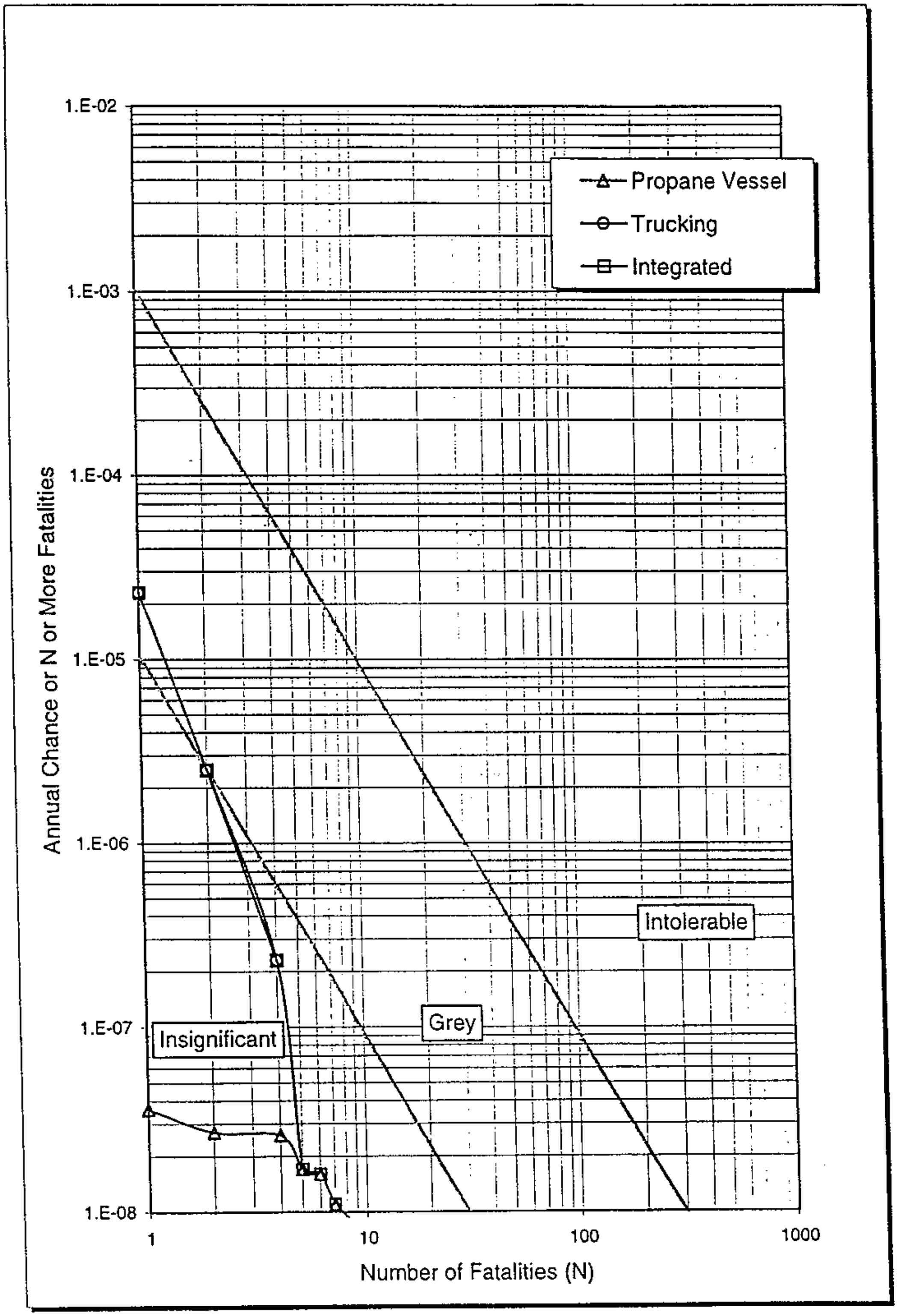


Figure 5.15
Public Risk Spectrum - Existing Facilities

CHAPTER 6

RISK MITIGATION

6.1 Approaches to Risk Mitigation for this Project

Risk mitigation measures are considered under two categories in this study. These are generic risk mitigation measures and specific risk mitigation measures. Generic risk mitigation measures are industry standard measures which have been considered to be incorporated in the facilities under consideration. Specific risk mitigation measures are those that have been explicitly omitted in the unmitigated risk analysis in order to emphasize their importance in the mitigated or resultant risk analysis described later. Thus, in the balance of this chapter, risk mitigation measures are broadly subdivided into generic risk mitigation measures and specific risk mitigation measures.

6.2 General Approach to Risk Mitigation for Industrial Projects

The objective of risk mitigation or safety measures is to reduce risks from a system while still permitting it to operate in a productive and cost-effective manner.

Risk mitigation can be addressed on two principal levels; namely, at the source and at the effect level. That is, we can reduce the frequency and volume of hydrocarbon releases or we can reduce the probability and magnitude of adverse consequences. Examples of pipeline source (or hazard) risk reduction include control of use and access to the right-of-way (R.O.W.) to help prevent third party damage; use of pipe with greater wall thickness to reduce corrosive and mechanical defect ruptures; or installation of a better system of line isolation valves to reduce accidental release volumes. Examples of consequence risk mitigation measures include pipeline route selection to minimize public exposure to accidental releases, enactment of land use zoning ordinances to restrict development in areas exposed to high consequence potential, and preparation and availability of appropriate emergency response measures to reduce accident effects.

Both these levels of safety enhancement can be further classified under the general headings of strategic or tactical. Strategic measures are ones designed to avoid accidents. Tactical measures are ones designed to minimize the adverse effect of an accident if it does take place. Thus, R.O.W. control, extra engineering and construction measures, and zoning regulations would be considered as strategic, while measures such as pipeline segment isolation, automatic shutdown, or emergency response, are tactical measures.

Figure 6.1 summarizes the principal levels and types of risk mitigation measures in block diagram form, under the general categories introduced above and utilized in the balance of the discussion in this chapter. Further, the types of risk mitigation measures are identified in the balance of this chapter by letter combinations, "F" for Failure, "C" for Consequence, "S" for Strategic, and "T" for Tactical. For example, a Failure-Tactical measure would be referred to as "F-T".

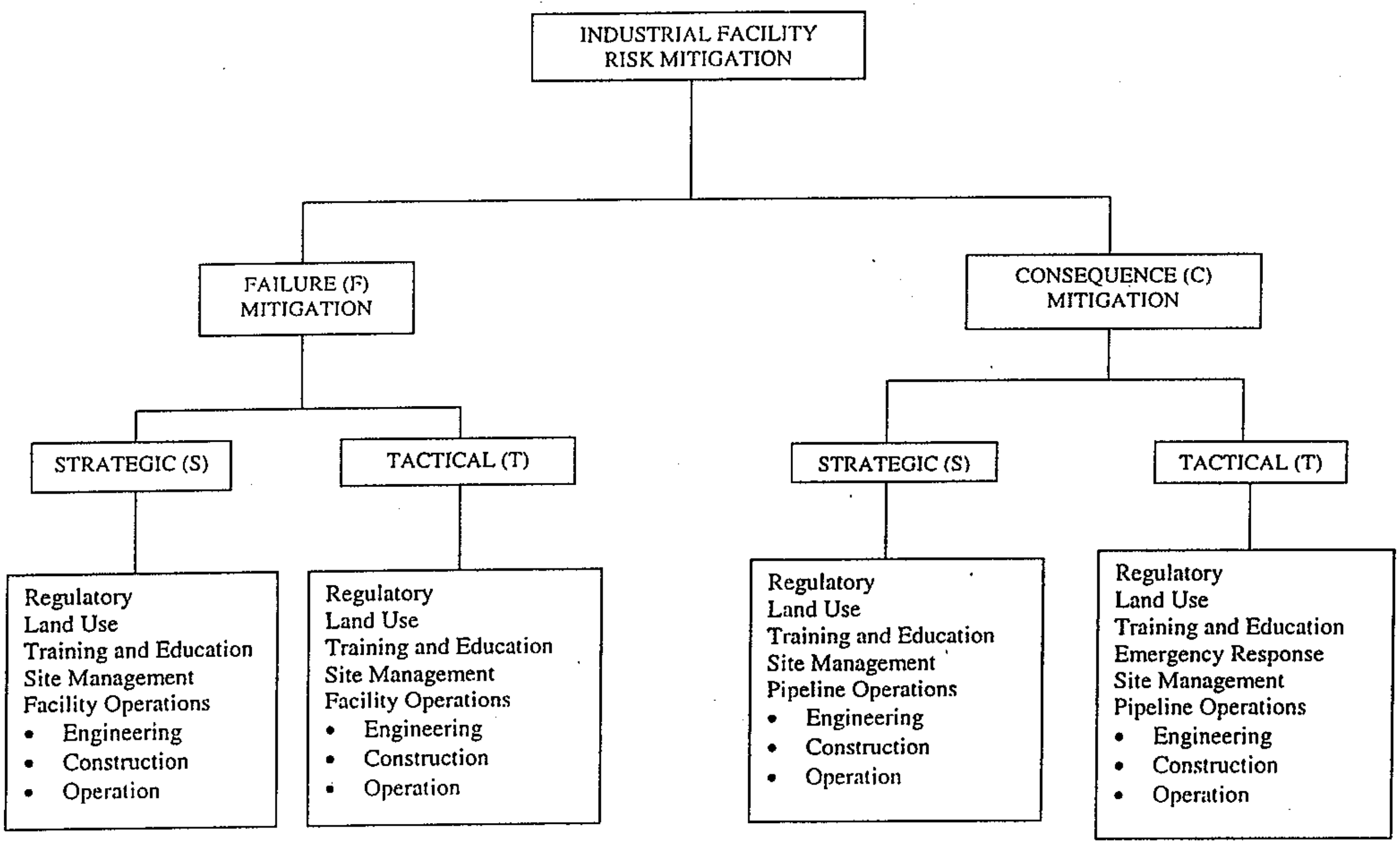


Figure 6.1
Schematic of Risk Mitigation Measures

6.3 Risk Mitigation Process

Once the unmitigated risks from a particular system have been evaluated, the analysis conducted can be used as a basis for the development and selection of optimal risk mitigation measures. First, principal causes of rupture and major consequence factors are identified.

For example, the leading cause of pipeline rupture is third party damage. Consequences are intrinsically dependent on proximity and density of population. Clearly, candidates for mitigation measures of rupture and consequences are reduction of third party damage and avoidance of high population density areas, respectively. Practical ways of achieving these mitigation measures are then developed. For example, third-party damage to pipelines can be reduced by R.O.W. signs, public education, mandatory excavation permits and proof of compliance, restrictive R.O.W. access, and excavation warning measures. Similarly, densely populated areas can be avoided by proper route selection for new pipelines. The effect on the risk of incorporation of each of the measures, individually, as well as in feasible combinations, is then conducted utilizing methods of risk analysis.

Among the principal hazards for hydrocarbon processing facilities are flammable gas clouds which result in jet fires, if ignited immediately and possible explosions and flash fires if ignited some time after the initial release. For the immediate ignition case, a fire wall between the source and the offsite population can reduce or eliminate jet fire effects. Similarly, the likelihood of delayed ignition of a light gas cloud gas be reduced by deflecting the cloud from ignition sources, again by a wall between the release source and offsite ignition sources.

6.4 Facilities Risk Mitigation

6.4.1 Generic Facilities Risk Mitigation Measures

The general classification of risk mitigation measures given in Figure 6.1 applies to facilities in the Test and Production Phase. Thus, mitigation measures can be broadly classified into initial and consequence mitigation measures of a strategic or tactical nature.

Table 6.1 summarizes risk mitigation measures for both failure and consequence risk mitigation, designating the type of measure in accordance with F,C,S,T system introduced earlier. The proposed action by MacPherson Oil Company (MOC) for each measure is given in the right column.

Regulatory measures, pertaining to control of territory and members of the public outside the plant boundary, include emergency response plans for the surrounding area, local agency personnel training, and general public awareness. Land use, again relating to control of territory by the City outside the plant boundary includes restrictions of future development in the near vicinity of the plant, certain buffer zones and setbacks, and control of access to the site vicinity.

Table 6.1
Hydrocarbon Processing Facilities Risk Mitigation Measures

MEASURE	F/C	S/T	DESCRIPTION	RESPONSE BY MOC
Regulatory	C	S	Emergency response plan requirements	Emergency Response Plan for facility on file with the City.
	F/C	S	Worker training	All operator personnel will be trained in risk management and facilities operations.
	C	S	Public awareness	Fire safety, public notification, warning and evacuation plan required by CUP.
Land Use	C	S	Site location away from existing and future developments	Site location selected by City of Hermosa Beach.
	C	S	Require buffer zone and setbacks	Site location selected by City of Hermosa Beach. Project located at intersection of two streets in an industrial zone.
	F	S	Control of site access	Perimeter chain-link/masonry walls all four sides. Site operated 24-hours, access permitted only to operational personnel or trained visitors.
Training	F/C	S/T	Personnel training in operations, emergency response, contingency plans	All operator personnel will be trained in risk management, emergency response procedures, contingency plans and facilities operations.
	C	T	Area public awareness and evacuation training	Fire safety, public notification, warning and evacuation plan required by CUP. Evacuation training to be determined by the City.
	F/C	T	Use of experienced personnel and thorough screening and training for new personnel	Only experienced and thoroughly trained operation personnel will be employed at the site.
Site Management	F	S	Site security entry / egress control	Perimeter chain-link/masonry walls all four sides. Site operated 24-hours, access permitted only to operational personnel or trained visitors.
	F/C	C	Night time security personnel and devices	Site operated 24-hours, operation personnel trained in site security.

Table 6.1 (cont.)
Hydrocarbon Processing Facilities Risk Mitigation Measures

MEASURE	F/C	S/T	DESCRIPTION	RESPONSE BY MOC
	F/C	S	Surroundings surveillance and monitoring	Site operated 24-hours.
Emergency response	C	T	Emergency response plan / team / facilities	Emergency Response Plan on file with the City. Emergency response team consisting of MOC personnel and Clean Coastal Waters (or equivalent agency) available 24-hours.
	C	T	Detection / alarm systems (gas/fire/overpressure)	Detection and alarm systems installed to provide notification to operating personnel of gas release, fire, overpressure and other malfunctions of system.
	C	T	Area public awareness	Fire safety, public notification, warning and evacuation plan required by CUP.
	C	T	Fire fighting equipment as required	A Fire Protection Plan is on file with the City delineating the fire protection facilities to installed at site.
	C	T	Coordination of local emergency capabilities including police, fire, hospital	Emergency Response Plan on file with the City provides procedures for coordination of local emergency capabilities with City Fire Department.
Operations				
• Engineering	C	S	Facilities layout to minimize hazards	Facilities have been designed to minimize hazards and for ease of operations.
	C	S	Site location to avoid exposure	Site location selected by the City of Hermosa Beach.
	F/C	T	ESD valves to isolate critical sections	ESD valves will be located to isolate critical sections of process and to minimize hazard.
	C	T	Emergency power and control double backup	Emergency power is not required. Facilities will safely shutdown when loss of electrical power occurs.
	C	T	Leak detection and monitoring	Facility site manned 24-hours, production facilities will be inspected on a regular basis throughout the day. Facility provided with a gas, hydrogen sulfide and flame detection system.
	C	T	Automatic shutdown	Critical process equipment are provided with alarm and automatic shutdown of equipment and in some

Table 6.1 (cont.)
Hydrocarbon Processing Facilities Risk Mitigation Measures

MEASURE	F/C	S/T	DESCRIPTION	RESPONSE BY MOC
				cases automatic shutdown of facilities.
	F/C	S	State of art engineering	Facilities engineered and designed to latest codes and standards. Facility design reviewed by independent engineering company. See HAZOP.
	C	T	Drainage/ venting systems release	Facility is equipped with vent and bleed system. The facility is provided with an emergency vent system for emergency releases.
	C	T	Connect to flare system for overpressure depressurization	All pressure vessels connected to emergency vent system with vent stack to safely permit depressurization of vessels.
	C	T	Overpressure PSV	All tanks and pressure vessels provided with pressure relief valves to protect tanks and pressure vessels from overpressure.
	C	S	HAZOP ongoing procedures	HAZOP study will be updated to reflect any proposed changes to processing facilities.
	C	T	Design for fire / explosion protection of critical facilities as required	An approved Fire Protection Plan is provided. Explosion protection will be provided and mitigated as per this risk assessment.
• Operation	F/C	S	Safe operating procedure philosophy	A safe operating procedure philosophy will be maintained throughout the life of the project.
	C	T	Alarm systems known to all personnel	All personnel will be thoroughly trained in operations procedures including alarm systems.
	C	T	Emergency response plans and facilities	Emergency response plans and equipment will be in place before startup of facilities.
	F	S	Regular inspection and maintenance	The operational procedures manual includes a documented inspection and maintenance program for a production facilities.
	F	S	Event-driven (e.g., overpressure) inspection and maintenance	The facilities will be inspected and evaluated after any major upset or event.

The site management program involves more stringent measures as the plant site is under direct control of MOC. Thus, site security, entry and rigorous control, nighttime security personnel and equipment, fencing, posting, and general access control as well as surveillance and monitoring of the site and its surroundings on a regular basis, are included in the site management. Immediate rectification of any threats to the facility both due to environmental causes such as subsidence or unanticipated ground water conditions, or third party intervention such as frequent recreation or usage of areas in close proximity should be rectified immediately.

All aspects of emergency response are important consequence-tactical risk mitigation measures for facilities such as those under consideration. Thus, emergency response planning, team designation, and facilities and equipment, are essential. More specifically, within the process area, fire, gas, and overpressure detection and alarm systems with appropriate levels of redundant backup are important to mitigate the consequences of any possible failures or deviations from normal processes.

Finally, engineering and operational risk mitigation measures again constitute the first, and most intrinsic mitigation measures within the process facility. Design of the facilities first, at a site location to avoid nearby exposure to the public, and second with the general layout to minimize hazards is essential. Location of potential release sources with respect to wind direction, flange orientation to avoid accidental release directed at vulnerable facilities. If layout alone will not satisfy safety requirements, erection of fire walls, explosion barriers, and other protective structures may be more feasible. Within the process network itself, emergency shutdown (ESD) capabilities for critical sections to isolate them and to reduce the volumes of accidental releases, are important. All ESD requires emergency power and backup. Leak detection systems, fire detection and automatic suppression, monitoring, and drainage for spills and venting systems for gas releases, all constitute state-of-the-art engineering provisions for safe process operation.

Operating procedures themselves, starting with a safety based operating philosophy, with appropriate personnel, training programs, backed by reliable detection and alarm systems are important for a safe facility. Regular inspection and maintenance, provision for unscheduled inspections in case of potentially damaging events, and thorough and meaningful process deviation and incident reporting round out a safe operating plant for the facility.

6.4.2 *Test Phase Facility Specific Risk Mitigation*

Specific risk mitigation measures included in the unmitigated risk analysis for the Test Phase facilities may be summarized as follows:

- Layout

    - Facilities will be installed in a non-congested layout minimizing the potential for the containment of vapors to create hazardous explosion conditions
- ESD valves to isolate inventory at least in the following sections:
    - Well manifold outlet
    - Process facility outlet to incinerator
    - Process facility outlet to storage
- Blowdown capability including each isolatable segment blowdown directly to flare
- Gas and fire detection at critical locations to facilitate rapid emergency response to minimize consequences of accidental releases of process fluids
- Drainage capability, draining away from facilities and control center in areas where flammable liquids are present
- Drainage away from truck loading area with sufficient capacity to drain loading spills up to 200 bbl
- Dykes of with a capacity for total storage tank contents
- Engineering
    - Formal risk analyses (HAZOP) carried out to identify hazards and implementation of risk mitigation measures thus derived throughout the design, engineering, and construction phases
    - Conservative design for stable operations, including adequate safety factors
    - Recovery from upsets done by operating team with a successful operating record
- Operations
    - Backup equipment systems for all critical elements, particularly for emergency response instrumentation including H_2S detection and shutdown
    - Use of experienced operators only, working to approved management and operating system
    - Extensive screening and thorough training of all new personnel and appropriate supervision particularly for critical operations supervision
    - Strategic gas, fire, leak, overpressure detection with appropriate alarm on the 24 hour basis with other operator controlled automatic emergency response including shut-down , depressurization, venting.
    - Fire-fighting capability, particularly in truck loading, control centre, and storage areas
    - Extensive and state-of-art operating plan including inspection, maintenance, unscheduled inspections, drills, and other aspects of state-of-art operating plan.
    - Best current engineering practice reducing corrosion potential including design, inspection and active protection such as cathodic protection.

Specific additional risk mitigation measures which are included in the mitigated risk event are the following:

- Fire/explosion proofing of control centre
- Fire resistant 30' high perimeter sound attenuation wall.

6.4.3 Production Phase Facility Specific Risk Mitigation Measures

Specific risk mitigation measures included in the current unmitigated risk may summarized as follows:

- Layout
    - Facilities to be installed in a non-congested layout minimizing the potential for containment of explosive vapors
- Isolation including ESD valves capable of isolating inventory at least in the following locations:
    - Production well manifold
    - Inlet to the plant
    - Outlet from plant
- Blowdown capability involving connection of pressure relief valves to the flare stack
    - Location of redundant gas, fire, overpressure detectors and automatic alarm systems at appropriate location throughout the process area
    - Isolation through remotely activated valves, hydrocarbon and fire detectors, blowdown directly to flare, level transmitters, and standard PSV design for overpressure.
- Engineering
    - Formal HAZOP carried out to identify hazards and implementation of risk mitigation measures throughout the design, engineering, and construction phases
    - Modern design for stable operations, recovery from upsets by an experienced engineering team with a successful record
- Operations
    - Backup equipment systems installed for critical elements including H_2S detection and shutdown
    - Experienced operators normally on duty working to proven management system in accordance a state-of-art operating plan for all aspects of operations
    - Extensive screening of all new personnel and supervision of all new personnel with experienced personnel during all critical operations
    - Fire fighting capability directed primarily at staffed area such as administrative and control buildings
    - State of art operating plan including inspection, procedures, maintenance, event-related inspection and maintenance, drills, pressure tests, etc.

Risk mitigation measures included in the mitigated risk assessment include the following:

- Installation 12' high concrete block perimeter wall the duration of the Production Phase

6.5 Pipeline Risk Mitigation

6.5.1 Generic Pipeline Failure Risk Mitigation Measures

Pipeline rupture probability can be reduced in a variety of ways, ranging from relatively subtle provisions such as changes in design codes, development guidelines, or educational programs, to very direct measures such as restricting access to pipeline right-of-ways or increasing pipeline wall thickness. The range of pipeline failure risk mitigation measures applicable to pipelines, is summarized under its principal classifications in Table 6.2 together with associated provisions by MOC.

A one call system should be participated in by all operators, development referral prior to approval should be required, and certain land use controls should be developed. The one call system is essentially one whereby a single phone number will provide information on pipeline locations for numerous different operators as well as receive information on intended excavations.

Land use controls are exercised primarily by the City. An application referral system requiring approval of an application by all parties, including relevant pipeline operators, facilitates risk mitigation. Future planning and zoning must consider both development and existing and potential pipeline facilities. Finally, setbacks to avoid right-of-way encroachments which could lead to third-party damage of pipelines should be utilized.

Training and education are probably among the most cost-effective mitigation measures. Cost of additional training for operating personnel is quickly recovered if only one major pipeline accident caused by operator error can be avoided as a result of that training. Likewise, specialized emergency training within the context of specific systems and their surroundings is important. Public awareness programs can be conducted effectively and inexpensively through the regular mail-out of a brochure describing the pipeline facility, potential consequences of accidents, and ways in which the public can help avoid such accidents. In addition, such brochures can contain guidelines for emergency response by the public, referred to in the next section. However, the material must be presented in a manner that will not provoke unnecessary fear or panic which could impair understanding of the concepts and procedures. The public too has a responsibility, particularly when information sessions with voluntary attendance are made available in communities by operators or the City.

A properly coordinated right-of-way management program instituted by the operator can add significant risk mitigation at relatively low cost. Easement agreements to determine encroachments should be reviewed periodically, R.O.W.s inspected for encroachments, any encroachments found should be

Table 6.2
Pipeline Failure Risk Mitigation Measures

MEASURE	STRATEGIC (S) TACTICAL (T)	DESCRIPTION	RESPONSE BY MOC
Regulatory	S	Design and construction codes and standards	Pipeline to be designed and constructed in accordance with ANSI B 31.4 & 31.8 Pipeline Standards, City & State Codes.
	S/T	Public awareness program requirements	City Conditional Use Permit requires notification of area residents w/in 300' of construction. Relocation of public transit stops along pipeline route. Emergency service providers to be informed of construction activities.
	S	Accident reporting	City of Hermosa Beach Fire Department to be notified of all construction accidents.
	S	One call system mandatory	City of Hermosa Beach Fire Department.
	S	Proof of communication for R.O.W. excavation permit	City of Hermosa Beach issues excavation permit.
Land Use	S	Design and develop to maximum setback	City requires pipelines to be installed in City R.O.W.
	S	Application referral system	Not applicable.
	S	Future planning consider both development and pipeline facilities	Pipeline route approved by City and considered during project issuance of Conditional Use permit.
	S	Setbacks to avoid R.O.W. third-party damage	City requires pipelines to be installed in City R.O.W.
Training & Education	S/T	Train operator personnel in risk mitigation and pipeline operation	All operator personnel will be trained in risk management and pipeline operations including compliance with the Crude Oil Pipeline Spill Contingency & Emergency Response Plan and Gas Pipeline Emergency Response Plan.
	S/T	Inform public of safety measures regularly	Permanent signs with operators telephone number to be installed along pipeline route. A notification process as required by the CUP will be in place to warn public of any safety requirements.

Table 6.2 (cont.)
Pipeline Failure Risk Mitigation Measures

MEASURE	STRATEGIC (S) TACTICAL (T)	DESCRIPTION	RESPONSE BY MOC
	S	Corrosion inhibitors	Corrosion inhibitor injection program to be in place for pipeline operation.
	S	Smart Pigging	Smart pigging as required by CCC permit.
	S	Elimination of free water	Crude oil must be refinery quality containing less than 3% water. Produced gas to be dehydrated before shipping.
	S	Improved training, maintenance	Proper training and maintenance procedure will be in place for pipeline operations.
	S	Control R.O.W. access by third-party	See R.O.W. Management above.
	T	Leak detection and alarm system	See Pipeline Operations, Engineering above.
	T	Emergency measures in place	Implementation of Emergency Response Plans.

removed, and an on-going surveillance and monitored program for the right-of-way should be conducted. Protection of right-of-ways can range from posting of warning and information signs to the erection of protective fencing and installation of pipeline shielding. Participation in a multi-operator one-call system, as mentioned earlier, is another cost-effective right-of-way management risk mitigation measure.

The way in which the pipeline itself is designed, constructed, and operated has had a significant impact on its probability of failure. A large number of pipeline operation risk mitigation measures have been identified, analyzed, publicly debated and implemented in various projects such as the Chevron Point Arguello Field and the Gaviota Pipeline and Processing Facility in California, and, in Alberta, the Shell Canada Caroline Sour Gas Gathering System and Processing Plant. In the latter case, numerous risk reduction measures were instituted. These included ones to reduce the probability of pipeline failure and gas released by two orders of magnitude below the historical average for sour gas pipelines and, second, stringent consequence risk mitigation measures as discussed in the next section. The measures given in Table 6.2 under Pipeline Operations are a summary of strategic and tactical measures in each of the operation categories which can be implemented to reduce risk. A more detailed description of these measures based on specific industry experience is given in Table 6.3. In general, such measures should be considered when warranted by the particular circumstances, and MOC provisions are given as appropriate.

6.5.2 Generic Pipeline Failure Consequence Mitigation Measures

Consequence risk mitigation measures are divided into the same categories as those pertaining to rupture risk mitigation. Consequence risk mitigation measures have the objective of reducing the adverse effects of a rupture if it does happen. They are directed at reducing the number of people exposed, at greater emergency response efficiency, at minimizing the amount of gas leaked, and at avoiding public exposure through proper planning. The principal consequence risk mitigation measures used or developed are summarized in Table 6.4 together with MOC comments and provisions.

Principal regulatory measures relate primarily to the requirements for emergency response plans and coordination of emergency response agencies. The City of Hermosa Beach can strategically influence pipeline safety enhancement with appropriate land use control, separating commercial and residential development as much as possible from pipelines and pipeline right-of-ways. In particular, emergency facilities and high population density public facilities such as schools should be set back from pipelines at distances dictated by risk criteria.

Availability of all relevant information to the emergency response team is essential for reducing accident consequences. Thus, the location of the emergency facilities, secondary hazard locations, right-of-way access routes, and demographic distributions are important data that should be maintained by both

Table 6.3
Operator Strategic Rupture Risk Mitigation Measures

RUPTURE CATEGORY	MEASURES AFFECTING REDUCTION IN RUPTURE RATE	RESPONSE BY MOC
A) Thermal Stress	Detailed stress	Pipelines to be designed in accordance with ASTM B 31.4 & B 31.8.
	Low hoop stress design	Pipelines have low operating pressure.
	Controlled burial temperature	Pipeline not located in freeze area.
B) Corrosion	No oxygen in pipelines	Tank vapors are controlled to eliminate oxygen in the production system using a fuel gas blanket system.
	Improved inhibitor performance and program	Corrosion inhibitor injection program to be in place for pipeline operations.
	Low hoop stress design	Pipelines have low operating pressures.
	Elimination of free water in gas & liquid mainlines	Crude oil must be refinery quality containing less than 3% water. Produced gas to be dehydrated before shipping.
	Detection of damage through inspection	Pipeline route will be visually inspected on a weekly basis and smart pigged as required by the California Coastal Commission (CCC) permit. Access to pipelines controlled by City permit.
	High quality external protective coating	Pipeline to have X-Tru-Cote exterior coating or equivalent. All welded joints to be primed and taped.
C) Third-Party Damage	High awareness of pipeline existence in area	Pipeline route and approval process through public hearing process. Area notification during pipeline installation. Emergency service providers notified of installation. Installation of permanent signs along pipeline route to notify public of pipeline location.
	Improved marking and identification of pipeline	Brightly colored plastic ribbon to be installed 12 to 18 inches above pipeline labeled without warning. Pipeline trench backfilled with cement-sand slurry. Installation of permanent signs along pipeline route to notify public of pipeline route.
	Pipeline taken out of service prior to excavation	Pipeline to be taken out of service prior to excavation activities for repair or maintenance to pipeline.
D) Weld Failure	Strict adherence to welding procedures	Pipelines constructed to ANSI B. 31.4 & B 31.8 Pipeline Standards, City and State Codes.
	Better construction environment due to non-winter construction	Pipeline not located in freeze area, mild winters.

Table 6.3 (cont.)
Operator Strategic Rupture Risk Mitigation Measures

RUPTURE CATEGORY	MEASURES AFFECTING REDUCTION IN RUPTURE RATE	RESPONSE BY MOC
	Improved standard of field quality control	All welds in City R.O.W. to be visually inspected and radiographic inspected by independent inspection service.
	Detailed stress and flexibility analysis	Design will comply with applicable codes.
	Improved radiographic techniques (high quality film, x-ray)	Welds in street R.O.W. will be 100% X-rayed.
E) Operator Error	Improved training, maintenance and operating procedures	The training, maintenance and operating procedures manual will detail all aspects of operating the pipeline system.
F) Construction Defect	Improved construction and inspection procedures	Pipeline construction inspection to be conducted by independent construction inspection service that specializes in pipeline installation.
	Use &calliper pigs and magnetic logging inspection tools for detection of defects prior to startup	Pipelines will be inspected with "smart pig" technology prior to startup to detect construction defects and to establish a base line inspection.
	Detailed stress and flexibility	Pipeline design & construction will comply with applicable codes.

Table 6.4
Pipeline Failure Consequence Risk Mitigation Measures

MEASURE	STRATEGIC/ TACTICAL	DESCRIPTION	RESPONSE BY MOC
Regulatory	T	Requirement for emergency response plan	Crude Oil Pipeline Spill Contingency and Emergency Response Plan
	T	Public and personnel education	The training, maintenance and operating procedures manual will detail all aspects of operating the pipeline systems. Pipelines to be buried in street R.O.W. with no access from public. Permanent signs with operators telephone number to be installed along pipeline route
	S	Accident reporting	City of Hermosa Beach Fire Department will be notified of accidents related to pipeline systems in City R.O.W.
	T	Coordination of emergency response agencies	Emergency Response Plans are coordinated with public agencies
	S	Land use control	Pipeline location in street R.O.W. established by City
	S	Setbacks for buildings and emergency facilities	Pipeline location in street R.O.W. established by City
Land Use	S	Site development to minimize exposure	Pipeline location in street R.O.W. established by City
	S	Require adequate setback	Pipeline location in street R.O.W. established by City
	S	Future planning for both zoning and pipelines	City of Hermosa Beach provides planning for zoning related to pipeline location
Training & Education	S/T	Operator personnel training in emergency procedures	Operating personnel will be trained in emergency procedures and use of the Emergency Response Plans
	S/T	Information to public on emergency procedures	Permanent signs with operator telephone number to be installed along pipeline route. A notification process as required by the CUP will be in place to warn public of any safety requirements

Table 6.4 (cont.)
Pipeline Failure Consequence Risk Mitigation Measures

MEASURE	STRATEGIC/ TACTICAL	DESCRIPTION	RESPONSE BY MOC
R.O.W. Management	T	Maintain emergency access routes	City street R.O.W. access available at all times
	T	Surveillance and monitoring - early leak detection	Pipeline route to be visually inspected on a weekly basis. Crude oil pipeline to be installed with SCADA system and all pipelines in R.O.W. to have high and low pressure and manual emergency shutdown systems
Emergency Response	T	Emergency response plan	Emergency Response Plan on file with City of Hermosa Beach
	T	Emergency response team and equipment	Emergency response team consisting of MOC personnel, Clean Coastal Waters (or equivalent agency) available 24-hrs
	T	Emergency training and drills	Operating personnel to be trained and drilled in emergency procedures and use of the Emergency Response System
	T	Public awareness of emergency response by evasion, evacuation, and tight shelter	Emergency Response Plans provide necessary awareness of emergency response
Pipeline Operations			
• Engineering	S	Route selection to avoid exposed population	City approved pipeline route
	T	Depressurisation to flare	Pipeline terminates in atmospheric tank, therefore depressurization to flare not required
	T	Failsafe isolation and block valves	Automated block/check valve combination to be installed at Herondo Storm Drain crossing and at any fault location. Block valves to be installed at intersection with EPTC facilities. Fail-closed block valves to be used.
	T	Plant isolation (LEV) valves	Facility isolation (block) valves will be installed
	T	Optimal isolation valve location & spacing	Isolation valves to be installed as required

MEASURE	STRATEGIC/ TACTICAL	DESCRIPTION	RESPONSE BY MOC
	T	Control and leak detection	SCADA system to be installed on crude oil shipping pipeline. High and low pressure alarm and shutdown to be installed on crude oil and gas shipping pipelines. Pipeline corrosion injection program to be in place with smart pigging as required by the California Coastal "Commission (CCC) permit
• Operation	T	Emergency response plans in place	Emergency Response Plans on file with City. ERPs to be implemented upon completion of installation of new pipelines in City R.O.W.
	S/T	Public awareness program	Permanent signs with operator telephone number to be installed along pipeline route. A notification process as required by CUP will be in place to warn public of any safety requirements
	T	Early warning system	High and low pressure alarm system on shipping pipelines to alert operator of pressure changes in piping system prior to automatic shutdown
	T	Emergency response team on call	Emergency response team consisting of MOC personnel, Clean Coastal Waters (or equivalent agency) available 24-hrs

local governments and their emergency response agencies and operators in a readily accessible form. The level of awareness of the public is particularly important in an emergency response situation.

Thus, the information provided to the public by the operator in regard to evacuation plans, evasive tactics such as seeking shelter indoors, and other tactical actions may be very significant in reducing consequences in an emergency situation. Further, local governments and local emergency agencies such as fire and police departments and hospitals should obtain all pertinent information on the facilities and possible emergency situations from the operator. Special assistance may be required from more senior levels of government with the provision of specialized training or high technology equipment necessary for handling certain emergencies.

The development and implementation of an emergency response capability is an essential element for successful tactical pipeline failure consequence reduction. Planning, establishment of a team and equipment, drills and training, and a high level of public awareness constitutes the basis for a successful emergency response capability. Right-of-way management procedures include maintenance of emergency access routes to the right-of-way, and monitoring which could assist in minimizing the impact of a rupture by early detection and quick deployment of a repair crew.

Optimal route selection is probably the most effective means to reduce consequence risk. Extensive effort should be made to minimize public exposure through often expensive re-routing to avoid multiple resident exposure within the zone of influence of the pipeline. Failsafe isolation valves, their location and spacing, fully redundant emergency power and control backup systems, and leak detection and monitoring equipment, are other engineering measures used to reduce consequence potential. Operational measures relate primarily to generating a capability for an effective and immediate response to an emergency. This involves both operator and emergency agency response as well as public readiness through appropriate awareness programs.

6.5.3 Specific Pipeline Risk Mitigation Measures

Generic risk mitigation measures incorporated in the unmitigated risk analysis for the project oil and gas pipelines were as follows:

- Emergency shutdown (ESD) valves at pipeline inlets and outlets
- Periodic internal corrosion inspection and right-of-way surveillance (F-S)
- Appropriate strength of pipe, or burial depth at any highway crossing (F-S)
- Warning signs along easement and periodic right-of-way surveillance (F-S)

- Emergency preparedness for both MOC personnel and area resident (C-T)
- pipeline leak detection system at control center (C-T)

No additional specific risk mitigation measures have been considered in calculating resultant risks.

6.6 Trucking Risk Mitigation

During the Test Phase, it is proposed that between 3 and 4 tanker trucks per day will load crude oil at the project site and transport it to a location outside Hermosa Beach. These tanker trucks will follow designated routes and follow a specified loading protocol at the test site. Table 6.5 lists generic strategic and tactical risk mitigation measures applicable to accident cause and consequence risk mitigation associated with tanker truck operations.

In the unmitigated risk analysis, it is assumed that the generic provisions listed in Table 6.5 are applicable.

Table 6.5
Trucking Risk Mitigation Measures

F/C	S/T	DESCRIPTION
C	S	Schedule truck trips to avoid peak population exposure times.
C	T	Develop a coordinated Emergency Response Plan.
F&C	S	Provide specialized driver training.
F	S	Develop inspection by non-destructive testing.
F	S	Monitor critical safety devices and systems.
F&C	S	Use designated routes in urban areas.
F	S	Company hiring policies to screen out unsafe drivers.
F	S	Policy violation penalties.
F	S	Zero tolerance drug and alcohol policy.
F	S	Incentive programs for drivers and other personnel responsible for truck safety.
F	S	Use of Vehicle Monitoring Systems (VMS) for monitoring drivers and vehicle performance.
F	T	Use of VMS for tracking trucks.
F	S	Use of simulators for driver training.
C	S	Improved emergency response training for drivers.
F	S	Utilization of approved fully protected and licensed carriers.

CHAPTER 7

MITIGATED RISKS

7.1 Approaches to Mitigated Risk Assessment

In this chapter, the results of a reassessment of the risks considering specific risk mitigation measures recommended for incorporation in the project are presented. Where no additional specific risk mitigation measures have been utilized or deemed necessary, the unmitigated risks are presented as the resultant risks.

7.2 Test Phase Mitigated Risk

No specific risk mitigations are required for the Test Phase due to its relatively short operational span of one year, and largely acceptable risks assessed. However, the presence of the sound attenuation wall has a risk mitigating effect, which should be considered. It is expected that the sound attenuation wall would effectively deflect a gas cloud well above the effects of offsite ignition sources. Accordingly, the effect of ignition probability reduction due to the sound attenuation wall can be modelled utilizing the consequence evolution event tree with reduced ignition probabilities as shown in Figure 7.1. In addition, because of the short duration (1 minute) of the only Test Phase jet fire that has a potential for offsite consequences, that associated with the rupture, it is likely that the sound attenuation wall would also prevent offsite effects of the jet fire. Inclusion of these mitigating effects in the individual risk isopleths is illustrated for each of the three representative atmospheric conditions in Figures 7.2, 7.3, and 7.4 for the Test Phase. The resultant risk spectrum for the principal Test Phase components and the total Test Phase including well blowouts, process releases, and trucking accidents, is shown in Figure 7.5.

7.3 Production Phase Mitigated Risks

The specific risk mitigation recommended for the Production Phase is the 12' high reinforced concrete block wall around the perimeter of the facility, with solid gates that would prevent vapour cloud egress during the normal closed condition. Although a 30' sound attenuation wall is also proposed for initial operation of the facility during the drilling of wells, it is not representative of the 30 year projected operational configuration for the facility and therefore is not considered. The reinforced block perimeter wall will serve both to deflect the buoyant gas clouds above ignition sources and to screen out effects of jet fires from the process facility components. Figure 7.6 shows the event tree for the mitigated Production Phase configuration, showing reduced ignition probabilities for all release scenarios. The resultant individual risk contours around the facility for each of the representative atmospheric conditions are shown in Figures 7.7, 7.8, and 7.9.

Further, the likelihood of integrity of the reinforced concrete block wall was assessed by comparing the predicted worst case explosion overpressure profile with the design

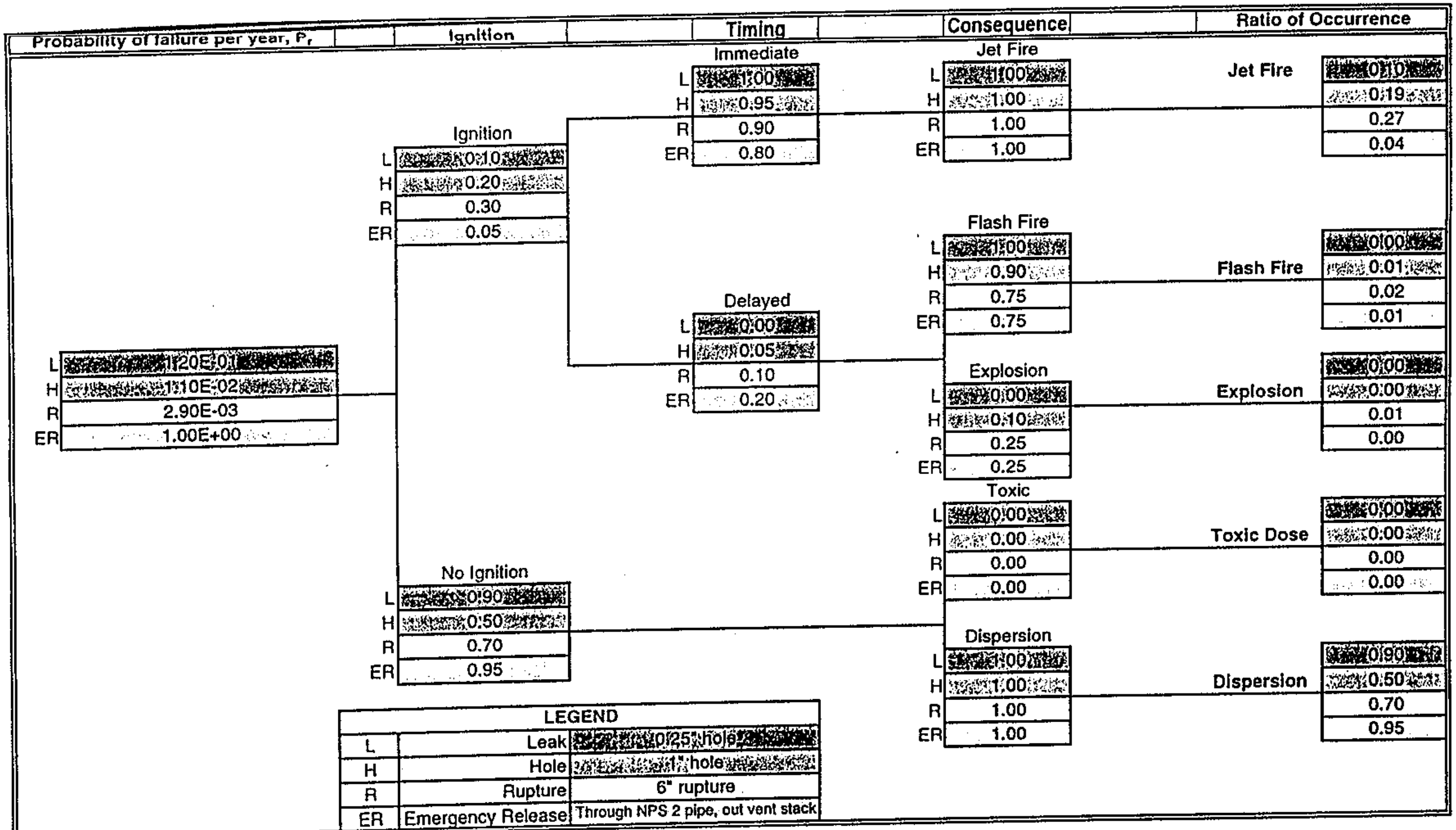


Figure 7.1
Event Tree - Test Phase - Process - Mitigated

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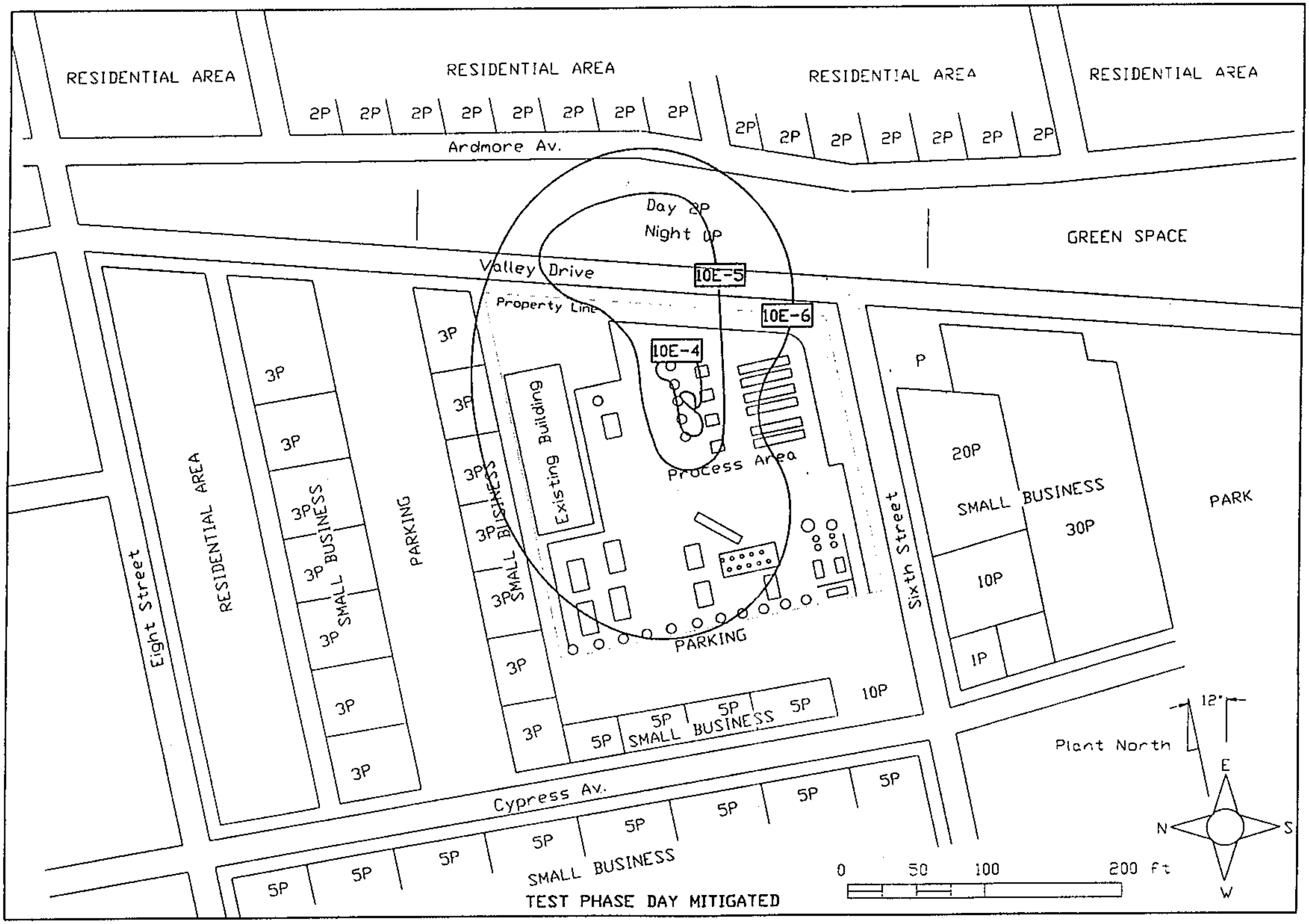

Figure 7.2
IR Contours for Test Phase - Day - Mitigated

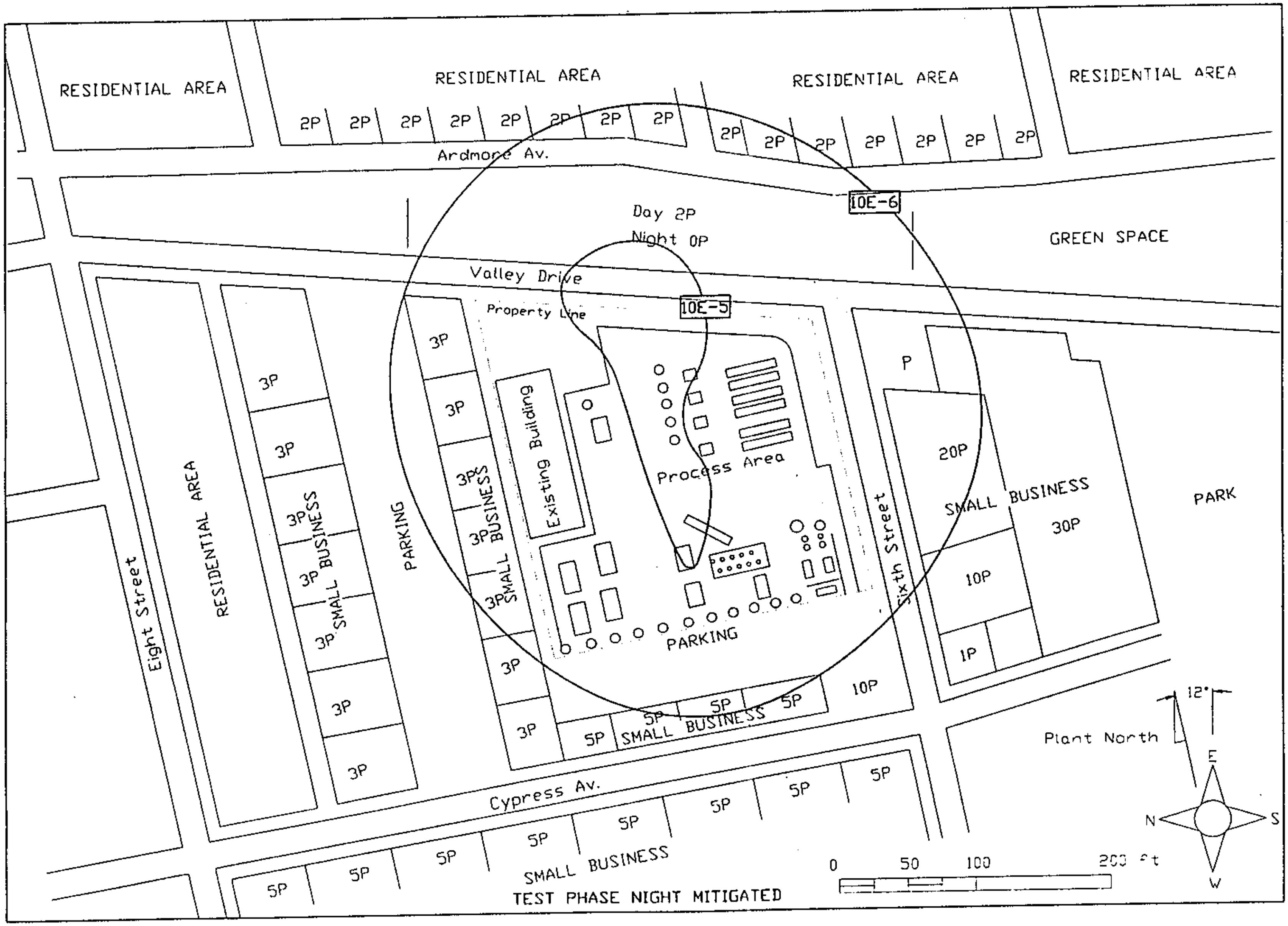

Figure 7.3
IR Contours for Test Phase - Night - Mitigated

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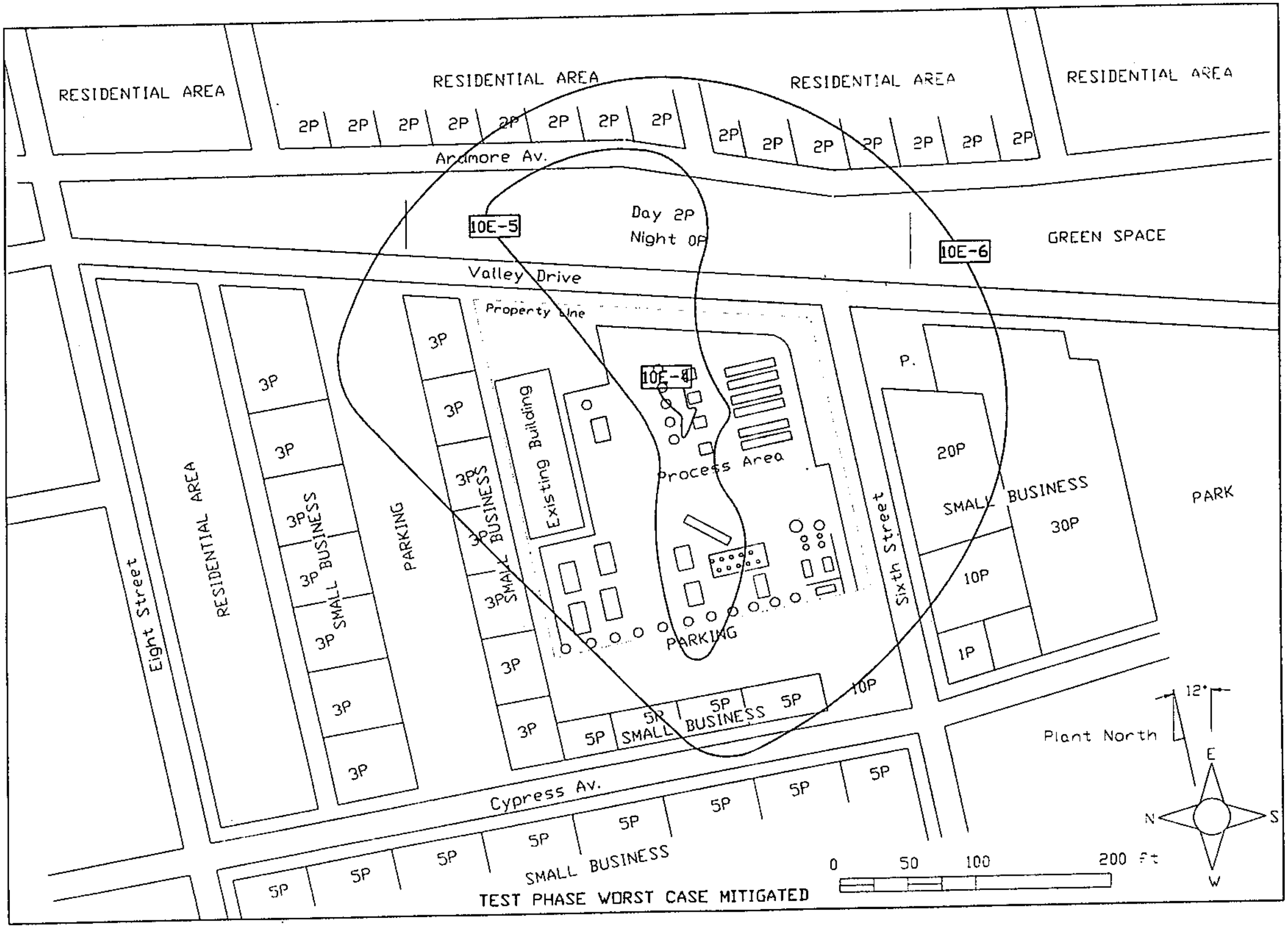

Figure 7.4
IR Contours for Test Phase - Worst - Mitigated

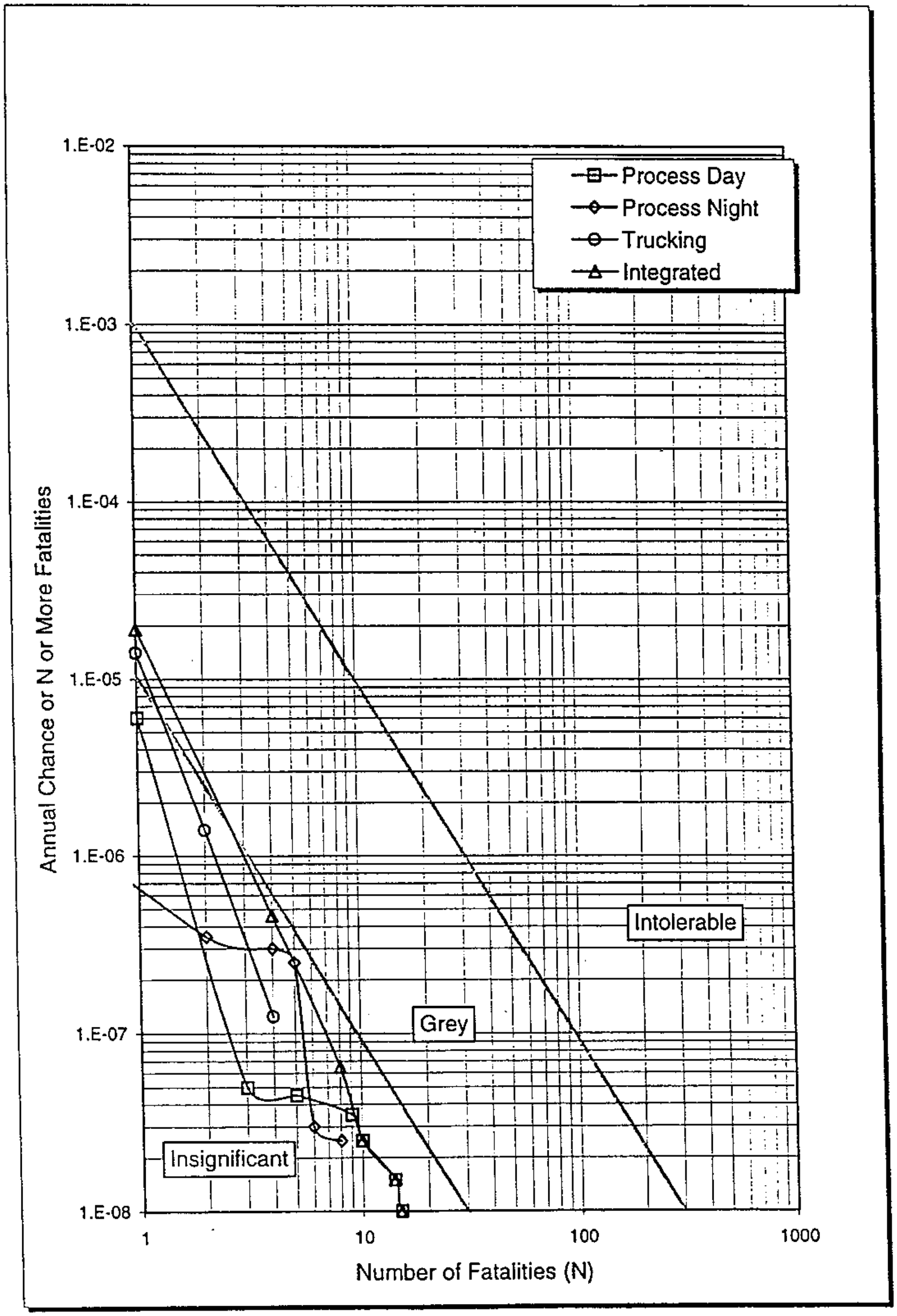

Figure 7.5
Public Risk Spectrum - Test Phase - Process and Trucking - Mitigated

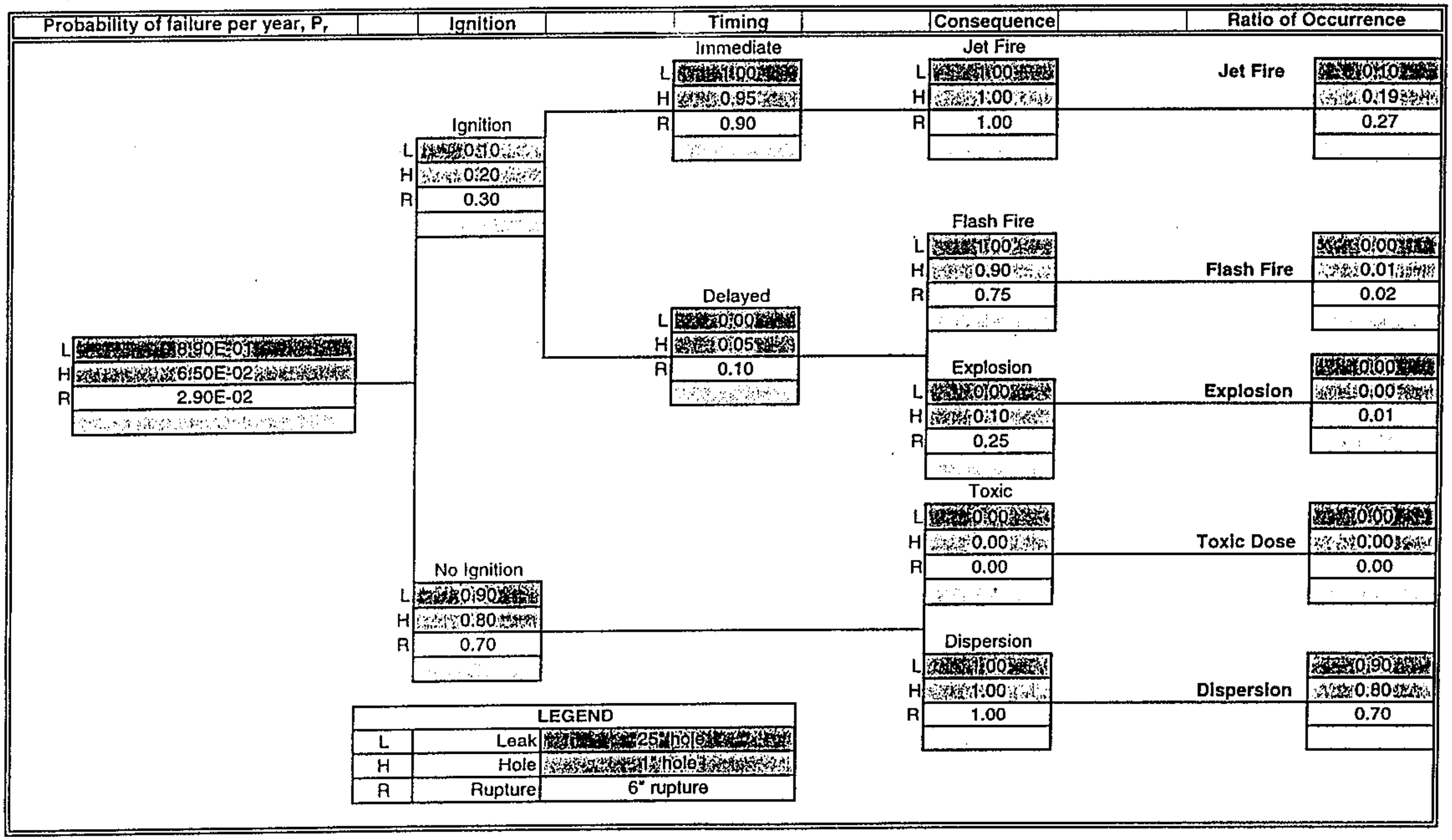

Figure 7.6
Event Tree - Production Phase - Process - Mitigated

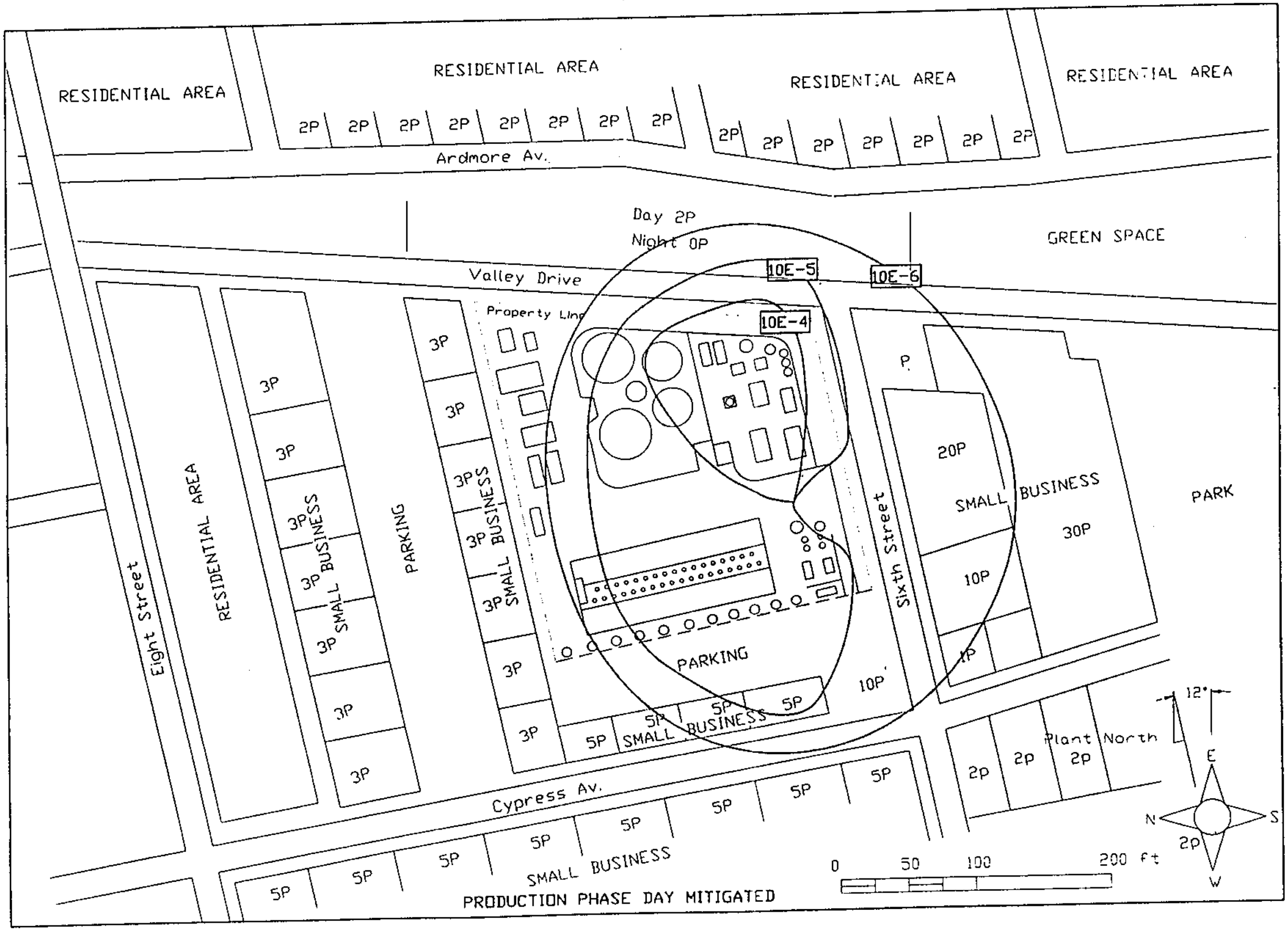

Figure 7.7
IR Contours for Production Phase - Day - Mitigated

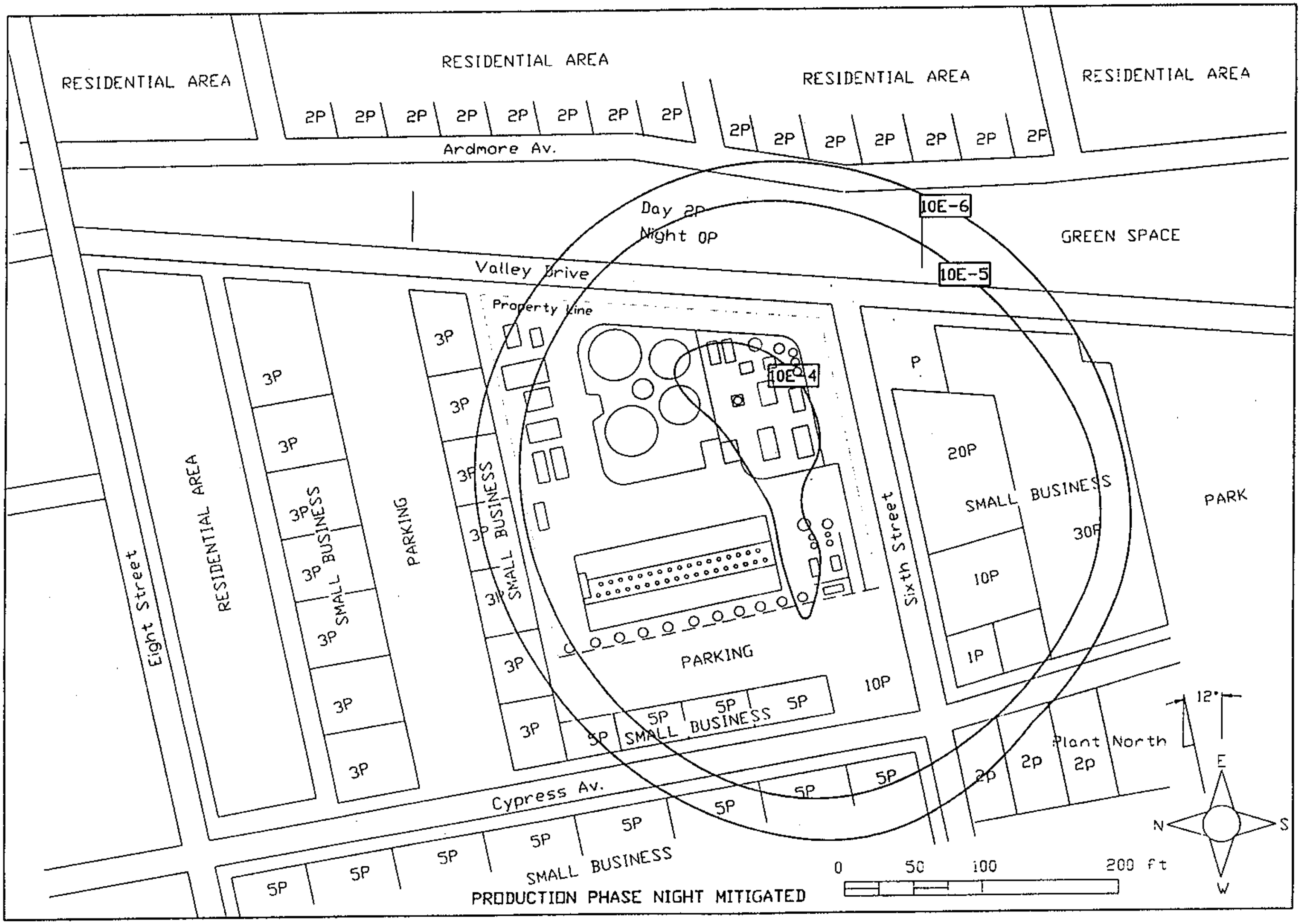

Figure 7.8
IR Contours for Production Phase - Night - Mitigated

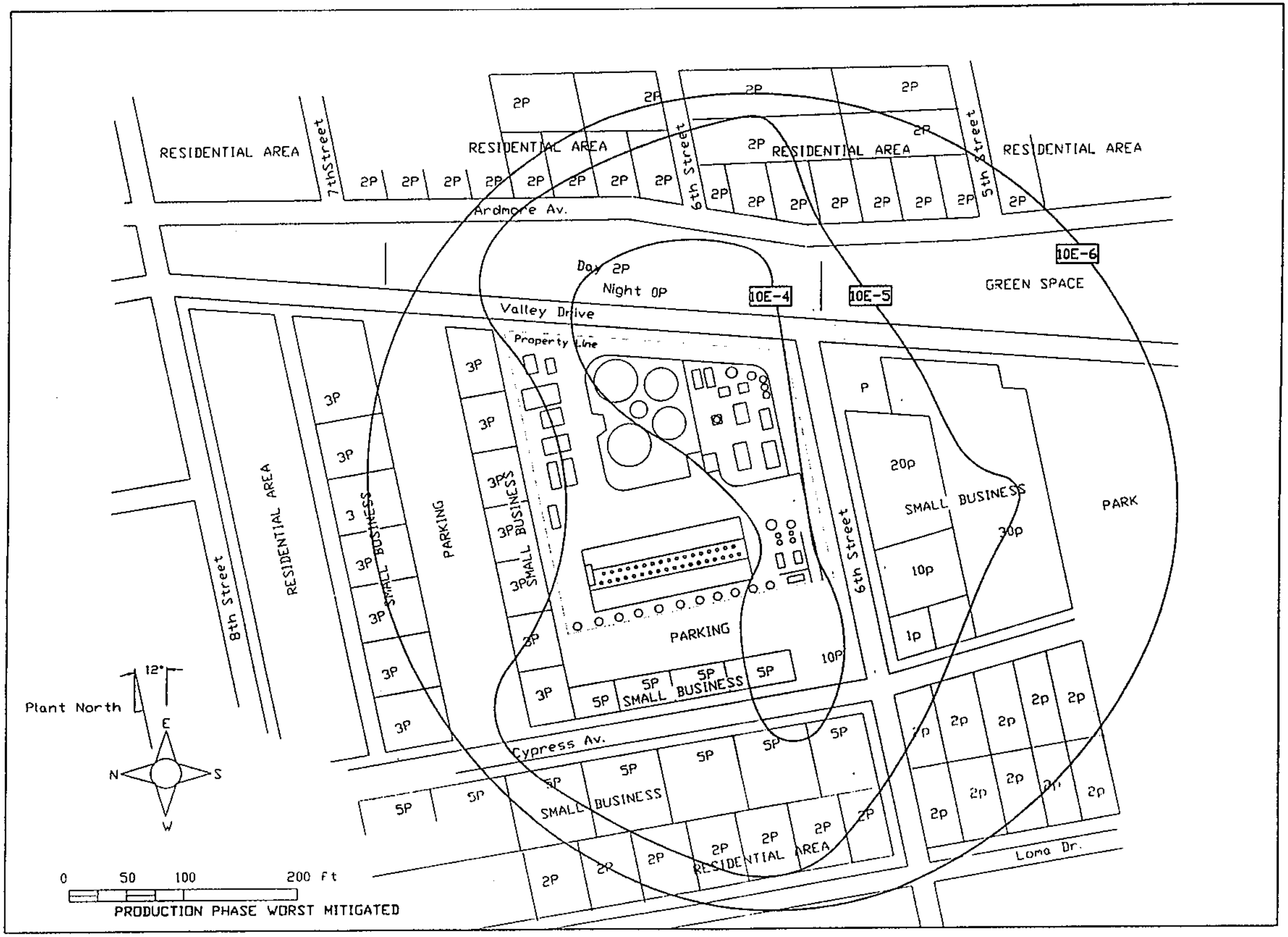

Figure 7.9
IR Contours for Production Phase - Worst - Mitigated

capacity of 0.5 psi of the wall. Figure 7.10 shows the overpressure profile variation with distance from the explosion epicentre.

The resultant risk spectrum considering the mitigation measures described above for the production facility is shown in Figure 7.11, both for the principal components and the complete facility.

7.4 Existing Facilities Resultant Risks

As no mitigation measures have been considered for the existing facilities risks, the resultant risks are the same as the unmitigated risks which are depicted graphically in the risk spectrum in Figure 7.12.

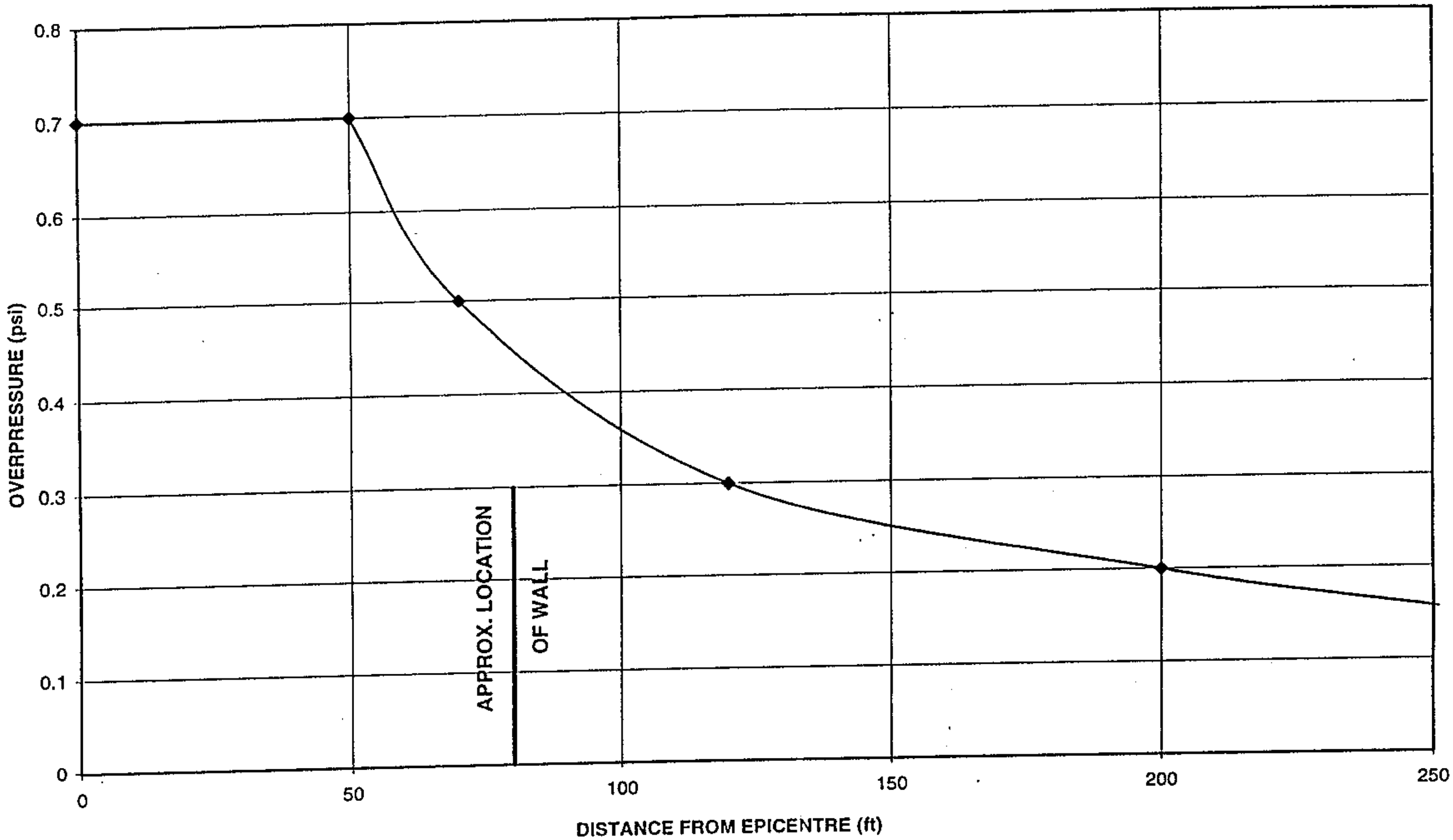

Figure 7.10
Explosion Overpressure Profile

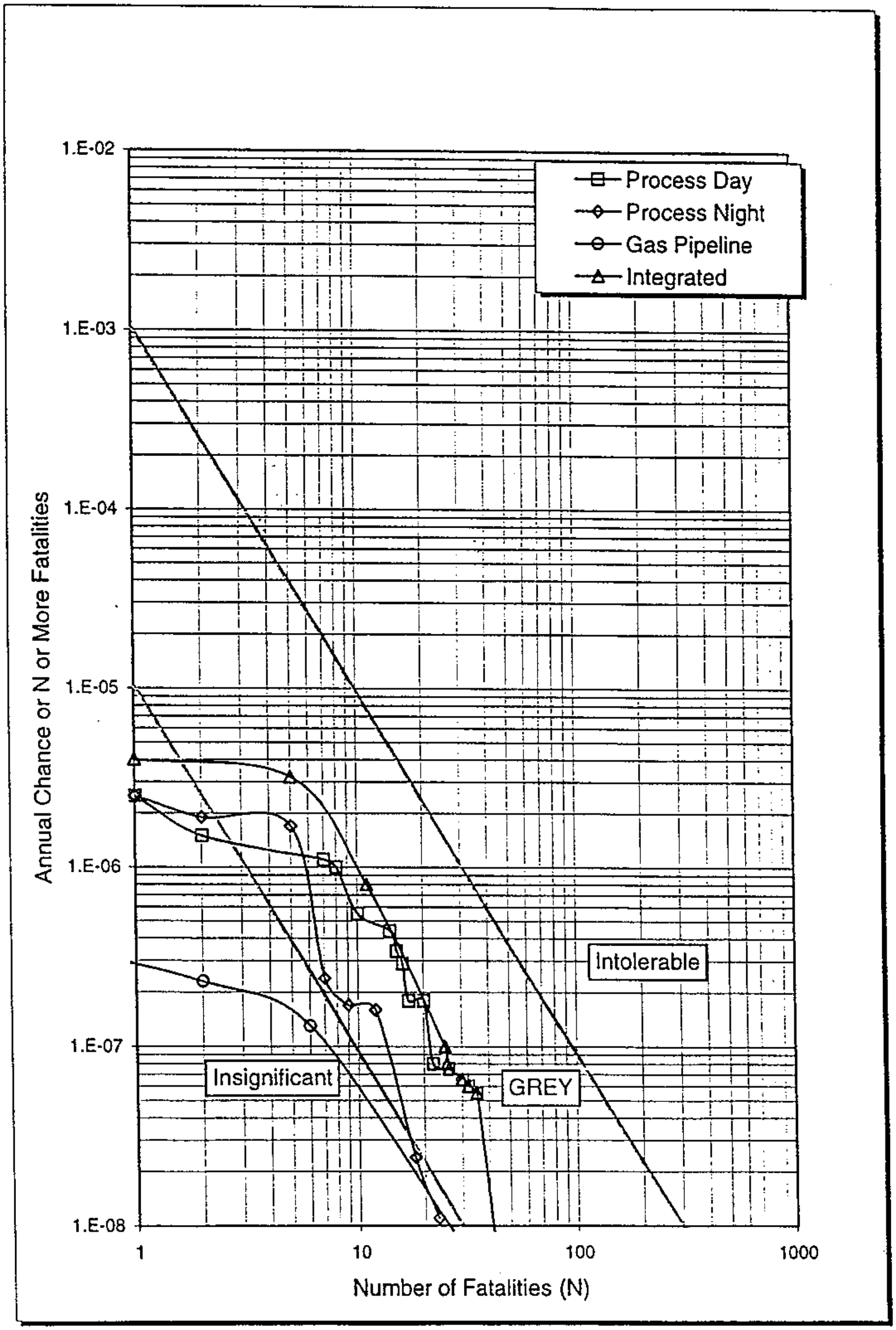

Figure 7.11
Public Risk Spectrum - Production Phase - Process Gas Pipeline - Mitigated

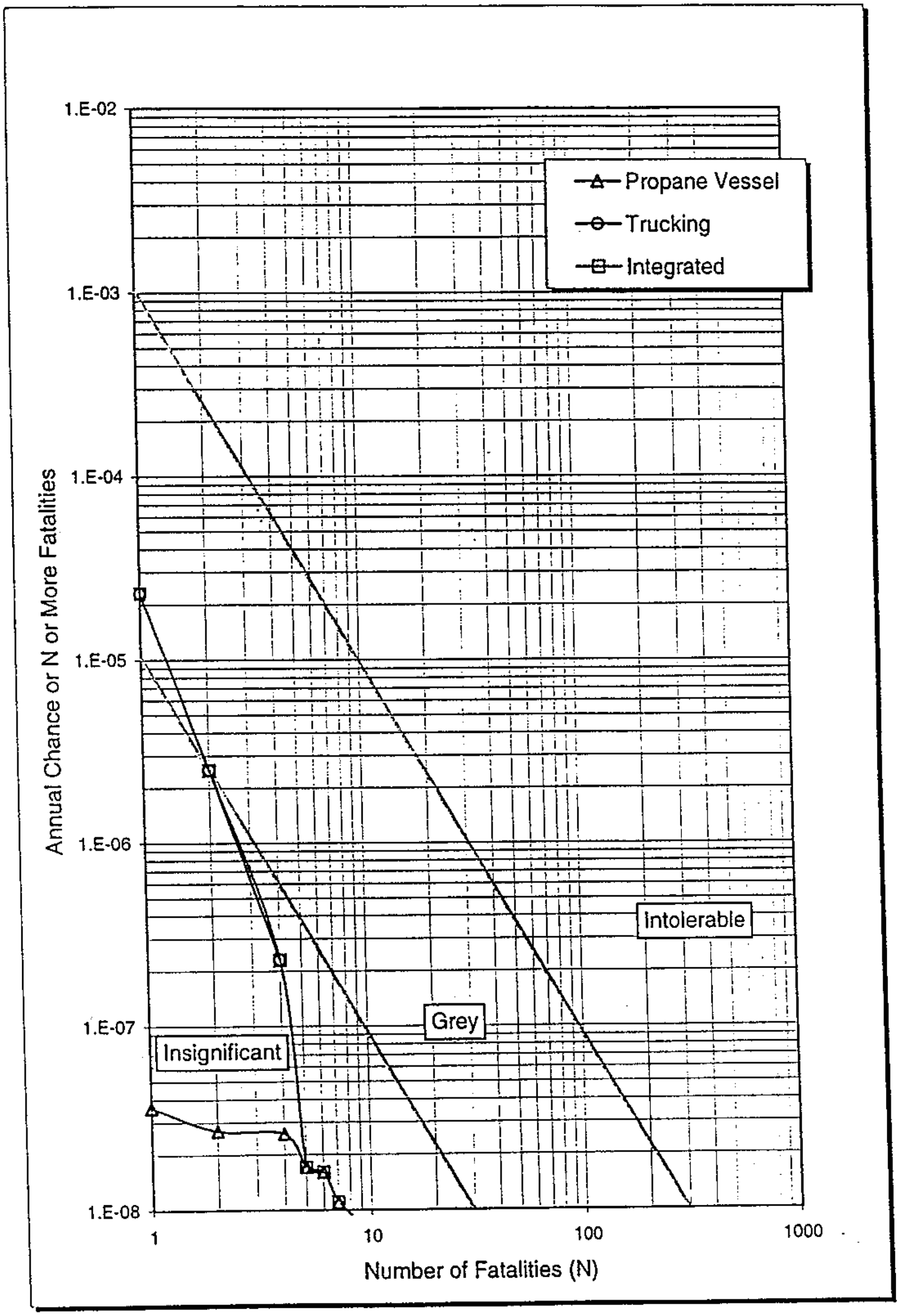

Figure 7.12
Public Risk Spectrum - Existing Facilities

CHAPTER 8

INTEGRATED RISK ANALYSIS

8.1 General Discussion of Integrated Risk Analysis

Much of the risk integration among components for annual fatality risks has been carried out in the work described in the previous chapters. However, the accumulation of risks over the project life for the Production Phase remains to be described as well as the expansion of risks from fatalities to include a consideration of risks of serious injuries. However, to avoid any confusion among mitigated, unmitigated, and component partial risks, the resultant integrated risks for the following will be given:

- Test Phase annual fatality mitigated risks
- Production Phase annual fatality mitigated risks
- Test Phase annual mitigated injury risks
- Production Phase annual mitigated injury risks
- Cumulative risks over project life including Test and Production Phase for incidents and public fatality and injury risks

8.2 Test and Production Phase Annual Public Fatality and Injury Risks

Individual specific risk contours, on the (conservative) assumption of an average OISR factor of 10% are shown in Figure 8.1 for the Test Phase, and in Figure 8.2 for the Production Phase. The associated fatality mitigated risk spectra are shown in Figure 8.3 for both the Test and Production Phases as well as the Existing Facilities. Based on a probability of injury 10 times greater than that of a fatality, the injury mitigated risk spectra superimposed on the appropriate (Santa Barbara County) injury risk thresholds are shown in Figure 8.4 for the Test and Production Phases.

8.3 Cumulative Risk Over Project Life

The Test Phase is proposed to take no more than 1 year, while the Production Phase may take up an additional 34 years. Although no projections were made available by the City of Hermosa Beach on changes in population density in the vicinity of the project, it has been assumed that the population density will not decrease. Accordingly, to the level of approximation used in this analysis, it can be assumed that the annual project risks of the Production Phase will remain constant over the 34 year life. It may be argued by the project proponents that as time goes on, they will become more efficient and reliable and ultimately safer in the conduct of the operation; the opposite argument also holds that as personnel become accustomed to the operation, with time they may grow careless. Also, a desirable residential and light commercial area such as Hermosa Beach seldom experiences a population density decline, but rather the opposite, an increase in

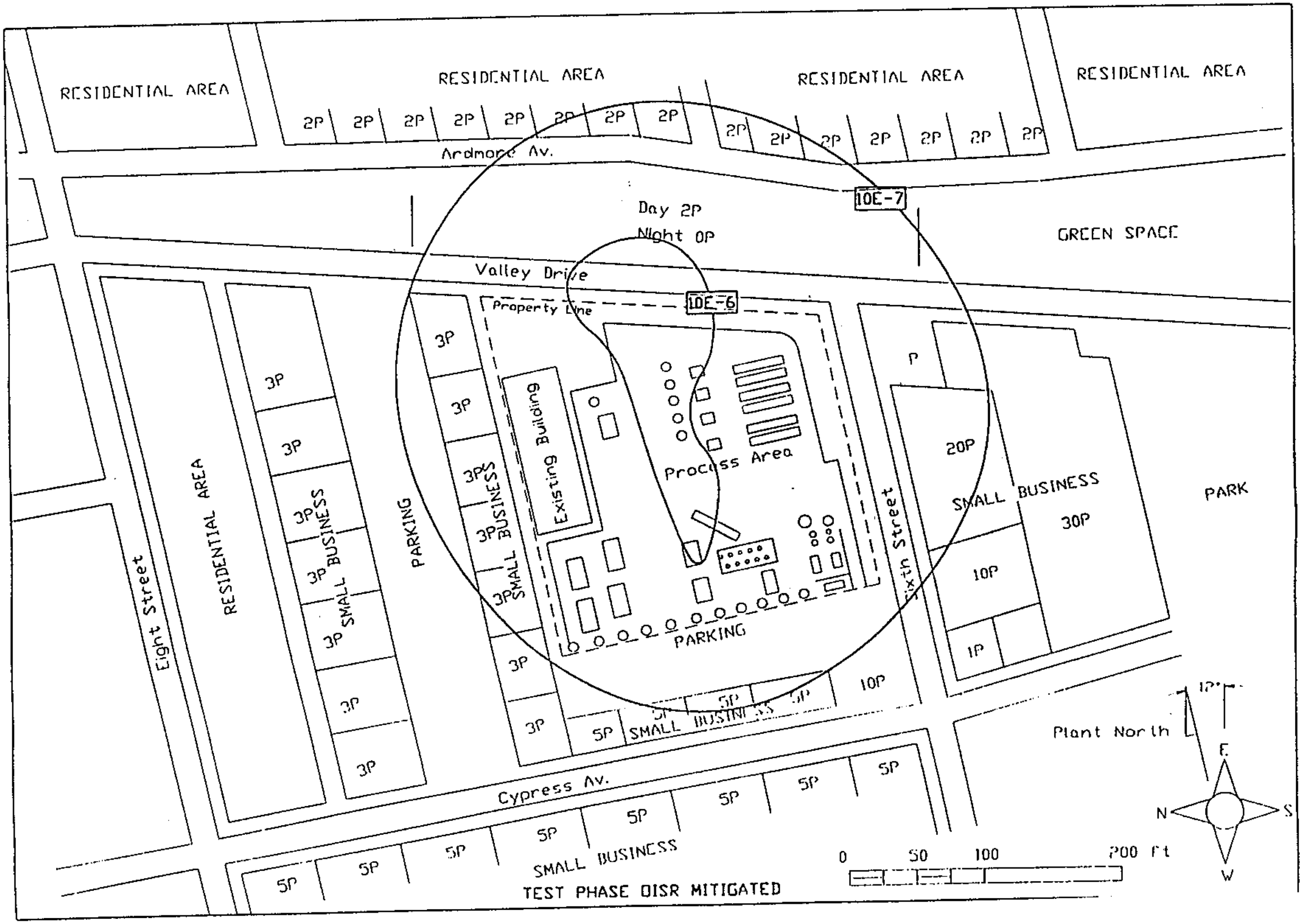

Figure 8.1
Individual Specific Risk Contours - Test Phase

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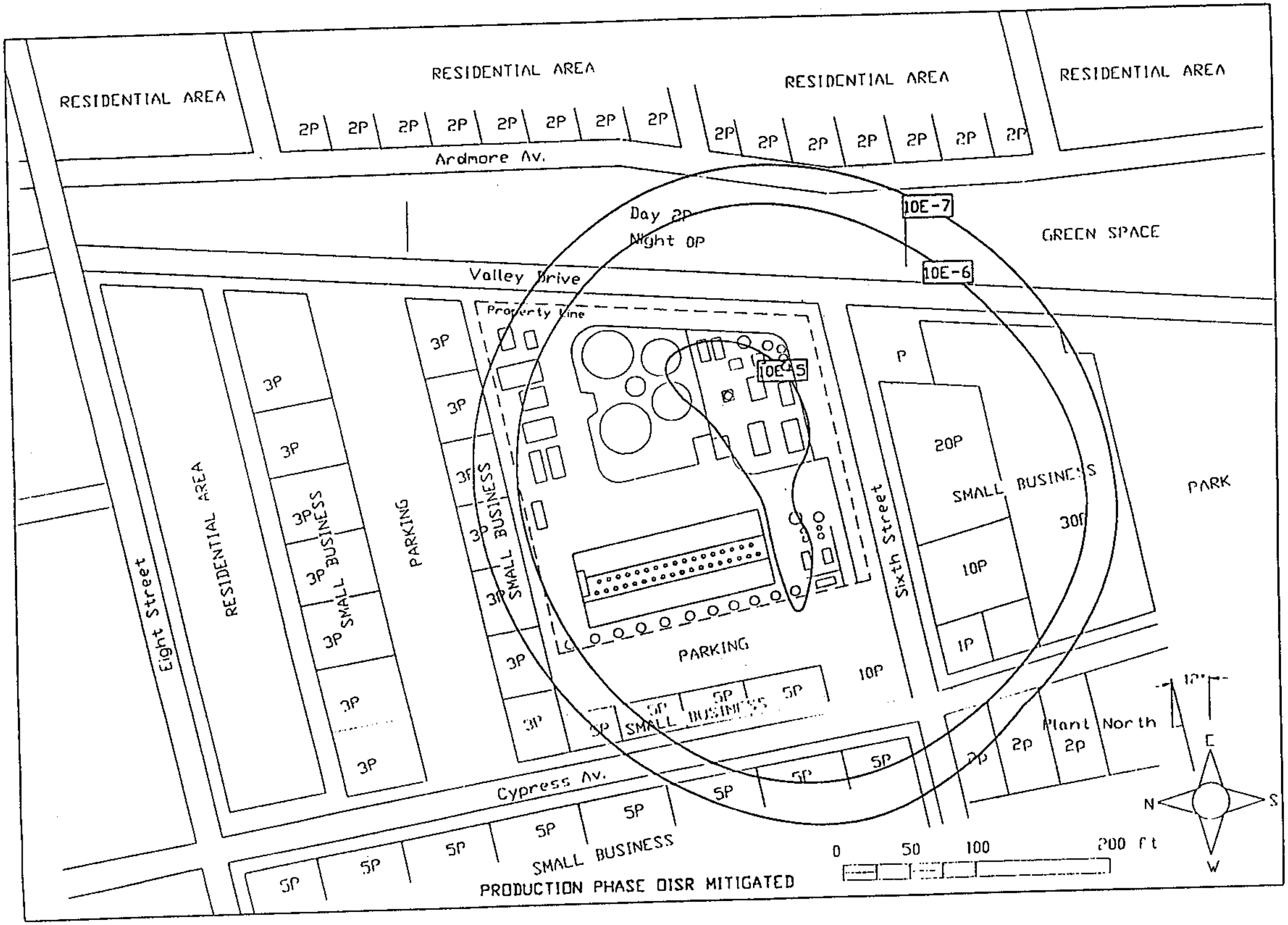

Figure 8.2
Individual Specific Risk Contours - Production Phase

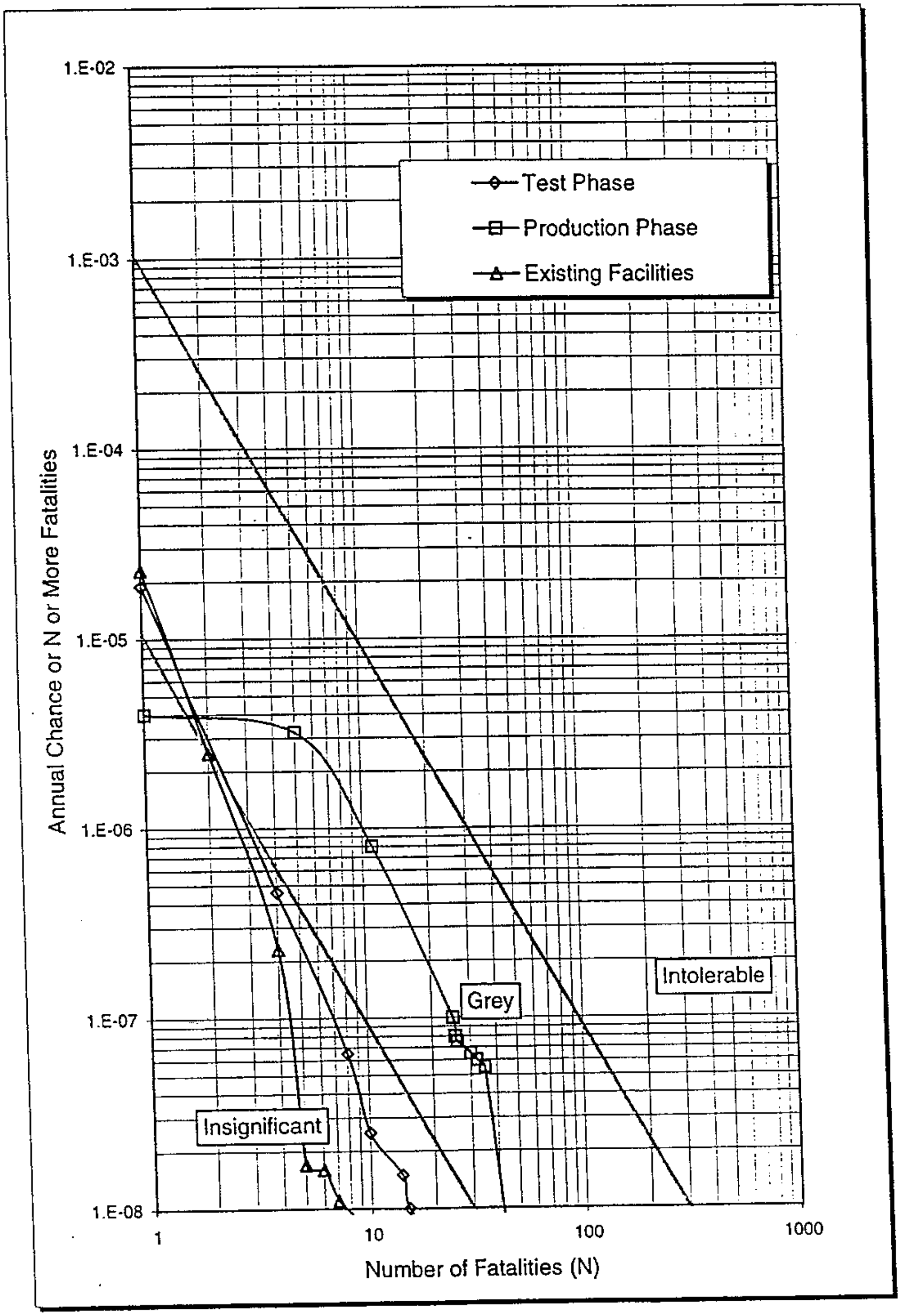

Figure 8.3
Public Risk Spectrum - Fatality

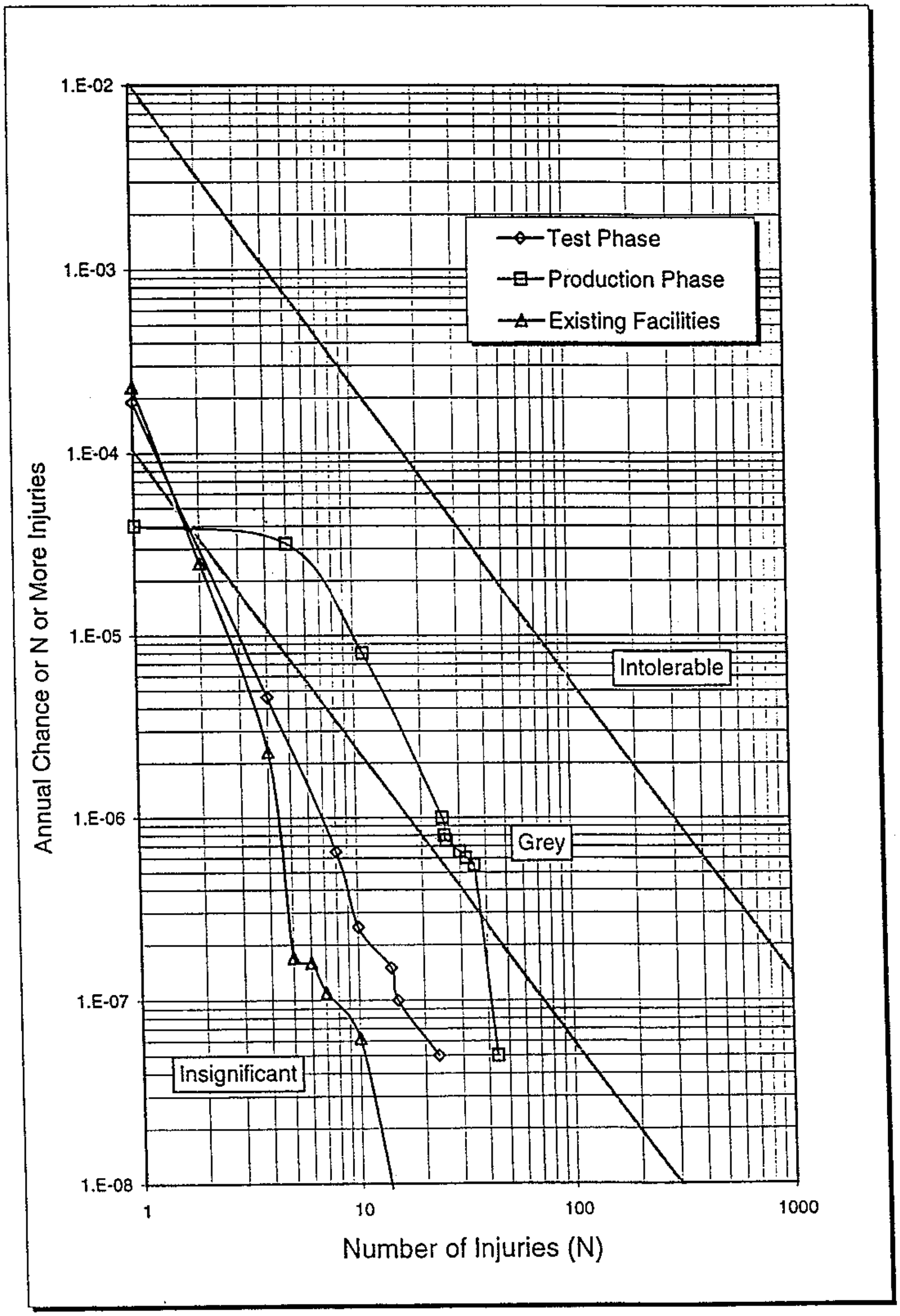

Figure 8.4
Public Risk Spectrum - Injuries

population density. Thus, the assumption that the risk will remain constant over the life of the project is a somewhat debatable one, but serves as a basis for identification of the project cumulative risk.

Based on a 35 year project life, Table 8.1 summarizes the expected number of releases for the principal hazard scenarios which may be expected to occur, together with the associated number of consequence and ultimate risk events. The first column on the left of the table identifies the most significant hazard scenarios used as a basis for event simulation in this table, together with their description, frequency per year, and the total number of releases of each type over the project life of 35 years. Next, the evolution of consequences, together with the associated explicit hazards, are given. Thus, of the 31 leaks which may be expected over the project life, 28 are likely to be dispersed, while 3 can result in jet fires. The next column indicates whether or not there is an offsite effect associated with each of the consequence evolution events. Thus, for example, for the leak, gas dispersion reaches offsite but a resultant jet fire would not reach offsite due to the small release rate associated with leaks. On the other hand, all of the consequences evolving from the rupture do have offsite effects, but of relatively low probability.

The final three columns at the right-hand side of the table are based on the integrated risks and take into account not only the process release scenarios, but also the well blowouts, storage facilities, and pipelines. The risk intensity, or maximum offsite annual individual specific risk, is given in the next column. It may be noted from the ISR contours that the 10^{-5} contour doesn't quite reach offsite, but is very close; in this table, it has been considered to reach offsite. Finally, the cumulative expected fatality and injury frequencies for 35 years are given in the last two columns. As can be seen, the chance of a fatality over the project life is approximately 1 in 7000, while the chance of a serious injury over the project life is approximately 1 in 700. Clearly, the chances given pertain to members of the public only, and not to onsite workers. It is important to note that the final figures in Table 8.1 pertain to the integrated effects of the project, including all components over the 35 year period. As there do not exist acceptability criteria for 35 year project life periods, the acceptability for the risks cited for the life of the project should be judged on the basis of the City of Hermosa Beach intuitive and analytical risk acceptability.

In order to assist in providing perspective on the risk levels cited , a table summarizing more customary day-to-day risks experienced by North American members of the public is presented as Table 8.2. It should be noted that both voluntary and involuntary risks are shown in this table. The voluntary risks pertain to activities which are undertaken for direct benefit to the individual and are not directly comparable to the involuntary risk levels that are likely to be associated with members of the public in the vicinity of the proposed project. Thus, the project risks which are given on an annual basis as well as a 35 year basis which pertain to involuntary risk reception are more appropriate to compare to those of the project. As may be seen, the Hermosa Beach Project poses risk levels to the residents which are comparable to some of the higher ones to which they are involuntarily exposed such as fires, poisoning, and electrocution. In the right-hand column of the table, are the expected casualties (fatalities and injuries) based on the 1 to

10 fatality/injury likelihood for the project. Finally, the cumulative 35 year risk spectra for fatalities and injuries for the project are shown in Figures 8.5 and 8.6.

Table 8.1
Expected Incidents During Life of Project

PRINCIPAL HAZARD SCENARIOS	DESCRIPTION	FREQ. PER YEAR (EXPCTD)	NO. OF RELEASES IN 35 YEARS	EVENT	NO. OF EVENTS IN 35 YEARS (NO. EXPECTED)	OFFSITE EVENT EFFECT	MAXIMUM FATALITY ISR (ANNUAL)	CHANCE OF 1 OR MORE FATALITIES IN 35 YRS	CHANCE OF 1 OR MORE INJURIES IN 35 YRS
HB-P-P-L	Leak from process unit	8.9×10^{-1} (1)	31	Dispersion	28.0 (28)	Y			
				Jet Fire	3.12 (3)	N			
				Flash Fire	0.0 (0)	N			
				Explosion	0.0 (0)	N			
HB-P-P-H	Hole from process unit	6.5×10^{-2} (1/15)	2.0	Dispersion	1.82 (2)	Y	10^{-5} (1/100000)	1.4×10^{-4} (1/7000)	1.4×10^{-3} (1/700)
				Jet Fire	0.43 (1)	Y			
				Flash Fire	0.02 (0)	Y			
				Explosion	0.0 (0)	N			
HB-P-P-R	Process from process unit	2.9×10^{-2} (1/35)	1.0	Dispersion	0.71 (1)	Y			
				Jet Fire	0.27 (1)	Y			
				Flash Fire	0.02 (0)	Y			
				Explosion	0.01 (0)	Y			

Table 8.2
Common Individual Risks of Casualty

CAUSE*		INDIVIDUAL RISK PER MILLION (per year)
Motor Vehicle Accidents (total)	V	240.0
Home Accidents	V	110.0
Falls	V	62.0
Motor Vehicle Pedestrian Collisions	V	42.0
Drowning	V	36.0
Fires	I	28.0
Inhalation and Ingestion of Objects	I	15.0
Firearms	V	10.0
Hermosa Beach Oil Project	I	8.0
Accidental Poisoning:	I	
Gases and Vapors		7.7
Solids and Liquids		6.0
(Not drugs or medicaments)		
Electrocution	I	5.3
Tornadoes	I	0.6
Floods	I	0.6
Lightning	I	0.5
Tropical Cyclones and Hurricanes	I	0.3
Bites and Stings by Venomous Animals and Insects	I	0.2

* V denotes "Voluntary"; I, "Involuntary"

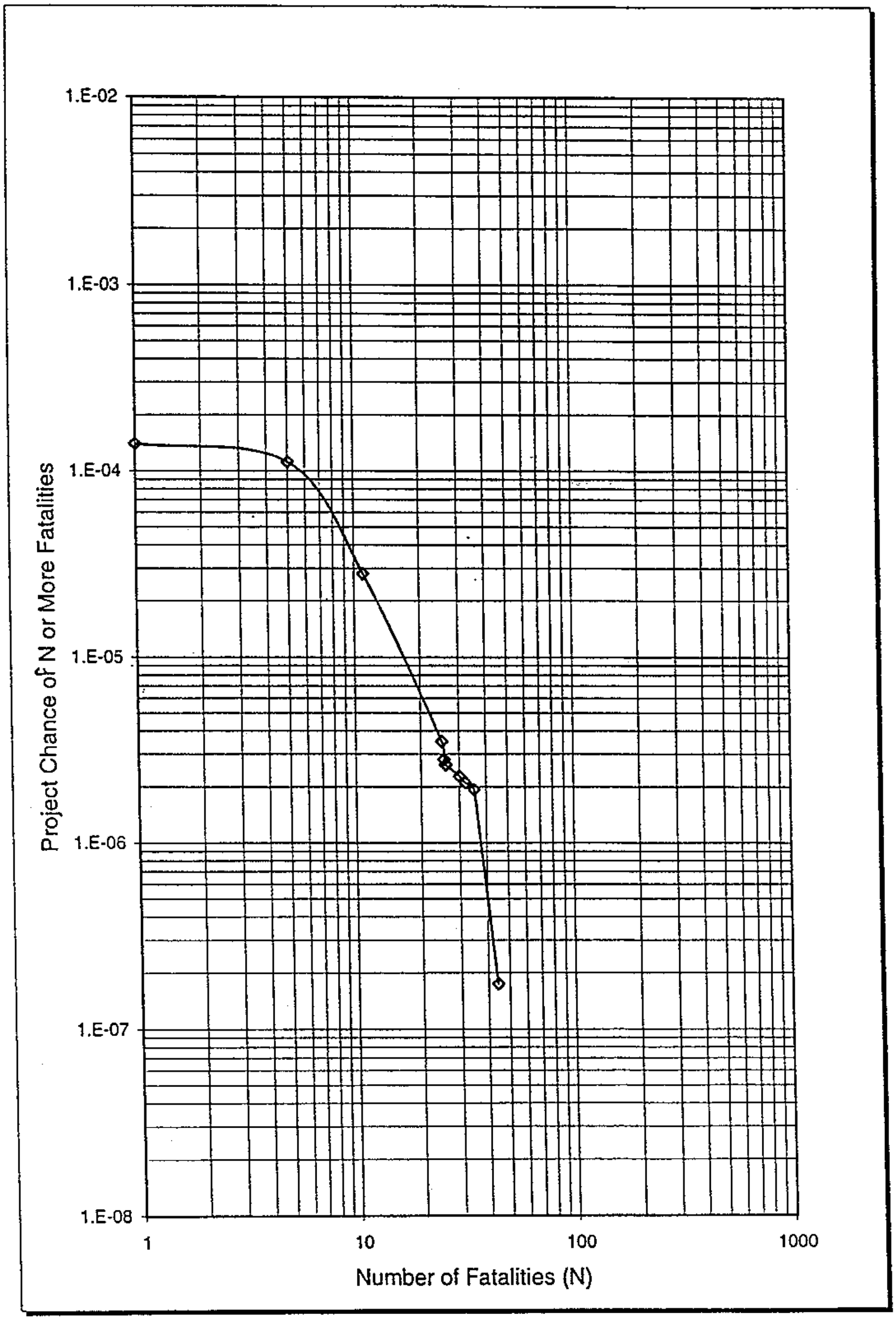

Figure 8.5
Public Risk Spectrum - Fatalities - Cumulative for 35 Years

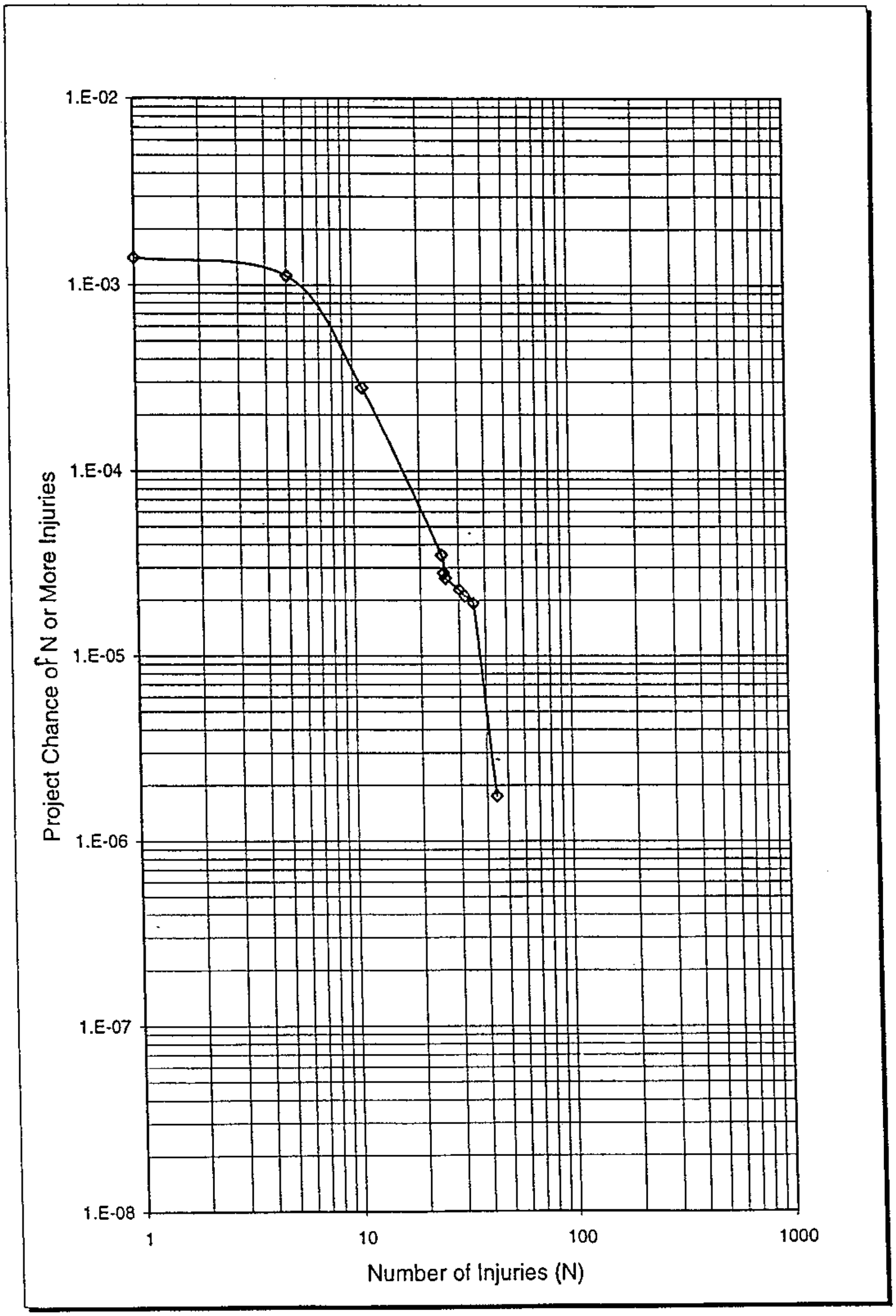

Figure 8.6
Public Risk Spectrum - Injuries - Cumulative for 35 Years

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

9.1 General Description of the Work Completed

An integrated risk assessment of the proposed MacPherson Oil Company Hermosa Beach Oil Project has been conducted. This assessment was conducted in response to the City of Hermosa Beach generic request for an integrated risk assessment as well as to specific requirements requested as a result of a stakeholder meeting conducted with the presentation of preliminary results from the project.

The scope of work consisted of the following principal tasks:

- Data acquisition
- Hazard scenario development
- Frequency analysis
- Consequence analysis
- Unmitigated risk assessment
- Risk mitigation
- Mitigated risk assessment
- Integrated risk assessment
- Conclusions and recommendations

The work spanned both the proposed Test Phase and the Production Phase of the project. Utilizing state-of-art techniques of risk analysis, including the Bercha Risk Software (BRISK) and a current multi-purpose consequence model (TRACE), both mitigated and unmitigated component and integrated Test and Production Phase risks for the project were determined. Results included annual individual and collective risks, as well as cumulated risks over the project life. Table 9.1 summarizes the salient results of the work, while a discussion of the principal assumptions and approximations and a systematic reporting of the conclusions for each phase follows in the balance of this summary.

9.2 Principal Assumptions and Approximations Made in the Work

9.2.1 Conservative Assumptions Made in the Work

Certain significant conservative assumptions and approximations were made, resulting in the tendency to overestimate the risks associated with the project. The principal ones among these may be summarized as follows:

- Test and Production Phase process release frequencies were based on the entire process facility releasing as one segment

- Leak and hole releases were assumed to blowdown until atmospheric pressure is reached within the segment (approximately 580 minutes for a leak) rather than be curtailed by shutdown
- Modelling of ground level releases rather than elevated releases as a basis for hazard assessment
- All releases in horizontal direction
- Test Phase jet fires penetrate sound attenuation wall

9.2.2 Non-Conservative Assumptions Made in the Work

Certain non-conservative assumptions to simplify and facilitate the work were made, which can result in an understatement of the risks. It is believed that these understatements are not significant, but these assumptions are nevertheless summarized, as follows:

- Topography was not explicitly considered due to its unlikely significant influence on dispersion isopleths
- Any outdoor receptors were considered at risk; indoor receptors were considered safe
- Population distributions were considered as remaining constant over the 35 year project life
- The wake effect of the perimeter wall, which could result in downward motion of the release due to turbulence, was ignored

9.2.3 Simplifying Assumptions and Approximation

Certain other simplifying assumptions and approximations were made during the conduct of the work in order to make its completion practicable while still providing meaningful results. These simplifying assumptions and approximations may have the effect of either overestimating or underestimating the risk, but to a negligible degree within the context of the present work. Such simplifying assumptions and approximations may be summarized as follows:

- Redondo Beach weather was considered representative of the Hermosa Beach site location
- Subdivision of release sizes into leak, hole, rupture, and double rupture for pipeline
- 20% extra volume allowance was added to allow for flow during the isolation of each segment
- The injury likelihood was assessed as ten times more likely than the fatality likelihood
- Mitigating effects of the Test Phase sound attenuation wall and Production Phase structural wall were modelled only in terms of their reduction of ignition of flammable vapour cloud ignition probabilities
- Cumulative risk was based on the integrated Production Phase mitigated annual risk

9.3 Test Phase Annual Risks

The Test Phase risks extend over a period of one year, and both the mitigated and unmitigated risks are largely in the insignificant risk region. The maximum individual specific risk to the public associated with the Test Phase is chances of a fatality of 1 in one million per year. Figure 9.1 shows the Test Phase risk spectra for both the mitigated and unmitigated case. Reduction in the risks from the unmitigated level results from the following risk mitigation measures:

- Installation of a 30-foot high perimeter sound attenuation wall for the duration of the Test Phase

9.4 Production Phase Annual Risks

Individual specific and collective risks for the Production Phase have been assessed. The maximum individual specific risk to the public from the Production Phase is approximately a 1 in 100,000 chance of fatality per year. Figure 9.1 shows the unmitigated risk and mitigated risk spectra for the Production Phase. As may be seen, the unmitigated risk spectrum extends into the unacceptable region. Although the basis for the risk estimates is quite conservative, the high level of unmitigated risk demonstrates that an industrial project in an urban setting can pose unacceptable risks if not appropriately mitigated.

The mitigated risk spectrum for the Production Phase is largely in the grey area, indicating that all practicable means to reduce the risks should be utilized. The principal requirement to reduce the risks for the Production Phase from the unacceptable region to the grey region was as follows:

- Installation of a 12-foot high perimeter structural wall to remain in place for the entire life of the project

In general, every effort should be made to further reduce risks associated with the Production Phase. Risk mitigation measures which have generally been proposed by MOC, but for which engineering details were not available during the course of this assessment, include the following:

- Emergency shutdown valves within the process component to reduce the frequencies and volumes of releases associated with that component
- Automatic gas detection, shutdown, isolation, and depressurization equipment for the process segment

9.5 Integrated and Cumulative Risks

The following hazardous events and associated ultimate risk events may be expected over the 35 year life of the project:

- 31 leaks, 2 major releases, and 1 rupture within the process segment
- Resulting offsite hazards including 2 jet fires, and a 4% likelihood of an offsite flash fire with potential for casualties
- A 1 in 7000 chance of one of more fatalities and a 1 in 700 chance of 1 or more serious injuries of members of the public

9.6 Existing Facility Risks

Figure 9.1 also shows the risk spectrum estimated for the existing use of the site as a City yard. As may be seen, the existing risk spectrum was somewhat lower than the Test Phase risk spectrum for fatalities in excess of 2, but is at a similar level for the Test Phase risk spectrum for at least 1 or 2 fatalities. This segment of both the Test Phase risk spectrum and the Existing Facilities risk spectrum is attributable primarily to vehicle traffic hazards.

9.7 Acceptability of Risks

The acceptability of the annual individual and collective risks can be assessed utilizing standards adopted by other jurisdictions. The highest annual individual specific risks for the Test Phase and the Production Phase are a maximum of 1 in 100,000. This level is deemed acceptable for public, commercial, and residential medium-density land use.

The annual collective risks from the Test Phase are primarily in the Insignificant region of the risk profile for both the mitigated and unmitigated case. Therefore, they may be deemed acceptable with respect to the risk thresholds indicated on the risk profile.

The integrated annual collective risks for the Production Phase extend into the Intolerable (unacceptable) region for the unmitigated case, necessitating risk reduction to the acceptable region. Such a risk reduction can be achieved by specific risk mitigation measures, the perimeter walls, and further risk mitigation should be implemented including some of the provisions detailed above. Consideration of the perimeter wall risk mitigation effect results in collective risks in the acceptable Grey region. Every effort should be made to reduce the risks for the Production Phase to a level as low as reasonably practicable.

The cumulative risks over the life of the project have also been estimated, but their acceptability must be assessed primarily in the light of the City of Hermosa Beach Council and residents' risk tolerance criteria. Naturally, although criteria for acceptability of the annual risks have been presented, the same City of Hermosa Beach sense of risk acceptability should be the overriding arbiter of what goes on within its jurisdiction in terms of annual risks.

In general, it can be said that the proposed project by a safe and reputable operator contains industry standard safety and reliability provisions, which will make it as safe as any comparable modern operation. Yet, because of its setting in a medium-density urban, commercial, and residential location, it poses risks. These risks have been quantified and presented, with an explanation of the approximations implicit in this quantification, and compared to standards and other measuring sticks that are available. The ultimate decision on the acceptability of the risks rests with the City of Hermosa Beach.

Table 9.1
Summary of Hermosa Beach Oil Project Mitigated Risks

COMPONENT	TYPE OF RISK	MAXIMUM VALUE	ACCEPTABILITY	MITIGATION INCLUDED
PROJECT	Annual individual specific risk or fatality	1/100,000 per year	Acceptable	• Perimeter wall • Industry standard measures
	Annual group risk of 1 or more fatalities	1/50,000 per year	Grey-Acceptable but mitigation recommended	
	Cumulative (35 year) individual risk of fatality	1/3000 for project	Up to City	
	Cumulative (35 year) group risk of 1 or more fatalities	1/7000 for project	Up to City	
	Cumulative (35 year) group risk of 1 or more injuries	1/700 for project	Up to City	
TEST PHASE	Annual individual specific risk of fatality	1/1,000,000 per year	Acceptable	• Perimeter wall • Industry standard measures
	Annual group risk of 1 or more fatalities	1/50,000 per year	Acceptable	
	Annual group risk of 10 or more fatalities	1/30,000,000 per year	Acceptable	
	Cumulative individual risk of fatality	1/1,000,000 for phase	Acceptable	
	Cumulative group risk of 1 or more fatalities	1/50000 for phase	Acceptable	
	Cumulative (35 year) group risk of 1 or more injuries	1/5000 for phase	Up to City	

Table 9.1 (cont.)
Summary of Hermosa Beach Oil Project Mitigated Risks

COMPONENT	TYPE OF RISK	MAXIMUM VALUE	ACCEPTABILITY	MITIGATION INCLUDED
PRODUCTION PHASE	Annual individual specific risk of fatality	1/100,000 per year	Acceptable	• Perimeter wall • Industry standard measures
	Annual group risk of 1 or more fatalities	1/250,000 per year	Acceptable	
	Annual group risk of 10 or more fatalities	1/1,000,000 per year	Grey-Acceptable but mitigation recommended	
	Cumulative 35 year individual risk of fatality	1/3000 for project	Up to City	
	Cumulative 35 year group risk of one or more fatalities	1/7000 for project	Up to City	
	Cumulative 35 year group risk of one or more injuries	1/700 for project	Up to City	
EXISTING FACILITY	Annual individual specific risk of fatality	1/1,000,000 per year	Acceptable	• As is
	Annual group risk of 1 or more fatalities	1/50,000	Acceptable	
	Annual group risk of 10 or more fatalities	0	Acceptable	

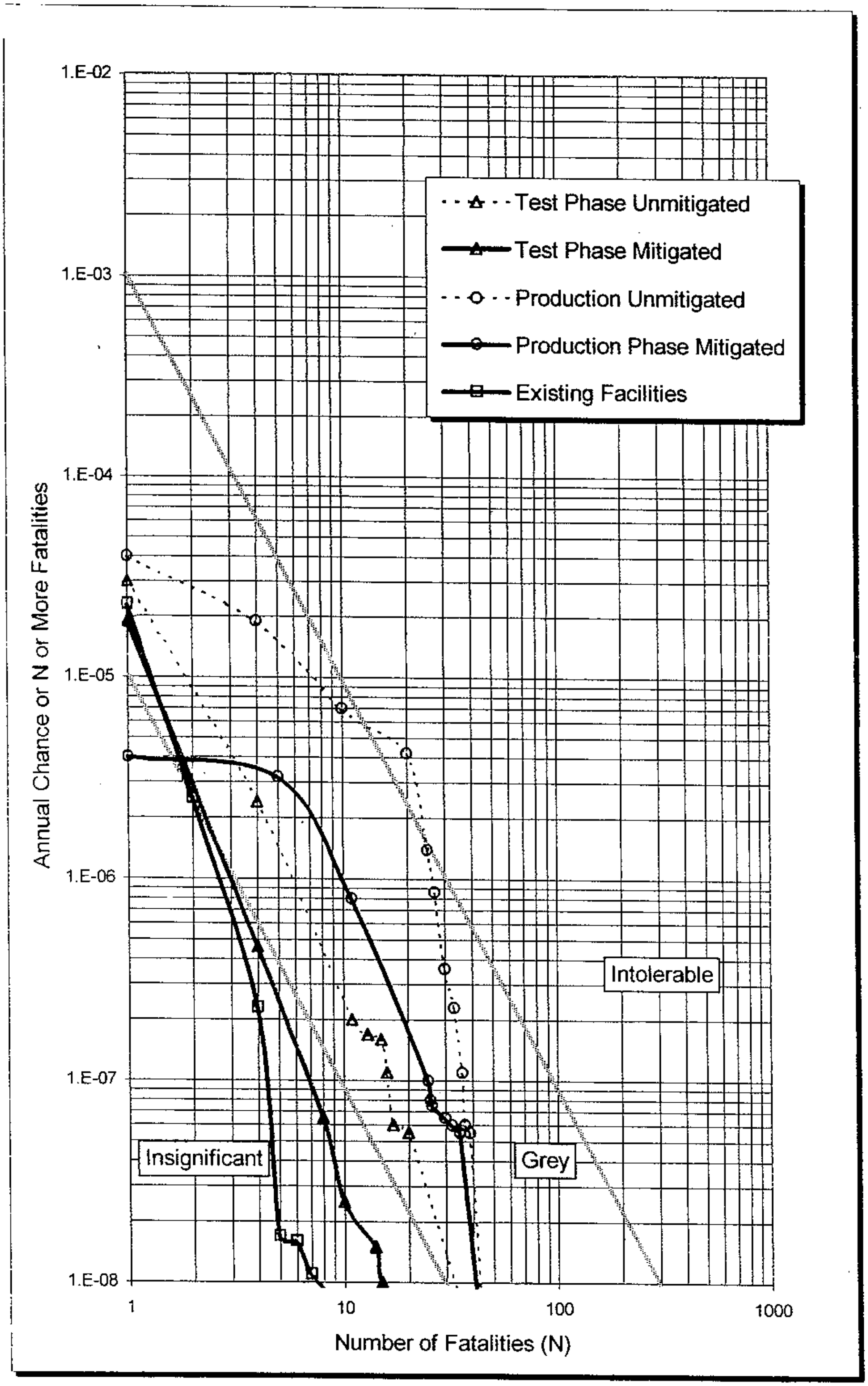

Figure 9.1
Project Mitigated and Unmitigated
Collective Risk Profiles

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