

APPENDIX C

WORST-CASE CONSEQUENCE ANALYSIS

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WORST-CASE CONSEQUENCE ANALYSIS FOR THE TESORO LOS ANGELES REFINERY

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WORST-CASE CONSEQUENCE ANALYSIS FOR THE TESORO LOS ANGELES REFINERY

1.0 INTRODUCTION

Quest Consultants Inc.[®] was retained by Environmental Audit, Inc. and Tesoro Refining & Marketing Company LLC (Tesoro) to perform a worst-case consequence analysis on the proposed Los Angeles Refinery changes. The primary authors of this report are John B. Cornwell and David W. Johnson, and their resumes are listed in Appendix A. The objective of the study was to compute the potential increase or decrease in hazards to the public due to the proposed changes to the facility.

The study was divided into three tasks.

Task 1. Determine the maximum credible potential releases, and their consequences, for existing process units, transfer systems, and storage areas.

Task 2. Determine the maximum credible potential releases, and their consequences, for the modifications to the facility which have been proposed by Tesoro.

Task 3. Determine whether the consequences associated with the proposed modifications generate potential hazards that are larger or smaller than the potential hazards which currently exist.

Potential hazards from the existing and proposed equipment are associated with accidental releases of toxic and flammable materials. Hazardous events associated with these types of releases include toxic vapor clouds, flash fires, torch fires, pool fires, and vapor cloud explosions.

For each type of hazard identified (toxic, radiant, overpressure), maximum distances to potentially injurious levels (vulnerability/hazard zones) are determined. The hazard levels used are those that have been developed by the U.S. Environmental Protection Agency (EPA) and American Industrial Hygiene Association (AIHA) for risk management purposes.

2.0 OVERVIEW OF TESORO LOS ANGELES REFINERY

2.1 Facility Location

The Tesoro Los Angeles Refinery is comprised of two parts, one which is located in Wilmington, California and the other which is located across the street in Carson, California. Both are in the Los Angeles area. The proposed project will better integrate the Wilmington and Carson operations and will comply with federal, state, and local regulations. The layout of the Wilmington facility is shown in Figure 2-1; the Carson facility is shown in Figure 2-2; and the new proposed Carson tankage is presented in Figure 2-3.

2.1.1 Wilmington Operations

Proposed modifications for the Wilmington Operations are described further in the following subsections.

2.1.1.1 FCCU Shutdown

The Wilmington FCCU will be shut down and the equipment will be permanently removed from service. Shutting down this unit will eliminate hazards associated with it.

2.1.1.2 HCU Modification

The Wilmington Hydrocracker Unit (HCU) capacity would be increased approximately 15 percent, the overall integrated Refinery capacity would remain unchanged. The reactor and fractionation sections will be modified to increase the production of ultra-low sulfur diesel and gasoline.

Additionally, to recover propane for the Propane Sales Treating Unit (PSTU), the HCU product recovery section will be modified by installing two new water cooled exchangers, one knockout drum, and associated piping and instrumentation.

2.1.1.3 DCU Fresh Feed Heater (H-100)

The existing equipment description of the Wilmington Delayed Coking Unit Fresh Feed Heater in the Title V permit will be revised to conform to SCAQMD/Industry standards. The description will be changed from the 'design heat release' basis (252 million Btu/Hr) to the industry standard 'maximum heat release' basis (302.4 million Btu/Hr). No physical modifications will be made to the heater. These modifications do not produce changes in hazards, and this unit was not evaluated in the analysis

2.1.1.4 Propane Sales Treating Unit (PSTU)

A new PSTU will be constructed at the Wilmington Operations. The PSTU conditions liquid propane for sale using absorbers and dryers to meet sales specifications.

2.1.1.5 CRU3 Modification

The Wilmington Operations Catalytic Reformer Unit 3 (CRU3) will be modified to recover Hydrocracker propane from the refinery fuel gas system.

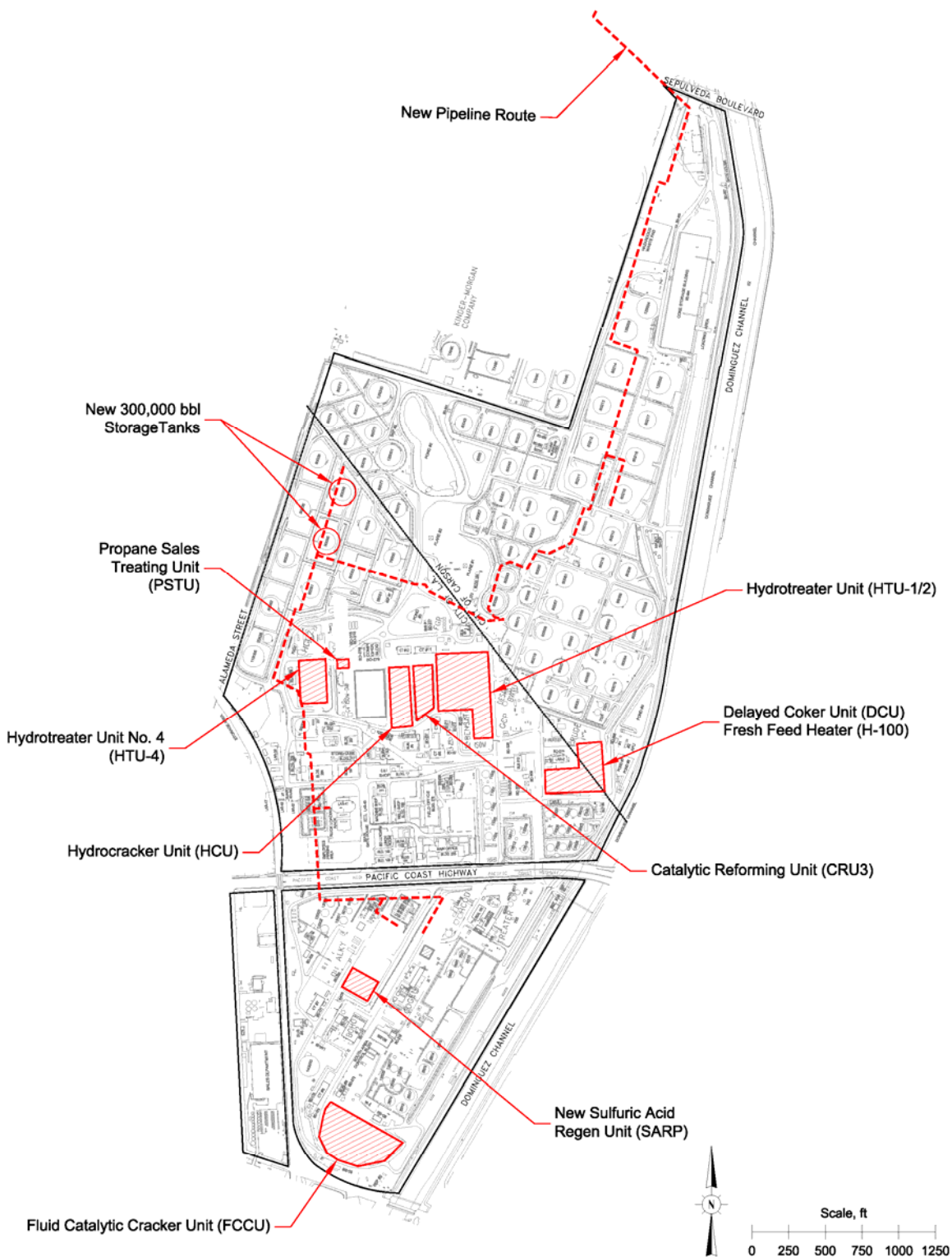


Figure 2-1
Plot Plan of Wilmington Operations at Tesoro Los Angeles Refinery

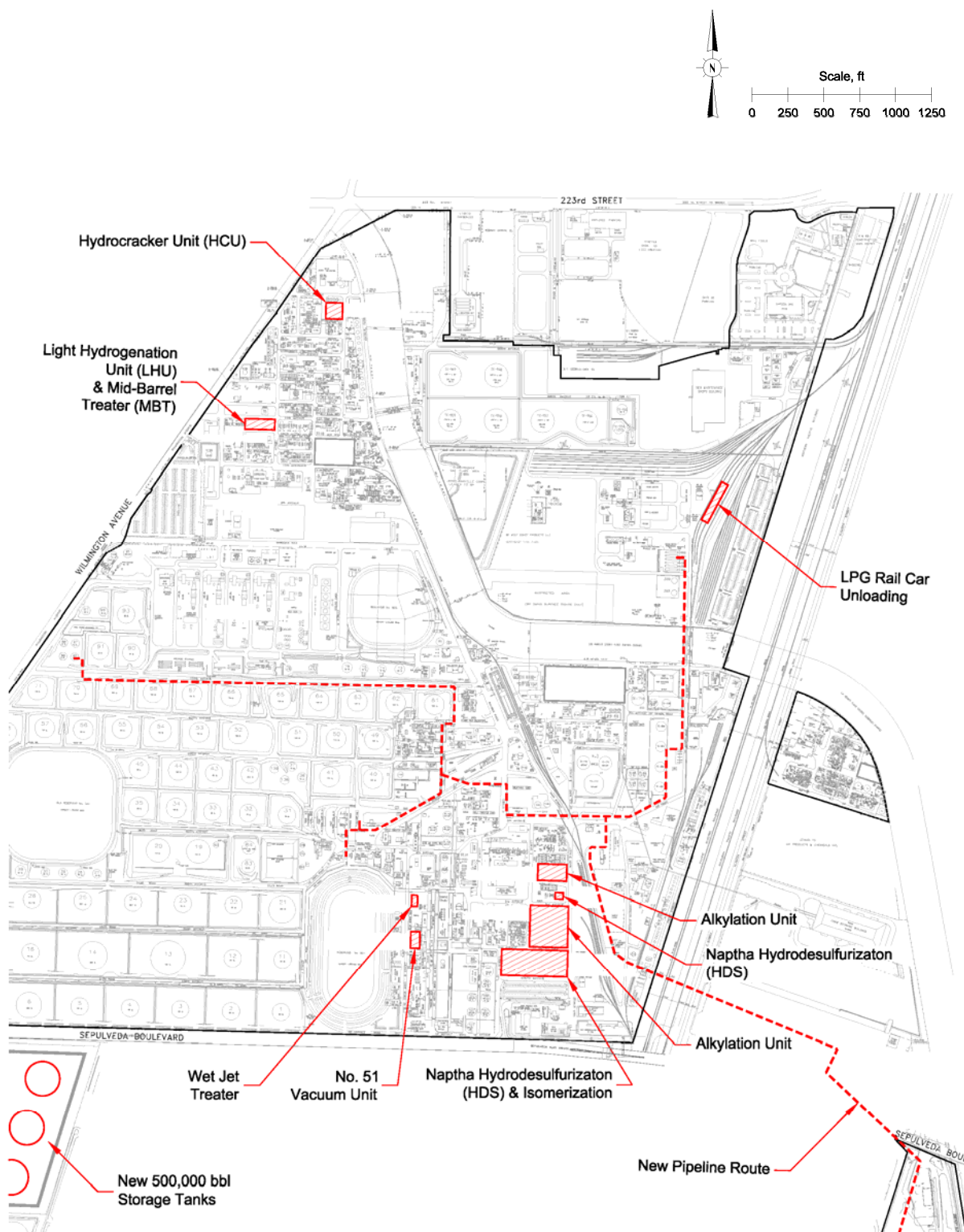


Figure 2-2
Plot Plan of Carson Operations at Tesoro Los Angeles Refinery

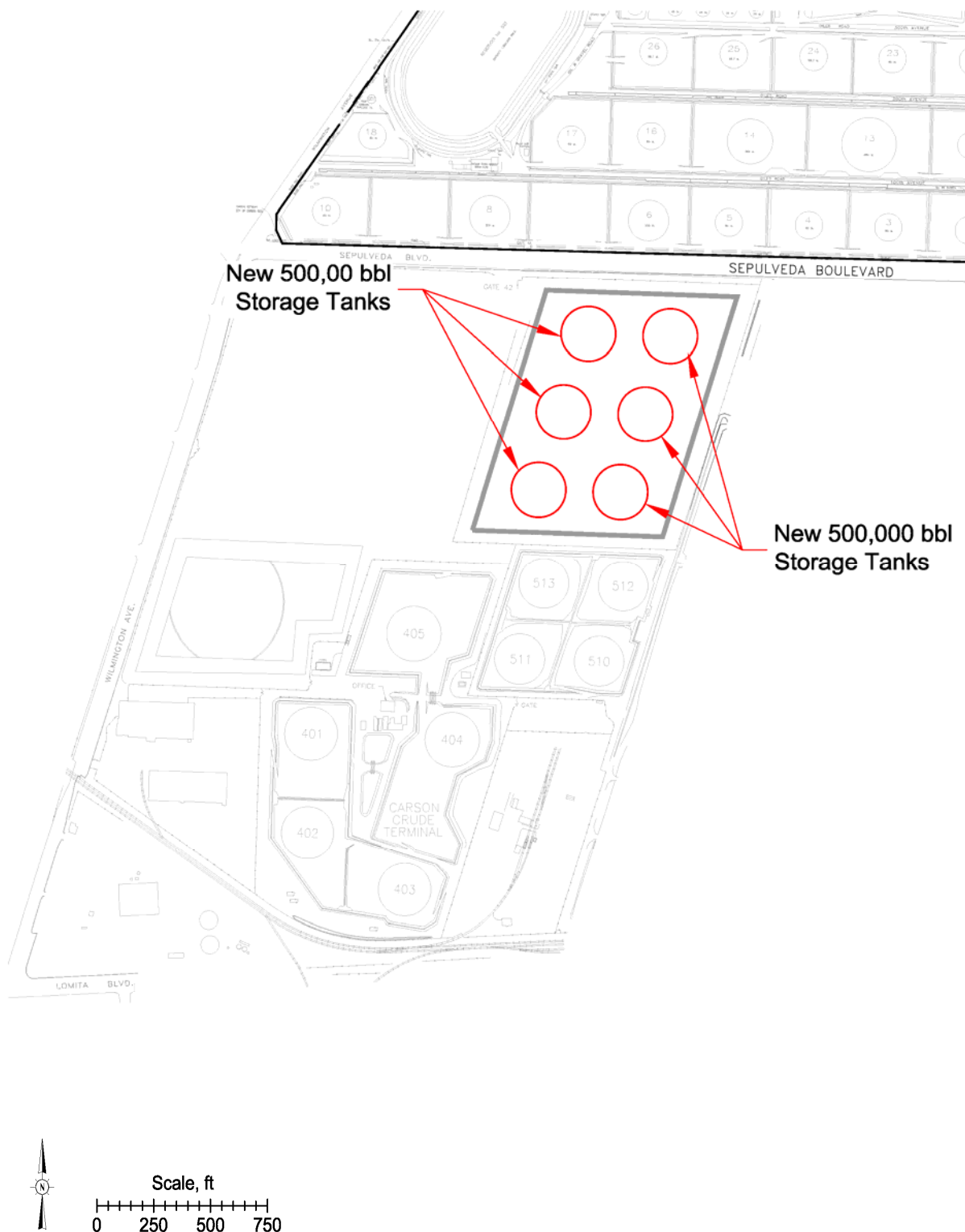


Figure 2-3
Plot Plan of New 500,000 bbl. Storage Tanks

2.1.1.6 HTU-1 and 2 Modifications (HTU-1/2)

The Wilmington Operations Hydrotreater Unit 1 (HTU-1) will be modified to hydrotreat approximately 20,000 BPD of FCCU gasoline to comply with the federally mandated Tier 3 gasoline specifications. HTU-2 feed will be separated from HTU-1 feed.

2.1.1.7 HTU-4 Modification

The Wilmington Operations Hydrotreater Unit No. 4 (HTU-4) will be modified to fully utilize the existing hydrotreating capacity to produce ultra-low sulfur diesel, to recover jet fuel, and to reduce energy consumption. These modifications do not produce changes in hazards, and this unit was not evaluated in the analysis.

2.1.1.8 New Sulfuric Acid Regeneration Plant

The proposed new Sulfuric Acid Regeneration Plant (SARP) will be constructed in the Wilmington operations area and will remove impurities from and recycle the Wilmington and Carson Operations spent sulfuric acid to produce fresh sulfuric acid.

2.1.1.9 Wilmington Storage Tanks

Two new 300,000 barrel internal floating roof storage tanks (Tanks 300035 and 300036) will replace two existing 80,000 barrel fixed-roof storage tanks (Tanks 80035 and 80036) in the north tank area of Wilmington Operations.

Tanks 80038, 80044, 80060, 80067, 80074, 80211, 80215, and 80217 will have increased utilization, increased throughput, or conversion to internal floating roofs. None of these changes will affect the hazard zone associated with each tank.

2.1.2 **Carson Operations**

Proposed modifications to the Carson Operations are described in the following subsections.

2.1.2.1 No. 51 Vacuum Unit Modifications

The No. 51 Vacuum Unit (51VAC) will be modified to provide the flexibility to increase diesel production by decreasing vacuum gas oil production by approximately 8,000 BPD.

2.1.2.2 New Wet Jet Treater

One new 50,000 BPD Wet Jet Treater (WetJet) will be installed at Carson Operations to remove mercaptans and to reduce the total acid number (TAN), or organic acid content, in jet fuel.

2.1.2.3 HCU Modification

The Carson Operations Hydrocracker (HCU) will be modified to add flexibility of running the distillate recovered from the No. 51 Vacuum and the Fluid Feed Hydrodesulfurization (FFHDS) Units. The HCU capacity will be increased by 10 percent.

2.1.2.4 LHU Modifications

The Carson Operations Light Hydrotreating Unit (LHU) will be modified to more effectively remove sulfur from FCCU gasoline to comply with the federally mandated Tier 3 gasoline sulfur specification.

2.1.2.5 Naphtha HDS Unit Modification

The Carson Operations Naphtha Hydrodesulfurization (Naphtha HDS) unit will be modified with the installation of new equipment to allow removal of contaminants from unit feed and sulfur from pentanes.

2.1.2.6 Naphtha Isomerization Unit Modifications

The Carson Operations Naphtha Isomerization Unit (ISOM) will be modified to recover propane and heavier material from the Unit off-gas.

2.1.2.7 Alkylation Modification

The Carson Operations Alkylation Unit (ALKY) will be modified to separate amylenes to feed the Carson Operations Alkylation Unit.

2.1.2.8 Mid-Barrel Distillate Treater Modifications

The existing Mid Barrel Distillate Treater (MBT) will be modified to remove sulfur from heavy FCCU naptha as well as to continue to treat straight run diesel.

2.1.2.9 Steam System Balance Modification

The Carson Operations steam system balance will be impacted due to Tier 3 conformance and the shifting of distillates draws. Implementing the projects described above will result in an increased steam demand at the Carson Operations. The increased steam demand will be met by a combination of; installing waste heat steam generators, generating more steam from the existing Cogen Units and reducing steam demand from existing steam turbines.

2.1.2.10 Carson Storage Tanks

Up to six new 500,000 barrel floating roof crude oil storage tanks will be constructed adjacent to the Carson Crude Terminal.

Tanks 14, 31, 62, 63, 64, 502, and 959 will have increased utilization. This will not affect the hazard zones associated with each tank.

2.1.3 Modifications to Supporting Equipment

2.1.3.1 Interconnecting Pipeway

The proposed project will require an interconnecting pipeway between the Wilmington and Carson Operations. The pipeway will be comprised of one pipe bundle of up to 15 pipelines ranging from 4 inches to 12 inches in diameter. The pipeway is proposed to exit the Carson Operations and be routed underneath S. Alameda Street to land near the Tesoro Coke Barn. The pipeway would then be routed underneath E. Sepulveda Boulevard to connect to the Wilmington Operations. The pipeway would then be routed above ground on pipe racks or ground level pipe supports into the respective product and supply manifolds within the Refinery.

2.1.3.2 Liquid Petroleum Gas (LPG) Rail Loading/Unloading

The LPG Rail Car Unloading facilities at Wilmington will be modified to allow increased receiving capacity of approximately 4,000 BPD at Wilmington of Alkylation Unit feedstocks (propane, propylene, butane, butylene, etc.). Butane is received from rail cars into pressurized tanks for use in the Refinery process. LPG Rail Unloading facilities will be used to transfer LPG to and from the Refinery to supplement Alkylation Unit feed and remove products

The LPG rail loading modifications will allow the Refinery to transfer up to about 15,000 BPD of LPG, resulting in the increase of about 4,000 BPD or ten rail cars per day at the Refinery. It is expected that these additional rail cars would be added onto existing trains that visit the Refinery.

3.0 MODELING METHODOLOGY

For any one of the hazards that are inherent to the existing or proposed process systems at the Tesoro Los Angeles Refinery facility to impact an area, a loss of containment (LOC) must occur. If the hydrocarbons normally contained within the piping or equipment at the site are released, the resulting flash fire, vapor cloud explosion (VCE), torch fire, pool fire, or toxic vapor cloud has specific consequences that can be described by modeling.

To describe the hazards at any facility handling or storing hazardous materials, release scenarios are developed to simulate the potential LOC events. This first requires calculations of material release rates and the properties of the material following release. Following these calculations, hazard models are applied to describe the extent of a toxic or flammable vapor cloud (flash fire), torch fire radiation, pool fire radiation, Boiling Liquid Expanding Vapor Explosion (BLEVE) or overpressure from a vapor cloud explosion. With the results of these calculations, the extent of the potential impacts can be determined.

3.1 CANARY Consequence Analysis Models

When performing site-specific consequence analysis studies, the ability to accurately model the release, dilution, and dispersion of gases and aerosols is important if an accurate assessment of potential exposure is to be attained. For this reason, Quest uses a modeling package, CANARY by Quest[®], that contains a set of complex models that calculate release conditions, initial dilution of the vapor (dependent upon the release characteristics), and the subsequent dispersion of the vapor introduced into the atmosphere. The models contain algorithms that account for thermodynamics, mixture behavior, transient release rates, gas cloud density relative to air, initial velocity of the released gas, and heat transfer effects from the surrounding atmosphere and the substrate. The release and dispersion models contained in the QuestFOCUS package (the predecessor to CANARY by Quest[®]) were reviewed in a United States Environmental Protection Agency (EPA) sponsored study [TRC, 1991] and an American Petroleum Institute (API) study [Hanna, Strimaitis, and Chang, 1991]. In both studies, the QuestFOCUS software was evaluated on technical merit (appropriateness of models for specific applications) and on model predictions for specific releases. One conclusion drawn by both studies was that the dispersion software tended to overpredict the extent of the gas cloud travel, thus resulting in too large a cloud when compared to the test data (i.e., a conservative approach).

A study prepared for the Minerals Management Service (MMS) [Chang, et al., 1998] reviewed models for use in modeling routine and accidental releases of flammable and toxic gases. The MMS recommends CANARY for use when evaluating toxic and flammable gas releases. The specific models (e.g., SLAB) contained in the CANARY software package have also been extensively reviewed.

CANARY also contains models for pool fire, torch fire, and boiling liquid expanding vapor explosions (BLEVEs) radiation. These models account for impoundment configuration, material composition, target height relative to the flame, target distance from the flame, atmospheric attenuation (includes humidity), wind speed, and atmospheric temperature. Both are based on information in the public domain (published literature) and have been validated with experimental data.

3.2 The QMEFS Model for Vapor Cloud Explosions

For vapor cloud explosion (VCE) calculations, Quest uses a model that is a variation of the Baker-Strehlow-Tang (BST) method. The Quest Model for Estimation of Flame Speeds (QMEFS) [Melton & Marx, 2009] is based on experimental data involving vapor cloud explosions, and is related to the amount of confinement and/or obstruction present in the volume occupied by the vapor cloud.

Quest's QMEFS model is based on the premise that the strength of the blast wave generated by a VCE is dependent on the reactivity of the flammable gas involved, the presence (or absence) of structures such as walls or ceilings that partially confine the vapor cloud, the spatial density of obstructions within the flammable cloud [Baker, et al., 1994, 1998], the average size of those obstacles, and the overall size of the confined or congested space [Mercx, 1994a, 1994b, 1997; Mercx, Van den Berg, & Van Dongen, 1996]. This model reflects the results of several international research programs on vapor cloud explosions, which show that the strength of the blast wave generated by a VCE increases as the degree of confinement and/or obstruction of the cloud increases. The following quotations illustrate this point.

“On the evidence of the trials performed at Maplin Sands, the deflagration [explosion] of truly unconfined flat clouds of natural gas or propane does not constitute a blast hazard.” [Hirst and Eyre, 1982] (Tests conducted by Shell Research Ltd., in the United Kingdom.)

“Both in two- and three-dimensional geometries, a continuous accelerating flame was observed in the presence of repeated obstacles. A positive feedback mechanism between the flame front and a disturbed flow field generated by the flame is responsible for this. The disturbances in the flow field mainly concern flow velocity gradients. Without repeated obstacles, the flame front velocities reached are low both in two-dimensional and three-dimensional geometry.” [van Wingerden and Zeeuwen, 1983] (Tests conducted by TNO in the Netherlands.)

“The current understanding of vapor cloud explosions involving natural gas is that combustion only of that part of the cloud which engulfs a severely congested region, formed by repeated obstacles, will contribute to the generation of pressure.” [Johnson, Sutton, and Wickens, 1991] (Tests conducted by British Gas in the United Kingdom.)

Researchers who have studied case histories of accidental vapor cloud explosions have reached similar conclusions.

“It is a necessary condition that obstacles or other forms of semi-confinement are present within the explosive region at the moment of ignition in order to generate an explosion.” [Wiekema, 1984]

“A common feature of vapor cloud explosions is that they have all involved ignition of vapor clouds, at least part of which have engulfed regions of repeated obstacles.” [Harris and Wickens, 1989]

The strength of the blast wave predicted by the QMEFS VCE model is directly related to the size of the obstructed or partially confined volume that is filled with a flammable mixture of gas and air, and fuel reactivity.

3.3 Hazards Identification and Modeling Endpoints

The potential hazards associated with this facility are common to most oil processing facilities worldwide, and are a function of the materials being processed, processing systems, procedures used for operating and maintaining the facility, and hazard detection and mitigation systems. The hazards that are likely to exist are identified by the physical and chemical properties of the materials being handled and the process conditions. For hydrocarbon fuel and petrochemical facilities, the common hazards are:

- toxic gas clouds (e.g., gas with hydrogen sulfide, sulfur dioxide, or sulfur trioxide)
- flash fires
- torch fires
- pool fires
- boiling liquid expanding vapor explosions (BLEVEs)
- vapor cloud explosions (VCEs)

When comparing a toxic hazard to a flammable or explosive hazard, the magnitude of the hazard's impact must be identically defined. For instance, it would not be meaningful to compare human exposure to nonlethal overpressures (low overpressures which break windows) to human exposure to lethal fire radiation (34,500 Btu/(hr•ft²) for five seconds). Thus, in order to compare the hazards of toxic gases, fires, and explosions on humans, equivalent levels of hazard must be defined.

The endpoint hazard criterion defined in this study corresponds to a hazard level which might cause an injury. With this definition, the injury level must be defined for each type of hazard (toxic, radiant heat, or overpressure exposure). Fortunately, data exist which approximate an equivalent injury level for each of the hazards listed. Table 3-1 presents the endpoint hazard criteria used by federal agencies and national associations for this type of analysis.

Table 3-1
Consequence Analysis Hazard Levels
(Endpoint Criteria for Consequence Analysis)

Hazard Type	Injury Threshold		
	Exposure Duration	Hazard Level	Reference
Sulfur Dioxide (SO ₂) exposure	Up to 60 min	3 ppm	ERPG-2 [AIHA, 2011]
Sulfur Trioxide (SO ₃) exposure	Up to 60 min	2.5 ppm	ERPG-2 [AIHA, 2011]
Hydrogen Sulfide (H ₂ S) exposure	Up to 60 min	30 ppm	ERPG-2 [AIHA, 2011]
Radiant heat exposure	40 sec	1,600 Btu/(hr•ft ²) †	40 CFR 68 [EPA, 1996]
Explosion overpressure	Instantaneous	1.0 psig ‡	40 CFR 68 [EPA, 1996]
Flash fires (flammable vapor clouds)	Instantaneous	LFL	40 CFR 68 [EPA, 1996]

ERPG-2. The maximum airborne concentration below which it is believed nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.

40 CFR 68. United States Environmental Protection Agency RMP endpoints.

† Corresponds to second-degree skin burns.

‡ An overpressure of 1 psi may cause partial demolition of houses, which can result in serious injuries to people, and shattering of glass windows, which may cause skin laceration from flying glass.

3.4 Weather Conditions

The weather conditions at the time of an accidental release (a LOC event) can influence the extents of the resulting hazards. For the purposes of a consequence-based study, a set of weather conditions – consisting of atmospheric stability and wind speed – must be assigned for each calculation. Atmospheric stability is classified by the letters A through F. In general, the most unstable atmosphere is characterized by stability class A. Stability A would correspond to an atmospheric condition where there is strong solar radiation and moderate winds. This combination of radiation and wind allows for rapid fluctuations in the air and thus greater mixing of the released gas with time. Stability D is characterized by fully overcast or partial cloud cover during both daytime and nighttime. The atmospheric turbulence is not as great during D conditions as during A conditions; thus, the gas will not mix as quickly with the surrounding atmosphere. Stability F corresponds to the most “stable” atmospheric conditions. Stability F generally occurs during the early morning hours before sunrise (thus, no solar radiation) and under low wind. The combination of low wind and lack of solar heating allows for an atmosphere which appears calm or still and thus restricts the ability to actively mix with the released gas.

For vapor dispersion calculations, the typical worst-case weather assumption is a stable atmosphere with low wind, which tends to produce longer vapor dispersion distances. The conditions chosen for the dispersion analyses are:

Atmospheric Stability	Class F
Wind Speed	4.5 mph (2.0 m/s)

For fire radiation, higher wind speeds generally result in longer impact distances due to flame bending. Atmospheric stability does not affect the size or characteristics of a flame. Thus, a worst-case wind speed for fire radiation was chosen as:

Wind Speed	20 mph (8.9 m/s)
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For all calculations, annual average air temperature and relative humidity values were taken from local meteorological data [weatherspark, 2014]:

Air Temperature	65°F (18.3 °C)
Relative Humidity	70%

4.0 IMPLEMENTATION OF WORST-CASE CONSEQUENCE MODELING METHODOLOGY

The results of the worst-case consequence modeling calculations for the existing and proposed processes are presented in this section. In addition, for several processes, the vulnerability zone which extends the greatest distance from the point of release is overlaid onto the local area in order to determine possible public exposure to the defined hazard levels.

4.1 Accident Selection

The inherent flammable hazards associated with refineries are well known. A review of the Los Angeles Refinery process shows that there are multiple release scenarios that could result in fire or explosion hazards that may generate significant impacts. The hazards from the various release scenarios are identified in the following sections.

4.2 Releases Resulting in the Largest Downwind Hazard Zones

When the hazard identification and consequence modeling calculations described in Section 3.0 are completed for the accidents selected in Section 4.1 for both the existing facility and the proposed changes to the facility, the releases which generate the largest hazard zones can be defined for the facility and associated pipeway. Table 4-1 summarizes the worst-case releases identified and Table 4-2 summarizes the maximum hazard zones for each worst-case release. In Table 4-2, P indicates a proposed modification and E indicates an existing unit.

4.3 Worst-Case Consequences

4.3.1 Flash Fires

Flash fires are the result of a release, formation of a flammable vapor cloud and ignition of the cloud. Flash fire hazard zones are defined by the maximum extent of the LFL portion of the vapor cloud. For example, a release from the line feeding the Carson light hydrotreater unit (LHU) stabilizer column could result in a flash fire.

In this release scenario, the flash fire is the maximum hazard. For the LHU, this scenario is the worst-case scenario because it goes further than the other scenarios chosen for the LHU, so it is used to define the vulnerability zone for the LHU.

An example hazard footprint and vulnerability zone associated with this “worst-case” event is illustrated in Figure 4-1. The vulnerability zone (the circle) depicts the potential area that could be affected due to a release from the feed line to the LHU stabilizer column. This presentation is misleading since all locations within this zone cannot be simultaneously exposed to potential flash fire hazard from any single accident. There are other possible hazard zones following this loss of containment that form smaller footprints. The scenario that creates the maximum hazard footprint is just one of the many possible outcomes found when considering variables such as hole size, orientation, wind speed, atmospheric stability, and wind direction. The hazard footprint in Figure 4-1 (the cross hatching) shows what would be expected if the pipe were to rupture, and low speed wind is blowing to the northeast, and the atmosphere is stable, and the release is oriented horizontal, and the gas is ignited after reaching a maximum extent.

As shown in Table 4-2, a large fraction of the worst-case release scenarios are flash fires.

Table 4-1
Summary of Unit Worst-Case Scenarios

Unit	Description of Release
Carson Refinery	
51 Vacuum	Vacuum column LGO product
Alkylation	Olefin feed from surge drums
HCU	Reactor 3 effluent
Mid-Barrel Hydrotreater	Reactor effluent
Naptha HDS	Debutanizer bottoms liquid
Naptha Isomerization	Hot flash drum liquid
LHU	Feed to stabilizer column
Wet Jet Treater	Liquid to reactors
New Crude Tanks	500,000 bbl. crude tank fire
Wilmington Refinery	
FCCU	Unit Shutdown – not evaluated
HTU-1/2	Liquid from HP Separator to Stripper
HTU4	No change in hazards – not evaluated
CRU3	Total liquid from depropanizer reflux receiver
PSTU	Liquid from depropanizer reflux receiver to treater
HCU	Liquid from 1 st stage surge drum and DEA contactor
SARP	Vapor from discharge of main compressor
Replace Crude Tanks	300,000 bbl. crude tank fire
Other	
Interconnecting Pipeway	<i>n</i> -Butane release
Rail Car Unloading	LPG BLEVE at loading/unloading area

Table 4-2
Summary of Worst-Case Hazard Distances

Unit	Case ID (P/E)	Distance to Hazard (feet)		Largest Hazard (P/E)
		Proposed (P)	Existing (E)	
Carson Refinery				
51 Vacuum	51V-03/02	150	155	Flash Fire
Alkylation	AU-04/04	360	585	Flash Fire
HCU	HC-08/08	1245	1250	Toxic
Mid-Barrel Hydrotreater	MBT-01/01	275	400	Torch Fire/ Toxic
Naptha HDS	IO-03/01	865	1035	Flash Fire
Naptha Isomerization	IS-02/01	665	530	Flash Fire
LHU	LH-04/04	600	585	Flash Fire
Wet Jet Treater	WJ-10	205	DNCE	Flash Fire
New Crude Tanks	TNK500k	340	DNCE	Pool Fire
Wilmington Refinery				
FCCU	Shutdown			
HTU1/2	HT-04/04	1170	1065	Flash Fire
HTU4	Modifications do not affect vulnerability zone			
CRU3	CR-04/20	1595	2190	Toxic
PSTU	CR-05/20	1085	2190**	Toxic
HCU	HC-07/10	1320	1450	Flash Fire
SARP	SAR-03A	1905	DNCE	Toxic
Replace Crude Tanks	TNK300k	265	190	Pool Fire
Other				
Interconnecting Pipeway	IC-01	380	DNCE	Flash Fire
Rail Car Unloading	C4BLEV	1700	1700	BLEVE

DNCE = Does Not Currently Exist

NCR = No Calculations Required

** Existing hazard in CRU3 unit. See Figure 4-2

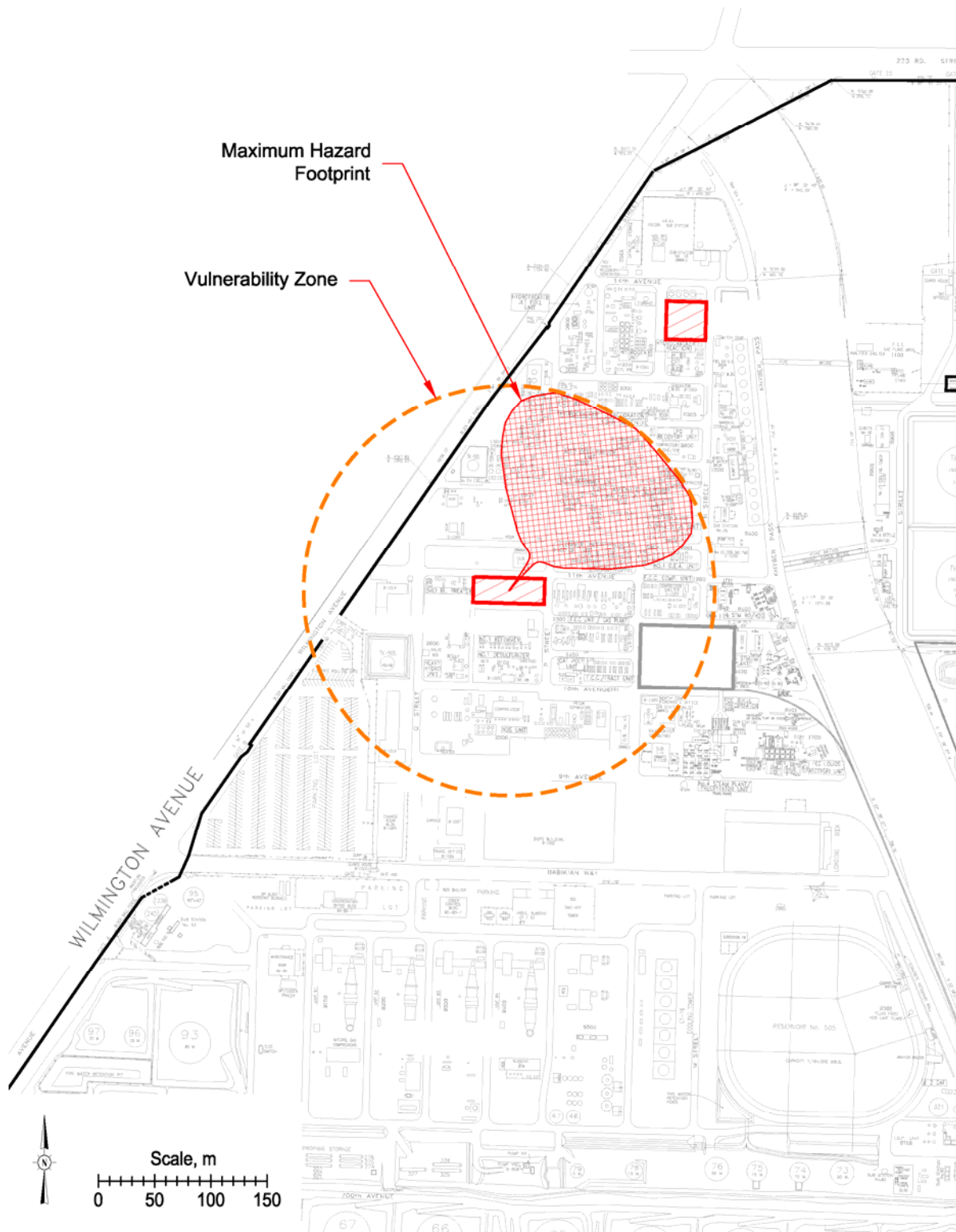


Figure 4-1
Example Vulnerability Zone

4.3.2 Fire Radiation

Fire radiation hazards for this facility are a result of torch fires, pool fires, or BLEVEs. Consequence results for the units where fire radiation is the worst-case scenario are shown in Table 4-2.

The largest fire radiation hazard shown in the table is an LPG rail car BLEVE.

4.3.3 Toxic Vapor Clouds

H₂S, SO₂, and SO₃ are the only toxic components in any of the processed fluids in the modified areas of the facility. A release of a stream containing H₂S, SO₂, or SO₃ may produce a toxic vapor cloud. The hazard zone of a toxic vapor cloud containing H₂S, SO₂, or SO₃ is defined by the ERPG-2 concentration level (30 ppm H₂S, 3 ppm SO₂, 2.5 ppm SO₃).

Releases of material containing H₂S produce worst-case vulnerability zones in four areas (Carson HCU and Wilmington CRU3, and PSTU). Releases of material containing SO₂ and SO₃ produce worst-case vulnerability zones in one unit (Wilmington SARP). The results from the toxic vapor cloud analysis are listed in Table 4-2.

4.3.4 Vapor Cloud Explosions (VCE)

One of the possible results of a flammable fluid or gas release is the potential ignition of the vapor which could then result in a VCE. There are no LOC events that could result in VCEs that are not also possible in the existing refinery configuration. No new vulnerability zones are produced by VCE events.

4.4 Summary of Maximum Vulnerability Zones

The maximum vulnerability zones for the existing equipment and proposed changes are presented in Figure 4-2 and 4-3 for the Wilmington operation and Figure 4-3 for the Carson operation. Figures 4-4 and 4-5 show the vulnerability zones for the new pipeway in the Wilmington and Carson operation areas. Figure 4-6 shows the vulnerability zone for the new 500,000 bbl. storage tanks.

Many of the units have vulnerability zones that are the same size or larger for the existing facility (solid blue lines) than for those that would be produced following the proposed changes (dashed orange lines). New units do not have existing vulnerability zones, so the proposed vulnerability zones would be larger (Carson Wet Jet, Wilmington PSTU and SARP units).

The potential hazard zones from releases originating inside the facility at the Carson operation are dominated by the toxic hazards from the HCU and at the Wilmington operation by toxic hazards in the CRU3, PTSU, and SARP areas. The largest potential hazard zone occurring within any modified area is found in the Wilmington SARP area and covers a vulnerability zone with a radius of 1,905 feet.

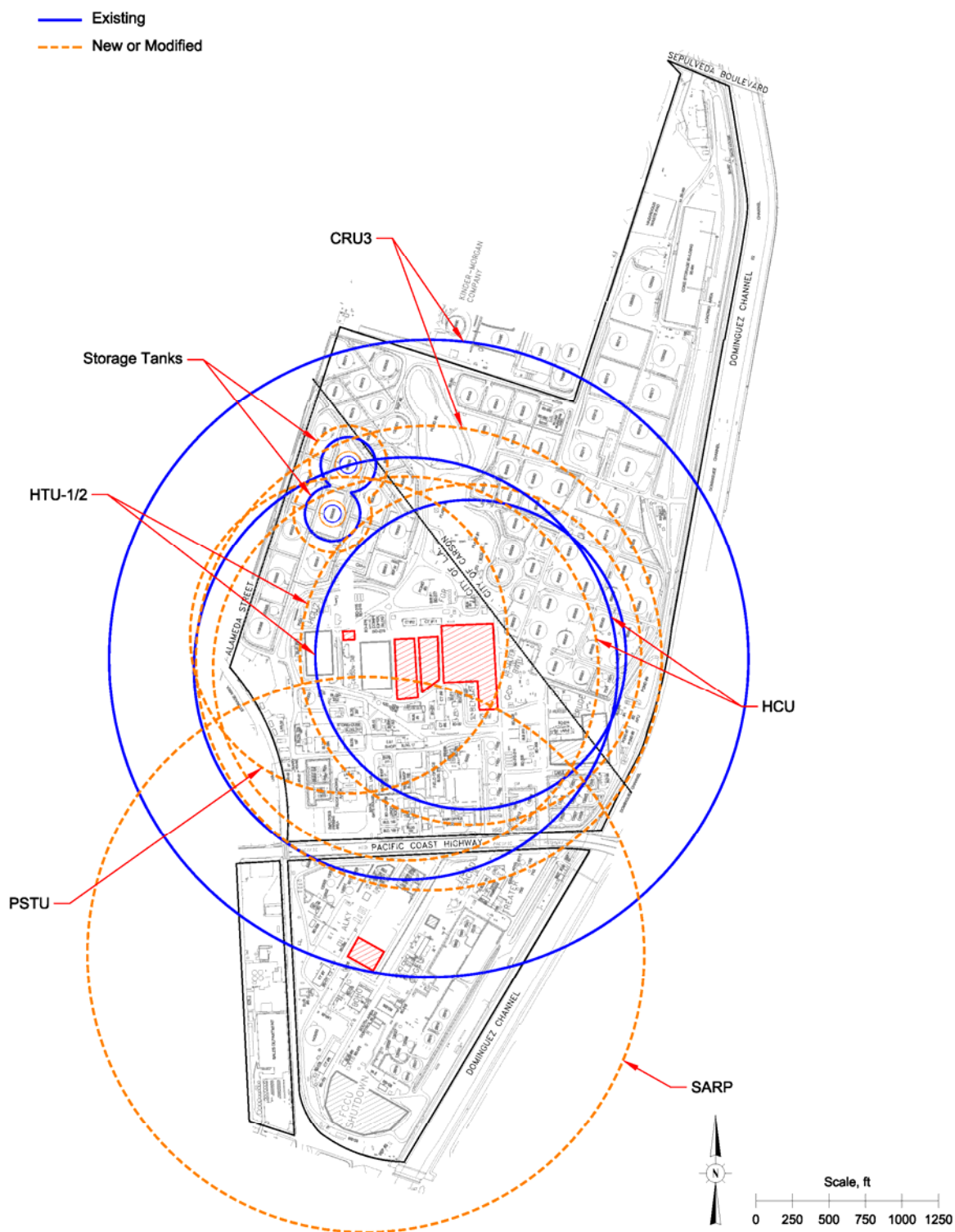


Figure 4-2
Vulnerability Zones for Wilmington Operations

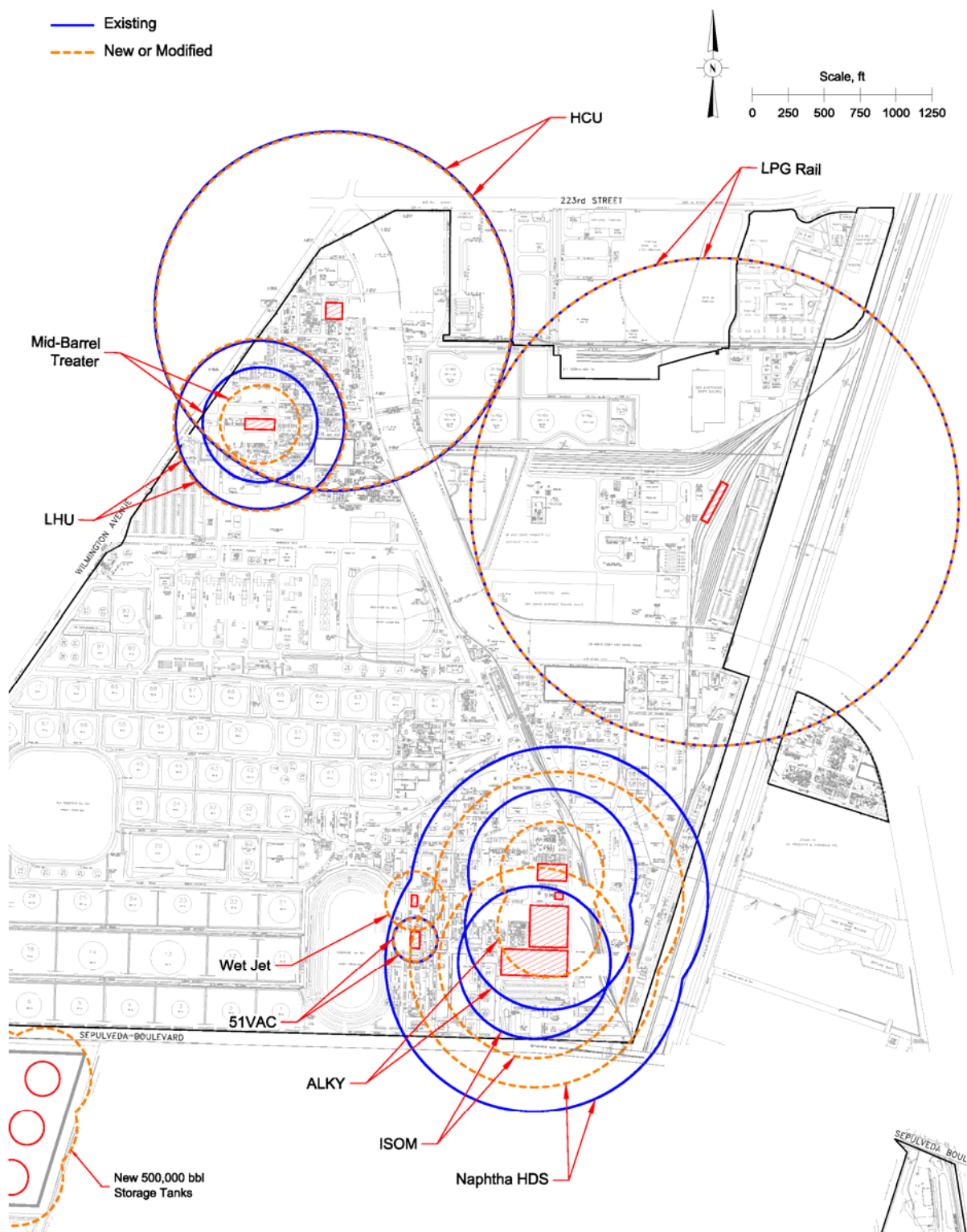


Figure 4-3
Vulnerability Zones for Carson Operations

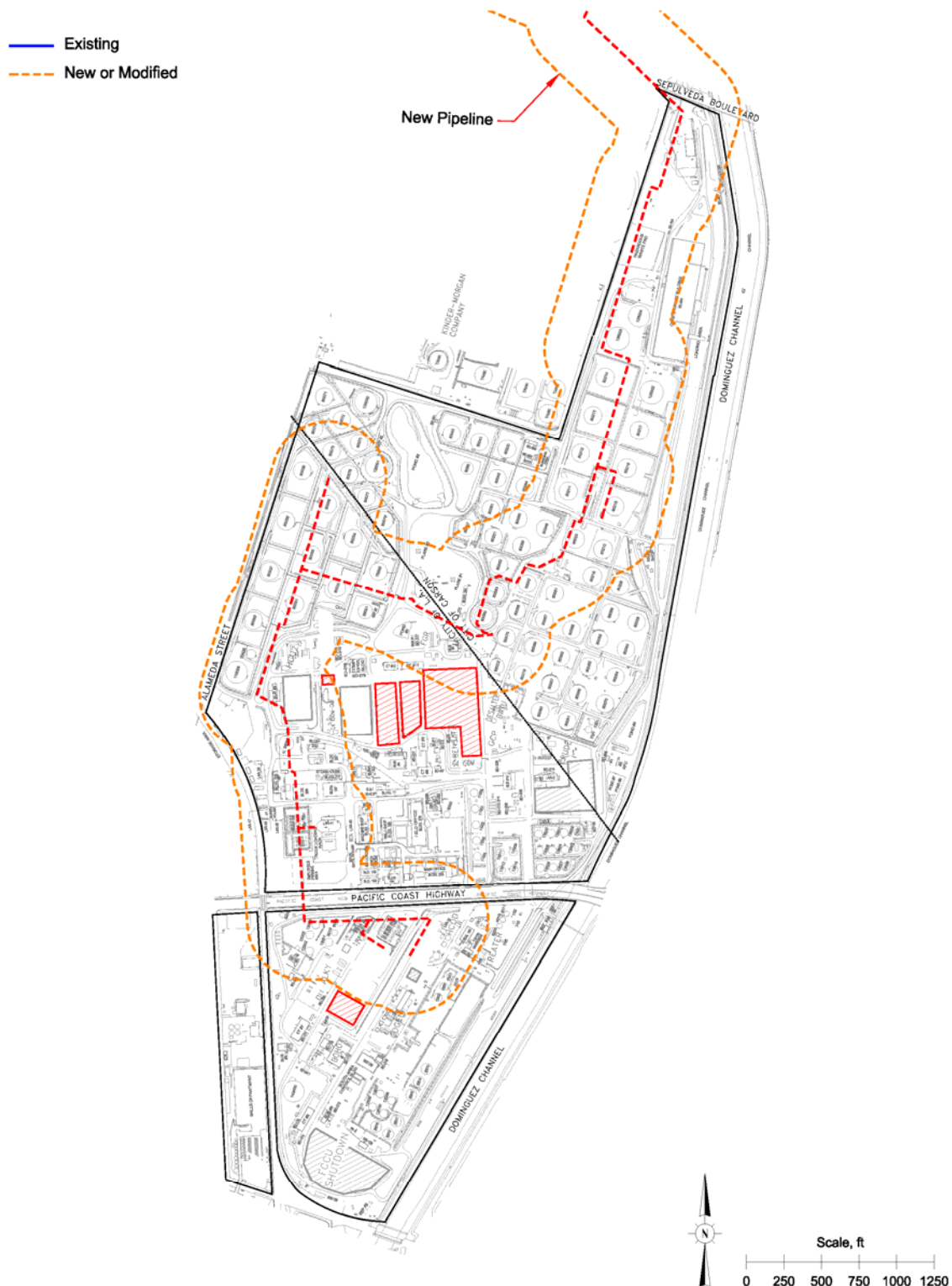


Figure 4-4
Vulnerability Zone for New Pipeway – Wilmington Operations



Figure 4-5
Vulnerability Zones for New Pipeway – Carson Operations



Figure 4-6
Vulnerability Zone for New 500,000 bbl. Storage Tanks

5.0 CONCLUSIONS

The primary conclusions drawn from the worst-case consequence modeling results are that for most potential releases, the proposed changes result in similar or smaller potential vulnerability zones than those posed by the existing facility configuration.

With the maximum vulnerability zones defined for each release evaluated under the existing and proposed refinery configurations, the areas can be divided into three categories, dependent on their potential to impact the public. The categories are defined as:

- Areas with no potential off-site impacts for proposed refinery configurations (hazard zones are contained onsite within the facility fence line).
Carson: Alkylation, Wet Jet, 51VAC, MBT
Wilmington: HTU-1/2, 80,000 to 300,000 bbl. tank replacement
- Areas with potential off-site impacts, but no public residential exposure under proposed refinery configurations where project modified impacts are similar to or smaller than existing impacts.
Carson: HCU, Naptha HDS, LHU, Rail Loading/Unloading
Wilmington: PSTU, CRU3, HCU
- Areas with potential off-site impacts, but no public residential exposure under proposed refinery configurations where project modified impacts are larger than existing impacts.
Carson: Naptha Isomerization, new 500,000 bbl. Tanks, New Pipeway
Wilmington: New Pipeway
- Areas with potential public residential exposure.
Carson: none
Wilmington: New SARP

These conclusions are driven by the nature of the proposed changes to the Tesoro Los Angeles Refinery. The consequences are determined by the process conditions at the time of release. The proposed changes to the Tesoro Los Angeles Refinery are not expected to significantly change those conditions. Thus, for the purposes of this study, using the hazard endpoints developed by the U.S. EPA and AIHA, the off-site hazard increases associated with the proposed project are limited to adjacent industrial areas near the facility.

6.0 REFERENCES

- AIHA, Emergency Response Planning Guidelines threshold values. American Industrial Hygiene Association, found at <http://www.aiha.org/1documents/Committees/ERP-erplevels.pdf>.
- Baker, Q. A., M. J. Tang, E. Scheier, and G. J. Silva (1994), "Vapor Cloud Explosion Analysis." 28th Loss Prevention Symposium, American Institute of Chemical Engineers (AIChE), April 17-21, 1994.
- Baker, Q. A., C. M. Doolittle, G. A. Fitzgerald, and M. J. Tang (1998), "Recent Developments in the Baker-Strehlow VCE Analysis Methodology." *Process Safety Progress*, Vol. 17, No. 4, Winter, 1998, pp 297-301.
- Chang, Joseph C., Mark E. Fernau, Joseph S. Scire, and David G. Strimatis (1998), *A Critical Review of Four Types of Air Quality Models Pertinent to MMS Regulatory and Environmental Assessment Missions*. Mineral Management Service, Gulf of Mexico OCS Region, U.S. Department of the Interior, New Orleans, November, 1998.
- EPA (1996), *Accidental Release Prevention Requirements: Risk Management Programs Under the Clean Air Act, Section 112(r)(7)*. Environmental Protection Agency, 40 CFR Part 68, 1996.
- Hanna, S. R., D. G. Strimaitis, and J. C. Chang (1991), *Hazard Response Modeling Uncertainty (A Quantitative Method), Volume II, Evaluation of Commonly-Used Hazardous Gas Dispersion Models*. Study cosponsored by the Air Force Engineering and Services Center, Tyndall Air Force Base, Florida, and the American Petroleum Institute; performed by Sigma Research Corporation, Westford, Massachusetts, September, 1991.
- Harris, R. J., and M. J. Wickens (1989), *Understanding Vapour Cloud Explosions—An Experimental Study*. The Institution of Gas Engineers, Communication No. 1408, 1989.
- Hirst, W. J. S., and J. A. Eyre (1982), "Maplin Sands Experiments 1980: Combustion of Large LNG and Refrigerated Liquid Propane Spills on the Sea." *Proceedings of the Second Symposium on Heavy Gases and Risk Assessment*, Frankfurt am Main, May 25-26, 1982: pp. 211-224.
- Johnson, D. M., P. Sutton, and M. J. Wickens (1991), "Scaled Experiments to Study Vapour Cloud Explosions." IChemE Symposium Series No. 124, *Hazards XI, New Directions in Process Safety*, Manchester, United Kingdom, April, 1991: pp. 67-85.
- Melton, T.A. and J.D. Marx (2009), "Estimating Flame Speeds for Use with the BST Blast Curves." *Process Safety Progress*, Vol. 28, No. 1, March 2009, pp 5-10
- Mercx, W.P.M., editor (1994a), *Modelling And Experimental Research Into Gas Explosions*, Overall final report of the project MERGE, CEC contract STEP-CT-0111(SSMA), European Commission, Directorate General XII, Brussels, Belgium.
- Mercx, W.P.M., A.C. Van den Berg, and Y. Mouilleau (1994b), *Modelling And Experimental Research Into Gas Explosions*, Contribution of TNO-PML to the MERGE project, TNO report, PML 1993-C137, Rijswijk, The Netherlands.
- Mercx, W.P.M., editor (1997), *Extended Modelling And Experimental Research Into Gas Explosions*, Final summary report of the project EMERGE, CEC contract EV5VCT930274, European Commission, Directorate General XII, Brussels, Belgium.

- Mercx, W.P.M., A.C. Van den Berg, and Ph. Van Dongen (1996), *Extended Modelling And Experimental Research Into Gas Explosions*, Contribution of TNO-PML to the MERGE project, TNO report, PML 1996-C16, Rijswijk, The Netherlands.
- TRC (1991), *Evaluation of Dense Gas Simulation Models*. Prepared for the U.S. Environmental Protection Agency by TRC Environmental Consultants, Inc., East Hartford, Connecticut 06108, EPA Contract No. 68-02-4399, May, 1991.
- van Wingerden, C. J. M., and J. P. Zeeuwen (1983), "Flame Propagation in the Presence of Repeated Obstacles: Influence of Gas Reactivity and Degree of Confinement." *Journal of Hazardous Materials*, Vol. 8, 1983: pp. 139-156.
- Weatherspark (2014) <https://weatherspark.com/averages/30723/Long-Beach-California-United-States>
- Wiekema, B. J. (1984), "Vapour Cloud Explosions—An Analysis Based on Accident" (Part I). *Journal of Hazardous Materials*, Vol. 8, 1984: pp. 285-311.
- Wiekema, B. J. (1984), "Vapour Cloud Explosions – An Analysis Based on Accident" (Part II). *Journal of Hazardous Materials*, Vol. 8, 1984: pp. 313-329.

APPENDIX A

RESUMES

John B. Cornwell
Quest Consultants Inc.[®]
Principal Engineer

EDUCATION

1978 M.S., Mechanical Engineering
University of Texas, Austin, Texas

1975 B.S., Chemical Engineering
University of Texas, Austin, Texas

EXPERIENCE

1989 - Present Quest Consultants Inc., Norman, Oklahoma
Principal Engineer

Directs the company's hazards analysis and risk analysis efforts. Directs the use of the company's state-of-the-art phenomenological models to determine the extent of potential flammable/toxic/explosive hazards. Presents the technology behind the studies to corporate and regulatory groups.

Directs quantitative risk analysis studies (QRAs) involving:

- LNG import and export terminals
- LPG storage/marketing terminals
- LPG import terminals
- Refinery complexes
- Alkylation units (HF and H₂SO₄)
- Ammonia plants
- Transportation of toxic materials (road and rail)
- Pipeline networks (natural gas, LPG, ammonia, liquids)
- Exploration and production systems (oil and natural gas)
- Gas plants

Directs development of computer software, CANARY by Quest[®], that provides analysis tools for the company. Oversees the use of public domain (e.g. DEGADIS, SLAB, LNGFIRE3) and special application software.

1985 - 1989 Energy Analysts, Inc., Norman, Oklahoma
Principal Engineer

Directed the development of computer models to simulate the hazards associated with accidental releases of toxic/flammable materials. These models were contained in a commercially available software package named EAHAP.

John B. Cornwell

Modeled the simulation of heavier-than-air gases and momentum jet releases of gases and aerosols. Directed the comparison analysis of several heavier-than-air gas dispersion models against the large-scale test data produced by the Thorney Island Trials, Desert Tortoise Ammonia Releases, and the Goldfish Hydrofluoric Acid Releases.

Directed numerous risk analysis/assessment studies using results of the consequence modeling and in-house risk modeling capabilities. Prepared and reviewed California RMPPs (Risk Management and Prevention Plans).

1984 - 1985 Los Alamos National Laboratory, Los Alamos, New Mexico
Staff Member/Research Scientist, Advanced Technologies Division
Security Clearance Level Q (DoE)

Evaluated advanced energy systems, including advanced fusion devices, liquid oxygen/liquid hydrogen turbogenerators, advanced photovoltaic systems, and conventional petroleum-based turbine systems.

1981 - 1984 Energy Analysts, Inc., Norman, Oklahoma
Senior Engineer

Directed the development of advanced simulation models for the dispersion of heavier-than-air vapors. Developed compatible thermodynamic systems and methodologies for predicting transient vaporization history of cryogenic fluids.

Directed development of a risk analysis model for use in conjunction with results of vapor dispersion and fire radiation analyses. The risk analysis model was employed in studies requiring the time-varying/site-dependent risk profile for petrochemical facilities and the surrounding area.

Evaluated transient fire hazards and the analysis of toxic combustion products.

1978 - 1981 University of Texas, Austin, Texas
Research Scientist, Center for Energy Studies

Developed a series of mathematical models to evaluate geopressured/geothermal resources along the Texas gulf coast.

PROFESSIONAL MEMBERSHIPS

American Institute of Chemical Engineers
Air and Waste Management Association
American Nuclear Society

John B. Cornwell

PUBLICATIONS

Authored papers on hazards analysis modeling, risk analysis methodologies, project siting issues, and model-to-test data analysis.

RELEVANT PROJECT EXPERIENCE

Quantitative Risk Analysis for an LNG Import Terminal: *Project Manager* for a full QRA of an LNG import terminal on Mexico's gulf coast. QRA was submitted to Mexico's Department of the Environment (SEMARNAT). Other studies completed under this contract included a qualitative risk analysis and siting study per Mexico's Secretary of Energy, Energy Regulation Commission (CRE). Terminal is now under construction. *Client: Shell Global Solutions.*

Quantitative Risk Analysis of a Refrigerated LPG Import Terminal: *Project Manager* for a study that included refrigerated LPG ship loading/unloading and cavern storage. Full QRA was completed and submitted for review to Chinese authorities. *Client: Caltex Corporation (now part of ChevronTexaco).*

LNG Facility Siting Safety Study for a Pacific Ocean Gravity Based Structure (GBS) for Use as an Import Terminal: Participant in a study to determine if a proposed LNG import terminal could be built upon a GBS in the Mexican waters off Baja California. The study applied Mexico's NOM-EM-001-SECRE-2002 to the design. The project involved vapor dispersion, fire radiation, and vapor cloud explosion modeling for numerous hypothetical releases of LNG. *Client: ChevronTexaco*

Quantitative Risk Analysis for an Existing HF Alkylation Unit: *Project Manager* for a full QRA of an existing HF alkylation unit. QRA was used to develop potential mitigation options. *Client: Sunoco*

Quantitative Risk Analysis for Natural Gas Transmission Pipeline: *Project Manager* for a full QRA of a natural gas transmission line spanning the Gulf of Mexico from Alabama to Florida. Torch fire and flash fire radiation hazards were defined. QRA was submitted to US FERC as part of project permitting. *Client: Willbros Engineers, Inc.*

Quantitative Risk Analysis of a Refrigerated and Pressurized LPG Storage Depot: *Project Manager* for a full QRA of a LPG storage depot and a nearby chemical facility. Analysis of terrorist threat included. Facility had been target of failed domestic terrorism in 1999. *Client: City of Elk Grove, California.*

Quantitative Risk Analysis for Natural Gas Gathering Pipeline Network: *Project Manager* for a full QRA of a natural gas gathering network in Venezuela. Wellhead, compression and pipeline releases were evaluated. Toxic (Hydrogen Sulfide) and fire radiation hazards were defined. QRA was submitted to Petroleos de Venezuela (PDVSA) for review and approved per PDVSA standard IR-S-02. *Client: Petroleos de Venezuela.*

Quantitative Risk Analysis for an Existing HF Alkylation Unit: *Project Manager* two full QRAs of an existing HF alkylation unit were conducted to identify the possible risk benefit afforded by the use of acid additive. *Client: Texaco*

John B. Cornwell

Quantitative Risk Analysis for an LNG Import Terminal: *Project Manager* for a full QRA of an LNG import terminal on Mexico's Pacific coast. QRA was submitted to Mexico's Department of the Environment (SEMARNAT). Other studies completed under this contract included a qualitative risk analysis and siting study per Mexico's Secretary of Energy (CRE). *Client: Sempra Energy.*

LNG Carrier Spill Hazards Analysis: *Project Manager* for an analysis of possible large scale LNG carrier releases in Boston Harbor. Results used by U.S. Department of Energy in designing LNG tanker operations in Boston Harbor following September 11, 2001 terrorist attacks. *Client: U.S. Department of Energy.*

Comparative Quantitative Risk Analysis for an HF Alkylation Unit Upgrade: *Project Manager* for a comparative (before and after) set of QRAs of an existing HF alkylation unit. The QRAs were used to demonstrate the benefits associated with three mitigation measures (individually or in concert); rapid dump system, water curtains, and water cannons. *Client: Ampol*

LNG Facility Siting Safety Study for Gulf of Mexico Gravity Based Structure (GBS) for Use as an Import Terminal: Participant in a study to determine if the proposed LNG import terminal could be built upon a GBS in the Gulf of Mexico. The study included meshing the import terminal design with applicable LNG standards. This involved vapor dispersion, fire radiation, and vapor cloud explosion modeling for numerous hypothetical releases of LNG. *Client: ChevronTexaco*

Consequence Analysis Course: *Instructor* for an introductory course covering the principals of consequence analysis. Course covers accidental releases and the methods to predict the extent of potential fire, explosion and toxic hazards. Course is provided through the Mary Kay O'Conner Process Safety Center located at Texas A&M University. *Client: Texas A&M University, College Station, Texas*

Quantitative Risk Analysis for an LNG Import Terminal: *Project Manager* for a full QRA of an LNG import terminal on Mexico's Pacific coast. QRA was submitted to Mexico's Department of the Environment (SEMARNAT). Other studies completed under this contract included a qualitative risk analysis and siting study per Mexico's Secretary of Energy (CRE). *Client: ConocoPhillips.*

Quantitative Risk Analysis for Natural Gas Gathering Pipeline Network: *Project Manager* for a full QRA of a natural gas gathering network. Wellhead and pipeline releases were evaluated. Toxic (Hydrogen Sulfide) and fire radiation hazards were defined. QRA was submitted to US EPA's technical staff for review and approved. *Client: Union Pacific Resources.*

Quantitative Risk Analysis for an HF Alkylation Unit Addition to Existing Refinery: *Project Manager* for a full QRA of a new HF alkylation unit to be added to an existing refinery. QRA was submitted to local and Federal Israeli authorities. Evaluation included acid additive as well as water spray mitigation systems. *Client: Paz Ashdod Refinery Limited.*

Quantitative Risk Analysis for a Proposed Gas-to-Liquids Facility: *Project Manager* for a full QRA of a new gas-to-liquids facility along the Nigerian coast. QRA was submitted to local and Federal Nigerian authorities. *Client: Chevron Energy and Technology*

David W. Johnson
Quest Consultants Inc.[®]
Principal Engineer

EDUCATION

1969 Ph.D., Chemical Engineering
 University of Oklahoma, Norman, Oklahoma

1965 B.S., Chemical Engineering
 University of Texas, Austin, Texas

EXPERIENCE

1989 - Present Quest Consultants Inc., Norman, Oklahoma
 Principal Engineer

Facilitated HAZOP, SIL/LOPA, What If?, HAZID, and HEMP (bowtie) reviews for numerous projects, including:

- Chemical complex
- Oil and gas processing facilities
- Refinery units
- LNG baseload (export) facilities
- LNG import facilities
- Offshore oil and gas processing

Performed consequence modeling for siting and safety studies of several liquefied natural gas (LNG) facilities. Involved in numerous consequence analysis, risk analysis, and facility siting studies involving refineries, gas plants, pipelines, and petrochemical plants.

Responsible for Quest's testing and research programs, and for the development and implementation of analytical models for predicting accidental release rates, aerosol formation, pool spreading, heat transfer, and vaporization rates.

Directed all major aspects of several experimental programs involving releases of hazardous fluids.

- On-site tests conducted to determine if the flammable cloud produced by emergency venting of ullage gas from a crude oil pipeline surge tank could reach associated process areas.
- Two field-test programs conducted to evaluate the efficacy of additives designed to reduce the amount of aerosol formed during accidental releases from HF alkylation units.
- Release tests conducted for the Petroleum Environmental Research Foundation (PERF) to determine the potential for a hydrocarbon/sulfuric acid emulsion to form an aerosol upon its release.

David W. Johnson

- Aerosol release tests conducted for the CCPS at the DOE Nevada Test Site.

Assisted in development of RMPPs for several refinery units in California, including alkylation, hydrotreating, hydrocracking, catalytic cracking, delayed coking, and product storage. This work included a review of unit HAZOPs, selection of potential release scenarios, estimation of accident frequencies, and supervision of hazard modeling.

1983 - 1989 Energy Analysts, Inc., Norman, Oklahoma
Principal Engineer

Conducted HAZOP study for a proposed refinery expansion in the Philippines. Trained refinery personnel as HAZOP leaders for future HAZOP studies.

Responsible for the technical content of the final safety analysis report (FSAR) for the Big Hill Strategic Petroleum Reserve (SPR) site. Tasks completed included identification and analysis of hazards; review of site layout and design; and equipment, piping, and instrumentation evaluation. Made recommendations to improve site operations.

Developed risk models in the areas of fire and thermal radiation, rate of fluid release from containment, and Gaussian dispersion for EAHAP hazards analysis computer code.

Designed and participated in several large-scale outdoor fire and fluid release tests designed to determine the burning and release characteristics of hydrocarbon fluids.

1977 - 1983 Applied Technology Corporation, Norman, Oklahoma
Vice President

Developed mathematical models in the areas of fire radiation, vapor dispersion, and heat transfer. Applied these models to LNG facility safety studies.

Designed and conducted several large-scale outdoor tests involving fire and materials combustion. Tests included the burning and subsequent extinguishment of hexane, LPG, and carbon disulfide pool fires.

1970 - 1977 University Engineers, Inc., Norman, Oklahoma
Senior Engineer

Project manager of a semi-works seawater desalination project utilizing direct contact heat transfer and freezing to produce potable water.

Involved in several large-scale outdoor fire tests to study the flammability characteristics of thermal insulation products.

1965 Celanese Fibers Corporation, Rock Hill, South Carolina
Development Engineer

Adapted existing plant equipment for new and more productive uses, developed computer models describing machine operations, and assisted in plant start-up.

David W. Johnson

PROFESSIONAL MEMBERSHIPS

National Society of Professional Engineers
American Institute of Chemical Engineers
Oklahoma Society of Professional Engineers

PUBLICATIONS

Authored more than twenty-five papers in the areas of physical properties, kinetics, and process plant safety.

RELEVANT PROJECT EXPERIENCE

Process Hazards Analysis (PHA) of a Large LNG Liquefaction Facility: *Directed* the HAZOP and LOPA studies for a large scale grass roots LNG facility in Texas. Studies for both the FEED and EPC were performed as well as Management of Change (MOC) reviews. *Client: Sabine Pass LNG.*

Process Hazards Analysis (PHA) of a Large LNG Liquefaction Facility: *Directed* the HAZOP and LOPA studies for a large scale grass roots LNG facility in Australia. Studies for both the FEED and EPC were performed as well as Management of Change (MOC) reviews. *Client: Gladstone LNG.*

Process Hazards Analysis (PHA) of Multiple Nitrogen Rejection (NRU) and Cryogenic Processing Units: *Directed* the HAZOP and MOC studies for multiple nitrogen rejection and cryogenic units in Texas, New Mexico, and Wyoming. *Client: BCCK Engineering.*

Process Hazards Analysis (PHA) of a Refinery Crude Unit: *Directed* the HAZOP for a refinery crude unit. *Client: Caltex Corporation (now part of ChevronTexaco).*

Development of an Improved Hydrogen Fluoride Alkylation Catalyst: *Project Manager* for a research project involving the large scale outdoor release of anhydrous hydrogen fluoride (HF) and hydrogen fluoride mixed with vapor pressure reducing additives. The purpose of the testing was to validate lab scale results with respect to the reduction of aerosol formation of the released HF. *Client: Mobil Research and Development Corporation (now a part of Exxon/Mobil).*

Development of an Improved Hydrogen Fluoride Alkylation Catalyst: *Project Manager* for a research project involving the large scale outdoor release of anhydrous hydrogen fluoride (HF) and hydrogen fluoride mixed with vapor pressure reducing additives. The purpose of the testing was to validate lab scale results with respect to the reduction of aerosol formation of the released HF. *Client: Texaco Inc.(now a part of ChevronTexaco).*