

**CONSEQUENCE ANALYSIS FOR THE
LOS ANGELES REFINERY PROPOSED
ULSD REACTOR MODIFICATIONS**

Prepared For

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CONSEQUENCE ANALYSIS FOR THE LOS ANGELES REFINERY PROPOSED ULSD REACTOR MODIFICATIONS

Quest Consultants Inc. was retained by Environmental Audit, Inc. (EAI) to perform a credible worst-case consequence analysis for a portion of the Conoco-Phillips Los Angeles refinery in California. The objective of the study was to compare the extent of potential hazards associated with a proposed modification to the diesel hydrotreating reactors to hazards that currently exist in the refinery.

Hazards Identification

The potential hazards associated with the refinery's existing and proposed units are common to many petrochemical 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. The focus of this analysis was the evaluation of the toxic and/or flammable hazards associated with the processed materials.

Because of the limited scope of the proposed modifications, this study only addresses changes to the diesel hydrotreating reactors in the mid-barrel hydrotreater (Unit 90). Modification to the reactors is being proposed so that the refinery can comply with California's Ultra-low sulfur diesel regulations. To achieve a 5-7 ppm sulfur content, the reactors in unit 90 require a longer residence time. This necessitates larger reactor vessels and a higher rate for the recycle hydrogen. Other modifications in the unit (e.g., replacing heat exchangers with higher efficiency units) do not create potential offsite hazards and thus are excluded from the analysis.

The reactor effluent is a stream composed primarily of hydrogen and heavy hydrocarbons. By its nature, the effluent will contain about 2% (molar basis) Hydrogen Sulfide (H_2S). Because of this, the analysis will consider both the toxic and flammable hazards associated with releases from the reactors.

Physiological Effects of Hydrogen Sulfide

Potential releases of fluids containing H_2S may result in persons downwind of the release being exposed to H_2S gas. H_2S is a colorless gas, with a strong, irritating odor (often described as a "rotten egg" smell). H_2S has a low threshold limit value (TLV) and is detectable by odor at concentrations significantly lower than those necessary to cause physical harm or impairment. The most serious acute hazard presented by H_2S is exposure to a high enough H_2S gas concentration for a long enough period of time such that the exposed person's ability to escape the release is impaired.

For this study, the hazard level to be evaluated is defined as the ERPG-2 level. The ERPG-2 level for a toxic hazard is defined as a hazard level that would irritate, but not seriously injure, exposed members of the public following exposure for up to sixty minutes. The ERPG-2 level for H_2S is 30 ppm.

Physiological Effects of Flash Fires

A potential consequence associated with most of the releases from the ConocoPhillips refinery is exposure to the heat of a flash fire, which is the result of delayed ignition of a flammable vapor cloud following a release of a flammable fluid. The physiological effect of fire on humans depends on the rate at which heat is transferred from the fire to the person, and the time the person is exposed to the fire. Even short-term exposure to high heat flux levels may be fatal. This situation could occur when persons wearing ordinary clothes are inside a flammable vapor cloud (defined by the lower flammable limit) when it is ignited. Persons located outside a flammable cloud when it is ignited will be exposed to much lower heat flux levels. If the person is far enough from the edge of the flammable cloud, the heat flux will be incapable of causing injuries, regardless of exposure time.

The endpoint used in the dispersion modeling for flammable vapor clouds is the lower flammable limit (LFL). This is expressed as a concentration of the released material, in air, and defines the extent of the flammable hazard.

Dispersion Modeling

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 study¹ and an American Petroleum Institute (API) study². 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 Service³ reviewed models for use in modeling routine and accidental releases of flammable and toxic gases. **CANARY** by Quest received the highest possible ranking in the science and credibility areas. In addition, the report recommends **CANARY** by Quest for use when

¹*Evaluation of Dense Gas Dispersion 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.

²*Hazard Response Modeling Uncertainty (A Quantitative Method); Volume II, Evaluation of Commonly-Used Hazardous Gas Dispersion Models*, S. R. Hanna, D. G. Strimaitis, and J. C. Chang. 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.

³*A Critical Review of Four Types of Air Quality Models Pertinent to MMS Regulatory and Environmental Assessment Missions*, Joseph C. Chang, Mark E. Fernau, Joseph S. Scire, and David G. Strimaitis. Mineral Management Service, Gulf of Mexico OCS Region, U.S. Department of the Interior, New Orleans, Louisiana, November, 1998.

evaluating toxic and flammable gas releases. The specific models contained in the CANARY by Quest software package have also been extensively reviewed. Descriptions of the models used in this analysis are presented in Appendix A.

This study evaluated the reactor release scenarios using worst-case conditions. This approach produces the maximum expected downwind hazard zones. The following parameters were applied to each potential release scenario:

Wind speed	1.5 m/s
Atmospheric stability	Pasquill-Gifford Class "F"
Air temperature	80°F
Relative humidity	70%
Release orientation	horizontal, with the wind
Release elevation	4 feet
Hole size	6"
Normal flowrate	Based on 32,000 bpd unit throughput

Table 1 lists the specific parameters used for each of the reactor scenarios, as well as the reactor effluent composition used in the modeling for each case.

**Table 1
Modeling Parameters**

Parameter	Existing Reactors	Modified Reactors
Effluent Temperature (°F)	720	647
Effluent Pressure (psig)	608	573
Molecular Weight	67.68	45.08
Total Reactor Volume (ft ³)	1,500	14,000
Component	Mole %	
Hydrogen	51.5471	73.2260
Hydrogen Sulfide	1.9266	2.0228
Methane	7.7806	2.4586
Ethane	3.1744	0.6520
Propane	1.5345	0.2693
n-Heptane	2.0837	--
n-Nonane	2.8194	1.2277
n-Undecane	3.7592	3.7107
Tridecane	8.4582	6.8912
Pentadecane	16.9163	7.4213
PHC-300	--	2.1204

Consequence Modeling Results

Table 2 presents the results for the reactor release scenarios. As can be seen in Table 2, the centerline of each cloud lifts off from grade, ending at some elevated level. This is a result of the buoyant nature (due to temperature and light components such as hydrogen) of the released materials. The side view plots for each release are presented in Appendix B.

Table 2
Dispersion Modeling Results

Scenario	Maximum Downwind Distance(feet) to LFL	Height (ft) of Cloud Centerline Above Grade when LFL is reached	Maximum Downwind Distance (feet) to ERPG-2 (30 ppm H₂S)	Height (ft) of Cloud Centerline Above Grade when 30 ppm H₂S is reached
Existing Reactors Effluent	260	30	655	38
Modified Reactors Effluent	275	22	940	93

APPENDIX A

CANARY BY QUEST® MODEL DESCRIPTIONS

The following model descriptions are taken from the CANARY by Quest User Manual.

Section A	Engineering Properties
Section E	Fluid Release Model
Section F	Momentum Jet Dispersion Model

Engineering Properties

Purpose

The purpose of this model is to provide an accurate means of computing physical and thermodynamic properties of a wide range of chemical mixtures and pure components using a minimum of initial information.

Required Data

- (a) Fluid composition
- (b) Temperature and pressure of the fluid prior to release

Methodology

Basic thermodynamic properties are computed using the Peng-Robinson equation of state [Peng and Robinson, 1976]. The necessary physical and thermodynamic properties are calculated in the following manner.

Step 1: The temperature and pressure of the fluid at storage conditions and the identity and mole fraction of each component of the fluid are obtained. Mixture parameters are determined using data from the extensive properties data base within CANARY.

Step 2: Each calculation begins with the computation of the vapor and liquid fluid composition. For cases where the temperature and pressure result in only one phase being present, the vapor or liquid composition will be the same as the initial feed composition. The composition calculation is an iterative procedure using a modification of the techniques described by Starling [1973].

Step 3: Once the vapor and liquid compositions are known, the vapor and liquid densities, enthalpies, entropies, and heat capacities can be computed directly. Other physical properties (viscosity, thermal conductivity, surface tension, etc.) are computed using correlations developed in Reid, Prausnitz, and Poling [1987].

Step 4: A matrix of properties is computed over a range of temperatures and pressures. Physical and thermodynamics properties required by other models within CANARY are then interpolated from this table.

Basic Thermodynamic Equations

$$Z^3 - (1 - B) \cdot Z^2 + (A - 3 \cdot B^2 - 2 \cdot B) \cdot Z - (A \cdot B - B^2 - B^3) = 0 \quad (1)$$

where: Z = fluid compressibility factor, $\frac{P \cdot V}{R \cdot T}$, dimensionless

P = system pressure, kPa

V = fluid specific volume, m³/kmol

R = gas constant, $8.314 \text{ m}^3 \cdot \text{kPa}/(\text{kmol} \cdot \text{K})$

T = absolute temperature, K

$$A = \frac{a \cdot P}{R^2 \cdot T^2}$$

$$a = 0.45724 \cdot \frac{R^2 \cdot T^2}{P_c} \cdot \alpha$$

$$\alpha = \left[1 + m \cdot (1 - T_r^{0.5})^2 \right]$$

$$m = 0.37464 + 1.54226 \cdot \omega - 0.26992 \cdot \omega^2$$

ω = acentric factor

$$T_r = \frac{T}{T_c}$$

T_c = pseudo-critical temperature, K

P_c = pseudo-critical pressure, kPa

$$B = \frac{b \cdot P}{R \cdot T}$$

$$b = 0.0778 \cdot R \cdot \frac{T_c}{P_c}$$

$$H = H^o + \frac{P}{\rho} - R \cdot T + \int_0^P \left[P - T \cdot \left(\frac{\partial P}{\partial T} \right)_\rho \right] \cdot \left(\frac{d\rho}{\rho^2} \right) \quad (2)$$

where: H = enthalpy of fluid at system conditions, kJ/kg

H^o = enthalpy of ideal gas at system temperature, kJ/kg

$$S = S^o - R \cdot \ln(\rho \cdot R \cdot T) + \int_0^P \left[\rho \cdot R - \left(\frac{\partial P}{\partial T} \right)_\rho \right] \cdot \left(\frac{d\rho}{\rho^2} \right) \quad (3)$$

where: S = entropy of fluid at system conditions, kJ/(kg·K)

S^o = entropy of ideal gas at system temperature, kJ/(kg·K)

$$R \cdot T \cdot \ln \left(\frac{f_i}{f_i^o} \right) = \left[(H_i - H_i^o) - T \cdot (S_i - S_i^o) \right] \quad (4)$$

where: f_i = fugacity of component i , kPa

f_i^o = standard state reference fugacity, kPa

References

Peng, D., and D. B. Robinson, "New Two-Constant Equation of State." *Industrial Engineering Chemistry Fundamentals*, Vol. 15, No. 59, 1976.

Reid, R. C., J. M. Prausnitz, and B. E. Poling, *The Properties of Gases and Liquids* (Fourth Edition). McGraw-Hill Book Company, New York, New York, 1987.

Starling, K. E., *Fluid Thermodynamic Properties for Light Petroleum Systems*. Gulf Publishing Company, Houston, Texas, 1973.

Fluid Release Model

Purpose

The purpose of the Fluid Release Model is to predict the rate of mass release from a breach of containment. Specifically, the model predicts the rate of flow and the physical state (liquid, two-phase, or gas) of the release of a fluid stream as it enters the atmosphere from a circular breach in a pipe or vessel wall. The model also computes the amount of vapor and aerosol produced and the rate at which liquid reaches the ground.

Required Data

- (a) Composition of the fluid
- (b) Temperature and pressure of the fluid just prior to the time of the breach
- (c) Normal flow rate of fluid into the vessel or in the pipe
- (d) Size of the pipe and/or vessel
- (e) Length of pipe
- (f) Area of the breach
- (g) Angle of release relative to horizontal
- (h) Elevation of release point above grade

Methodology

Step 1: Calculation of Initial Flow Conditions

The initial conditions (before the breach occurs) in the piping and/or vessel are determined from the input data, coupled with a calculation to determine the initial pressure profile in the piping. The pressure profile is computed by dividing the pipe into small incremental lengths and computing the flow conditions stepwise from the vessel to the breach point. As the flow conditions are computed, the time required for a sonic wave to traverse each section is also computed. The flow in any length increment can be all vapor, all liquid, or two-phase (this implies that the sonic velocity within each section may vary). As flow conditions are computed in each length increment, checks are made to determine if the fluid velocity has exceeded the sonic velocity or if the pressure in the flow increment has reached atmospheric. If either condition has been reached, an error code is generated and computations are stopped.

Step 2: Initial Unsteady State Flow Calculations

When a breach occurs in a system with piping, a disturbance in flow and pressure propagates from the breach point at the local sonic velocity of the fluid. During the time required for the disturbance to reach the upstream end of the piping, a period of highly unsteady flow occurs. The portion of the piping that has experienced the passage of the pressure disturbance is in accelerated flow, while the portion upstream of the disturbance is in the same flow regime as before the breach occurred.

To compute the flow rate from the breach during the initial unsteady flow period, a small time increment is selected and the distance that the pressure disturbance has moved in that time increment is computed using the sonic velocity profile found in the initial pressure profile calculation. The

disturbed length is subdivided into small increments for use in an iterative pressure balance calculation. A pressure balance is achieved when a breach pressure is found that balances the flow from the breach and the flow in the disturbed section of piping. Another time increment is added, and the iterative procedure continues. The unsteady period continues until the pressure disturbance reaches the upstream end of the pipe.

Step 3: Long-Term Unsteady State Flow Calculations

The long-term unsteady state flow calculations are characterized by flow in the piping system that is changing more slowly than during the initial unsteady state calculations. The length of accelerated flow in the piping is constant, set by the user input pipe length. The vessel contents are being depleted, resulting in a potential lowering of pressure in the vessel. As with the other flow calculations, the time is incremented and the vessel conditions are computed. The new vessel conditions serve as input for the pressure drop calculations in the pipe. When a breach pressure is computed that balances the breach flow with the flow in the piping, a solution for that time is achieved. The solution continues until the ending time or other ending conditions are reached.

The frictional losses in the piping system are computed using the equation:

$$h = \left(\frac{4 \cdot f \cdot L \cdot U_{ls}^2}{2 \cdot g_c \cdot D_e} \right) \quad (1)$$

where: h = head (pressure) loss, ft of fluid
 f = friction factor
 L = length of system, ft
 U = average flowing velocity, ft/sec
 g_c = gravitational constant, 32.2 lb_m · ft/(lb_f · sec²)
 D_e = equivalent diameter of duct, ft

The friction factor is computed using the following equation:

$$\frac{1}{\sqrt{f}} = 1.74 - 2.0 \cdot \log_{10} \left[\frac{2 \cdot \varepsilon}{D_e} + \frac{18.7}{Re \cdot \sqrt{f}} \right] \quad (2)$$

where: ε = pipe roughness, ft
 Re = Reynolds number, $D_e \cdot U \cdot \rho / \mu$, dimensionless
 ρ = fluid density, lb/ft³
 μ = fluid viscosity, lb/(ft · sec)

Equations (1) and (2) are used for liquid, vapor, and two-phase flow regimes. Since the piping is subdivided into small lengths, changes in velocity and physical properties across each segment are assumed to be negligible. At each step in the calculation, a check is made to determine if the fluid velocity has reached or exceeded the computed critical (sonic) velocity for the fluid. If the critical velocity has been exceeded, the velocity is constrained to the critical velocity and the maximum mass flow rate in the piping has been set.

If the fluid in the piping is in two-phase flow, the Lockhart and Martinelli [1949] modification to Equation (1) is used. The Lockhart and Martinelli equation for head loss is shown below:

$$h_{TP} = \Phi^2 \cdot \left(\frac{4 \cdot f \cdot L \cdot U_{ls}^2}{2 \cdot g_c \cdot D_e} \right) \quad (3)$$

where: h_{TP} = head loss for two-phase flow, ft of fluid

Φ = empirical parameter correlating single- and two-phase flow, dimensionless

U_{ls} = superficial liquid velocity (velocity of liquid if liquid filled the pipe), ft/sec

This equation is valid over short distances where the flowing velocity does not change appreciably.

Validation

Validation of fluid flow models is difficult since little data are available for comparison. Fletcher [1983] presented a set of data for flashing CFC-11 flowing through orifices and piping. Figures E-1 through E-4 compare calculations made using the Fluid Release Model with the data presented by Fletcher. Figure E-1 compares fluid fluxes for orifice type releases. These releases had length-to-diameter (L/D) ratios less than 0.88. Figure E-2 compares computed and experimental release fluxes for an L/D ratio of 120 at several levels of storage pressure. Figure E-3 compares similar releases for an L/D of 37.5. Figure E-4 shows predicted and experimental release fluxes at a given pressure for L/D ratios from 1 to 200.

Figures E-5 and E-6 compare computed and experimental gas discharge rates for the complete breach of two pipes. One pipe had an internal diameter of 6.2 inches (0.157 m); the other had a diameter of 12 inches (0.305 m). These pipes were initially pressurized to 1,000 psia with air and then explosively ruptured. The experimental values were reported in a research paper for Alberta Environment, authored by Wilson [1981].

Aerosols and Liquid Droplet Evaporation

Liquids stored at temperatures above their atmospheric pressure boiling point (superheated liquids) will give off vapor when released from storage. If the temperature of storage is sufficiently above the normal boiling point, the energy of the released vapor will break the liquid stream into small droplets. If these droplets are small enough, they will not settle, but remain in the vapor stream as aerosol droplets. The presence of aerosol droplets in the vapor stream changes its apparent density and provides an additional source of vapor. Droplets large enough to fall to the ground will lose mass due to evaporation during their fall.

The prediction of aerosol formation and amount of aerosol formed is based on the theoretical work performed for the Center for Chemical Process Safety (CCPS) by CREARE. CREARE's work has been extended and corrected by Quest. The extension to the model computes the non-aerosol drop evaporation. In Figure E-7, the four experimental data sets available for comparison (chlorine (Cl₂), methylamine (MMA), CFC-11, and cyclohexane) are compared to the values computed by the CANARY Aerosol Model.

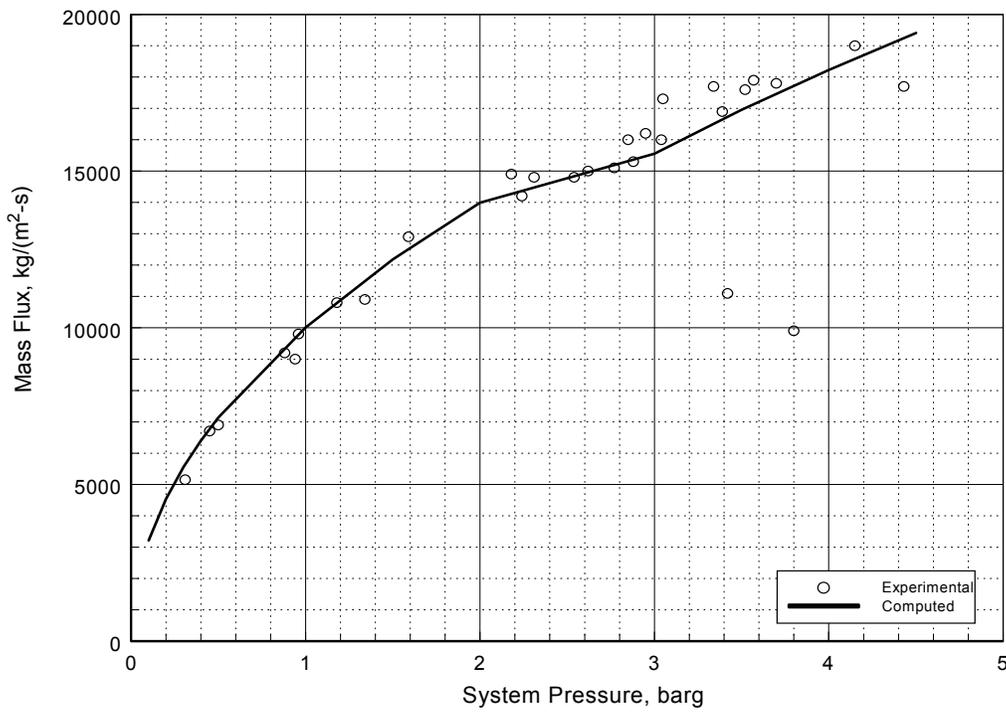


Figure E-1
Comparison of CFC-11 Orifice Releases as a Function of System Pressure

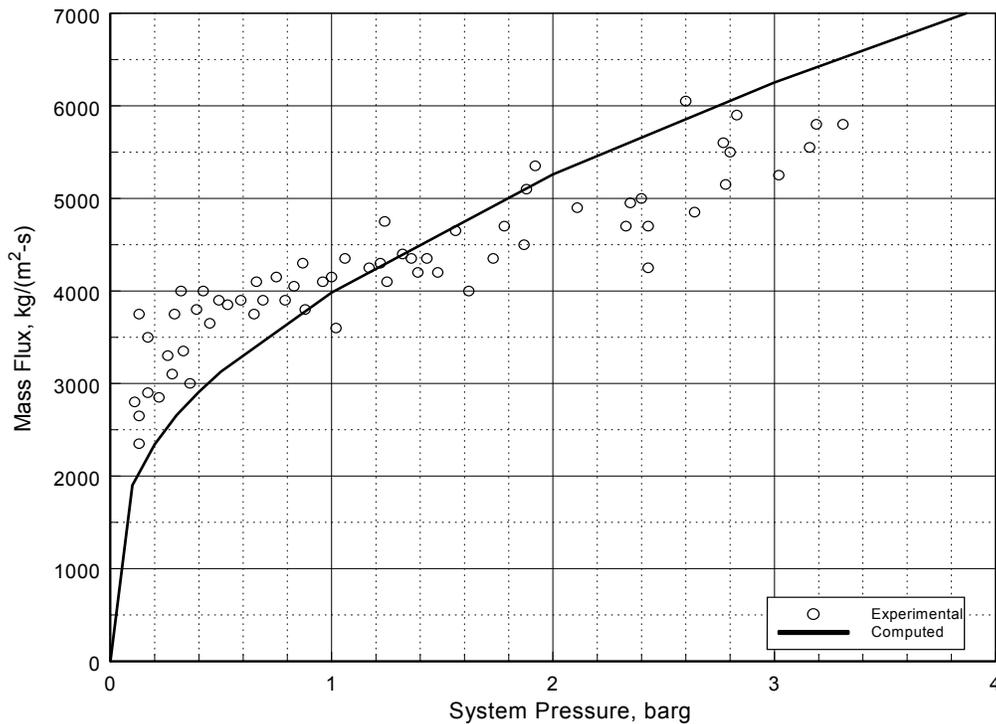


Figure E-2
CFC-11 Release Rate Comparison with L/D of 120

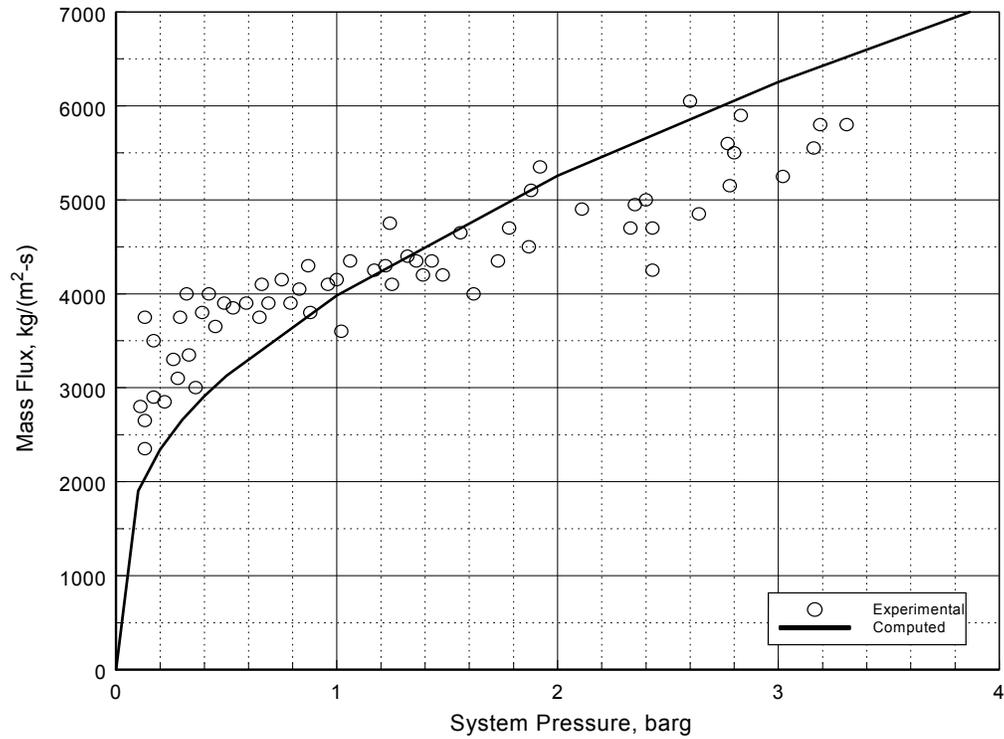


Figure E-3
CFC-11 Release Rate Comparison with L/D of 37.5

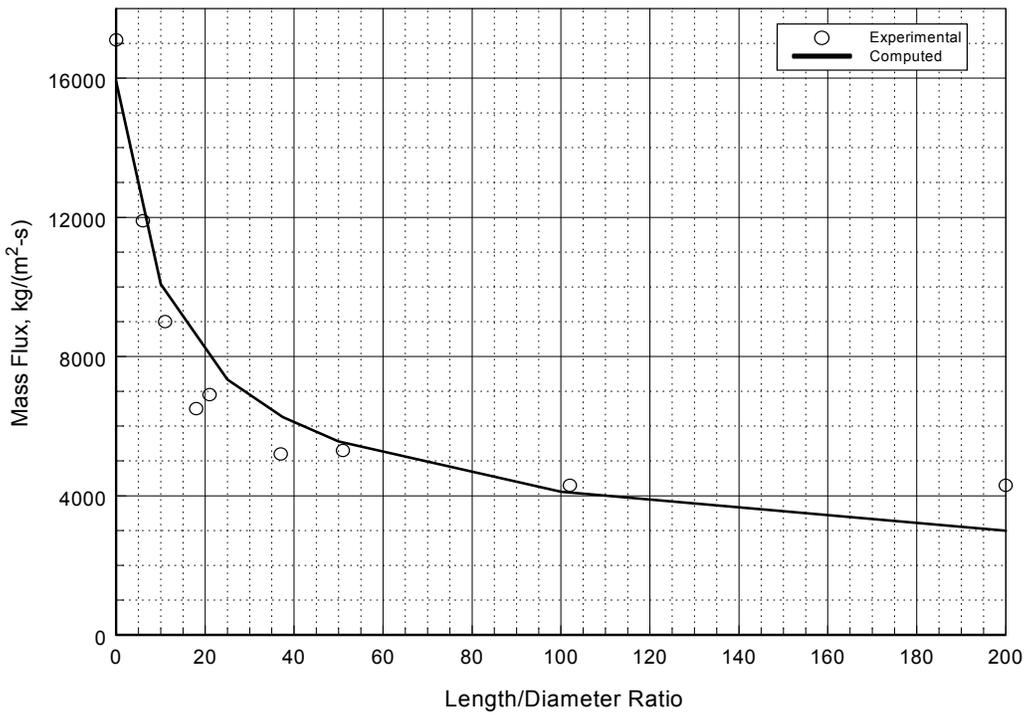


Figure E-4
CFC-11 Release Rate Comparison at Varying L/D Ratios

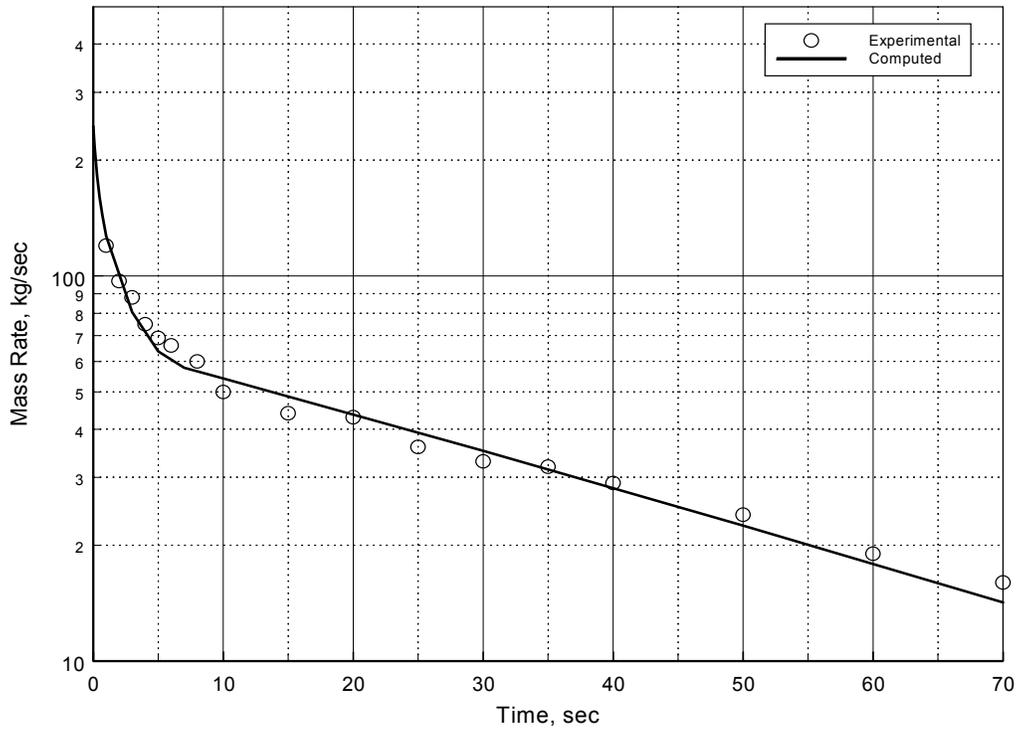


Figure E-5
Air Discharge Rates for 0.157 m Diameter Piping

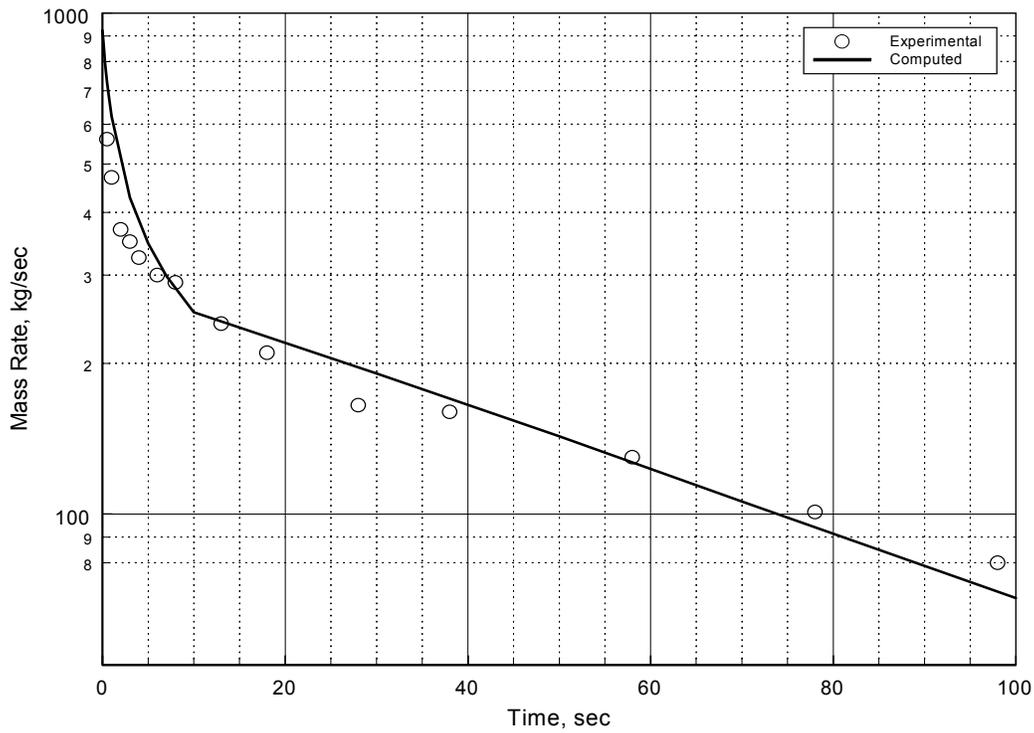


Figure E-6
Air Discharge Rates for 0.305 m Diameter Piping

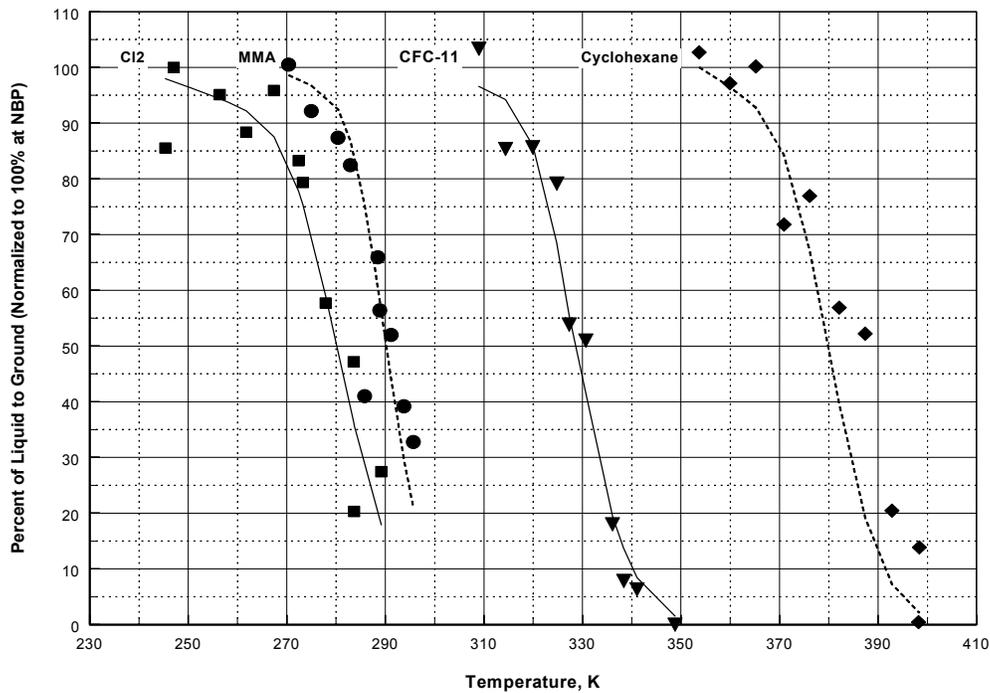


Figure E-7
Aerosol Formation as a Function of Storage Temperature

References

- Fletcher, B., "Flashing Flow Through Orifices and Pipes." Paper presented at the AIChE Loss Prevention Symposium, Denver, Colorado, 1983.
- Lockhart, R. W., and R. C. Martinelli, "Proposed Correlation of Data for Isothermal Two-Phase, Two-Component Flow in Pipes." *Chemical Engineering Progress*, Vol. 45, 1949: p. 39.
- Wilson, D. J., "Expansion and Plume Rise of Gas Jets from High Pressure Pipeline Ruptures." Research Paper, Pollution Control Division, Alberta Environment, April, 1981.

Momentum Jet Dispersion Model

Purpose

The purpose of this model is to predict the dispersion of a jet release into ambient air. It is used to predict the downwind travel of a flammable or toxic gas or aerosol momentum jet release.

Required Data

- (a) Composition and properties of the released material
- (b) Temperature of released material
- (c) Release rate of material
- (d) Vertical release angle relative to wind direction
- (e) Height of release
- (f) Release area
- (g) Ambient wind speed
- (h) Ambient Pasquill-Gifford stability class
- (i) Ambient temperature
- (j) Relative humidity
- (k) Surface roughness scale

Methodology

Step 1: An assumption is made that flow perpendicular to the main flow in the plume is negligible, that the velocity and concentration profiles in the jet are similar at all sections of the jet, that molecular transport in the jet is negligible, and that longitudinal turbulent transport is negligible when compared to longitudinal convective transport. The coordinate system is then defined in s and r , where s is the path length of the plume and r is the radial distance from the plume centerline. The angle between the plume axis and horizontal is referred to as θ . Relationships between the downwind coordinate, x , vertical coordinate, y , and plume axis are given simply by:

$$\frac{dx}{ds} = \cos(\theta) \quad (1)$$

and

$$\frac{dy}{ds} = \sin(\theta) \quad (2)$$

Step 2: Velocity, concentration, and density profiles are assumed to be cylindrically symmetric about the plume axis and are assumed to be Gaussian in shape. The three profiles are taken as:

$$u(s, r, \theta) = U_a \cdot \cos(\theta) + u^*(s) \cdot e^{\frac{-r^2}{b^2(s)}} \quad (3)$$

where: u = plume velocity, m/s
 U_a = ambient wind speed, m/s
 u^* = plume velocity relative to the wind in the downwind direction at the plume axis, m/s
 $b(s)$ = characteristic width of the plume at distance s from the release, m

$$\rho(s, r, \theta) = \rho_a + \rho^*(s) \cdot e^{\frac{-r^2}{\lambda^2 \cdot b^2(s)}} \quad (4)$$

where: ρ = plume density, kg/m³
 ρ_a = density of ambient air, kg/m³
 $\rho^*(s)$ = density difference between plume axis and ambient air, kg/m³
 λ^2 = turbulent Schmidt number, 1.35

$$c(s, r, \theta) = c^*(s) \cdot e^{\frac{-r^2}{\lambda^2 \cdot b^2(s)}} \quad (5)$$

where: c = pollutant concentration in the plume, kg/m³
 $c^*(s)$ = pollutant concentration at plume centerline, kg/m³

Step 3: The equation for air entrainment into the plume and the conservation equations can then be solved. The equation for air entrainment is:

$$\begin{aligned} \frac{d}{ds} \left(\int_0^{b\sqrt{2}} \rho \cdot u \cdot 2 \cdot \pi \cdot dr \right) \\ = 2 \cdot \pi \cdot b \cdot \rho_a \cdot \{ \alpha_1 \cdot |u^*(s)| + \alpha_2 \cdot U_a \cdot |\sin(\theta)| \cos(\theta) + \alpha_3 \cdot u' \} \end{aligned} \quad (6)$$

where: α_1 = entrainment coefficient for a free jet, 0.057
 α_2 = entrainment coefficient for a line thermal, 0.5
 α_3 = entrainment coefficient due to turbulence, 1.0
 u' = turbulent entrainment velocity (root mean square of the wind velocity fluctuation is used for this number), m/s

Step 4: The equations of conservation of mass, momentum, and energy are given as:

$$\frac{d}{ds} \left(\int_0^{b\sqrt{2}} c \cdot u \cdot 2 \cdot \pi \cdot dr \right) = 0 \quad (7)$$

$$\begin{aligned} \frac{d}{ds} \left(\int_0^{b\sqrt{2}} (\rho \cdot u^2 \cdot \cos(\theta)) \cdot 2 \cdot \pi \cdot dr \right) \\ = 2 \cdot \pi \cdot b \cdot \rho_a \cdot \{ \alpha_1 \cdot |u^*(s)| + \alpha_2 \cdot U_a \cdot |\sin(\theta)| \cdot \cos(\theta) + \alpha_3 \cdot u' \} \\ + C_d \cdot \pi \cdot b \cdot \rho_a \cdot U_a^2 |\sin(\theta)| \end{aligned} \quad (8)$$

$$\begin{aligned} \frac{d}{ds} \left(\int_0^{b\sqrt{z}} \rho \cdot u^2 \cdot \cos(\theta) \cdot 2 \cdot \pi \cdot dr \right) & \quad (9) \\ = \int_0^{b\sqrt{z}} g \cdot (\rho_a - \rho) \pi \cdot r \cdot dr \pm C_d \cdot \pi \cdot b \cdot \rho_a \cdot U_a^2 \cdot \sin(\theta) \cdot \cos(\theta) \end{aligned}$$

$$\begin{aligned} \frac{d}{ds} \left(\int_0^{b\sqrt{z}} \rho \cdot u \left(\frac{1}{\rho} - \frac{1}{\rho_{a0}} \right) \cdot 2 \cdot \pi \cdot r \cdot dr \right) & \quad (10) \\ = \rho_a \cdot 2 \cdot \pi \cdot b \left(\frac{1}{\rho_a} - \frac{1}{\rho_{a0}} \right) \cdot \left\{ \alpha_1 \cdot |u^*(s)| + \alpha_2 \cdot U_a \sin(\theta) \cdot \cos(\theta) + \alpha_3 \cdot \dot{u} \right\} \end{aligned}$$

The subscript 0 refers to conditions at the point of release. These equations are integrated along the path of the plume to yield the concentration profiles as a function of elevation and distance downwind of the release.

Step 5: After the steady-state equations are solved, an along-wind dispersion correction is applied to account for short-duration releases. This is accomplished using the method outlined by Palazzi, et al. [1982].

Step 6: If the plume reaches the ground, it is coupled to the Heavy Gas Dispersion Model (described in Section G) and the dispersion calculations continue.

Validation

The Momentum Jet Dispersion Model used in CANARY was validated by comparing results obtained from the model with experimental data from field tests. Data used for this comparison and the conditions used in the model were taken from an American Petroleum Institute (API) study [Hanna, Strimaitis, and Chang, 1991]. For this model, comparisons were made with the Desert Tortoise, Goldfish, and Prairie Grass series of dispersion tests. Results of these comparisons are shown in Figure F-1.

References

- Astleford, W. J., T. B. Morrow, and J. C. Buckingham, *Hazardous Chemical Vapor Handbook for Marine Tank Vessels* (Final Report – Phase II). U.S. Coast Guard Report No. CG-D-12-83, April, 1983.
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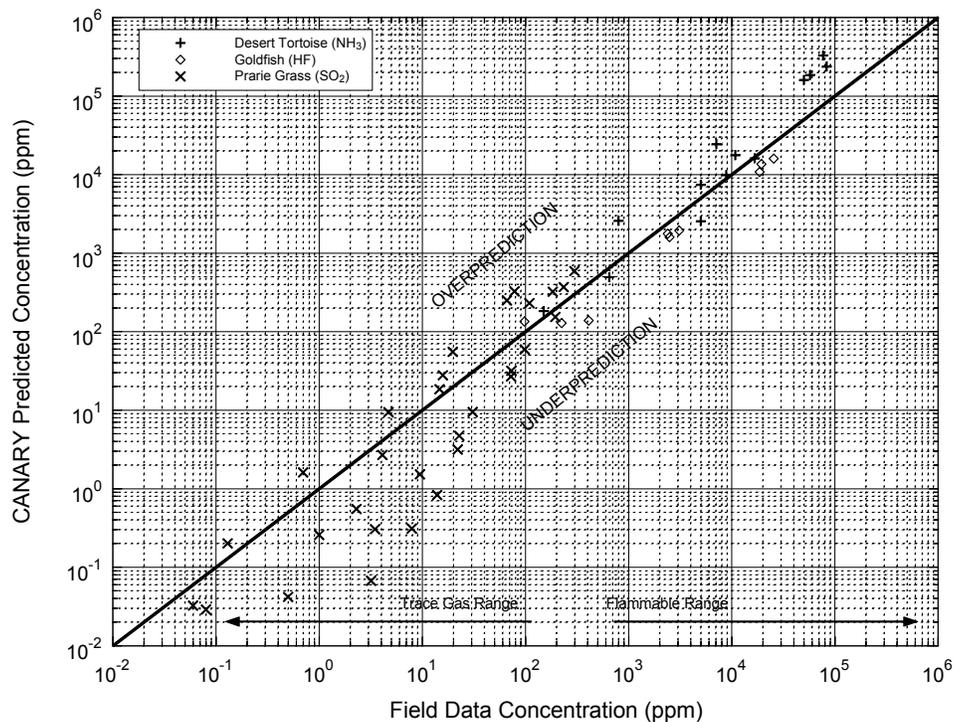


Figure F-1

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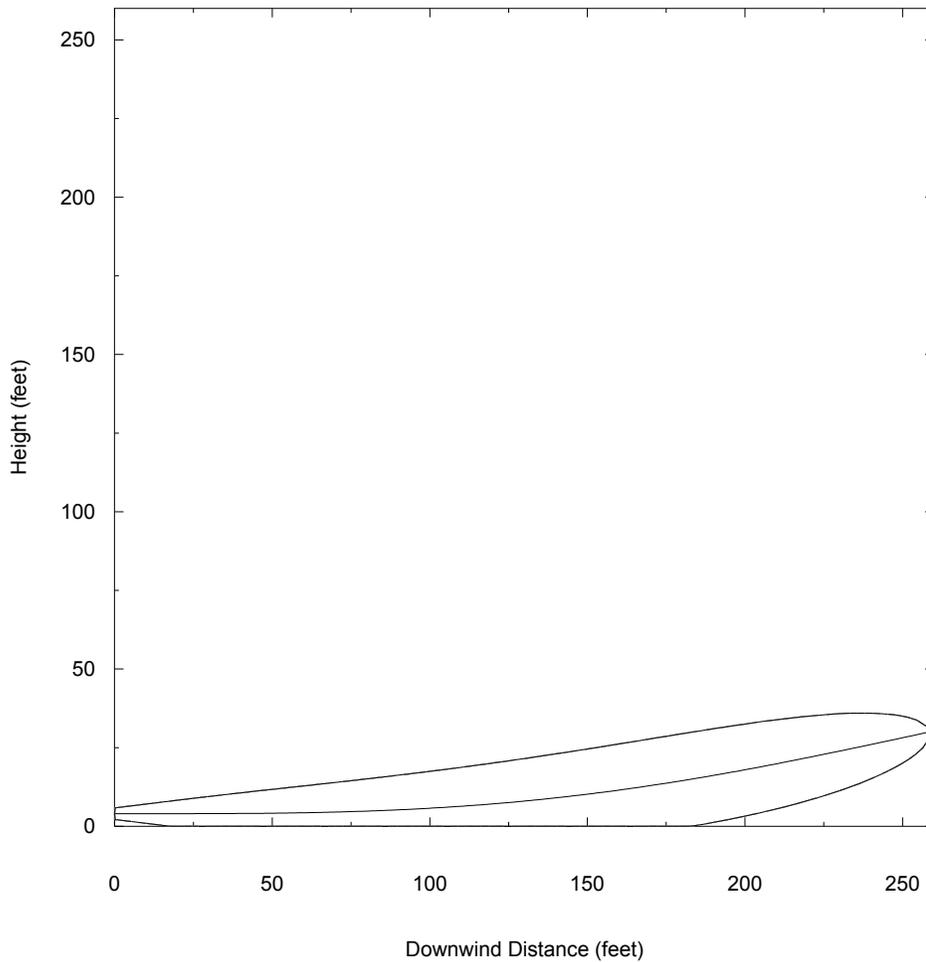
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APPENDIX B
SIDE VIEW PLOTS FOR EACH RELEASE

CONCENTRATION CONTOURS: SIDE VIEW

Momentum Jet Cloud

ULSD Reactor Release - Existing Design



- 1.29 mole percent
- 1.29 mole percent
- - - - 1.29 mole percent

casename=rx_e_vf

windspeed = 3.4 mph

F stability

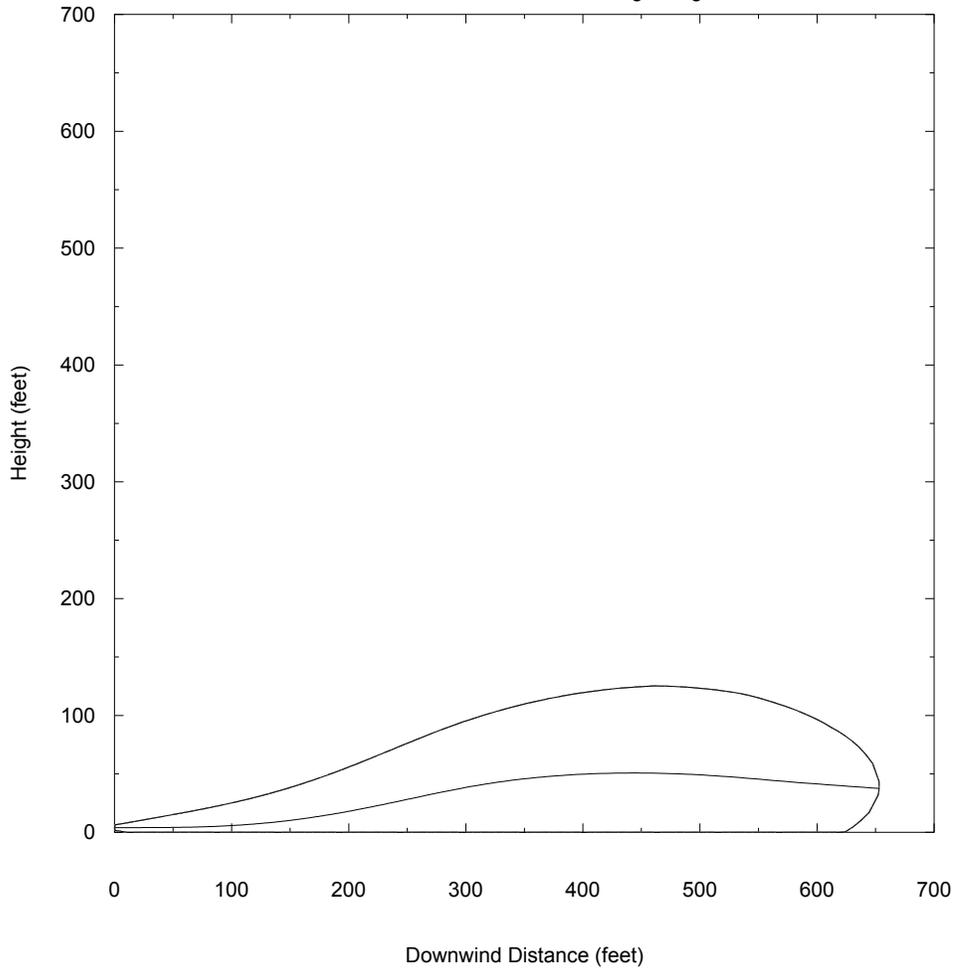
CANARY by Quest

Thu Nov 06 14:36:56 2003

CONCENTRATION CONTOURS: SIDE VIEW

Momentum Jet Cloud

ULSD Reactor Release - Existing Design



- 30.0 ppm Hydrogen Sulfide
- 30.0 ppm Hydrogen Sulfide
- - - - 30.0 ppm Hydrogen Sulfide

casename=rx_e_vt

windspeed = 3.4 mph

F stability

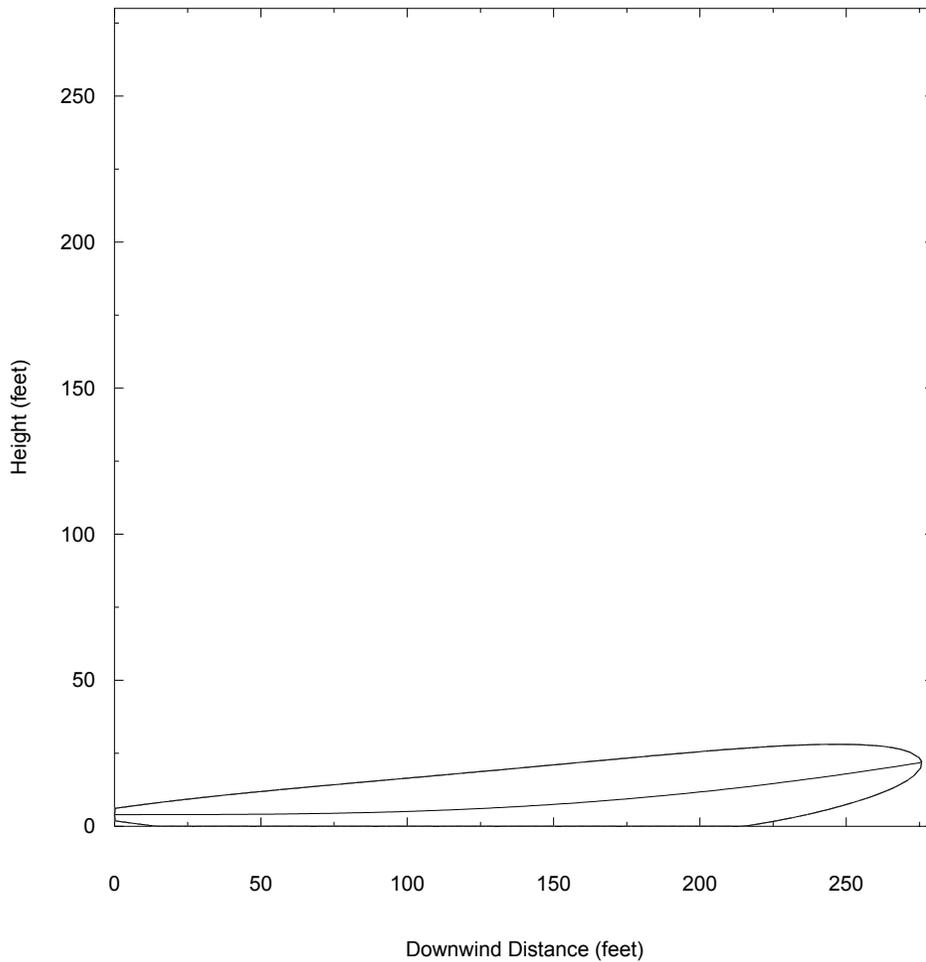
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Thu Nov 06 14:41:25 2003

CONCENTRATION CONTOURS: SIDE VIEW

Momentum Jet Cloud

ULSD Reactor Release - Modified Design



—— 1.79 mole percent
- - - 1.79 mole percent
..... 1.79 mole percent

casename=rx_m_vf
windspeed = 3.4 mph
F stability

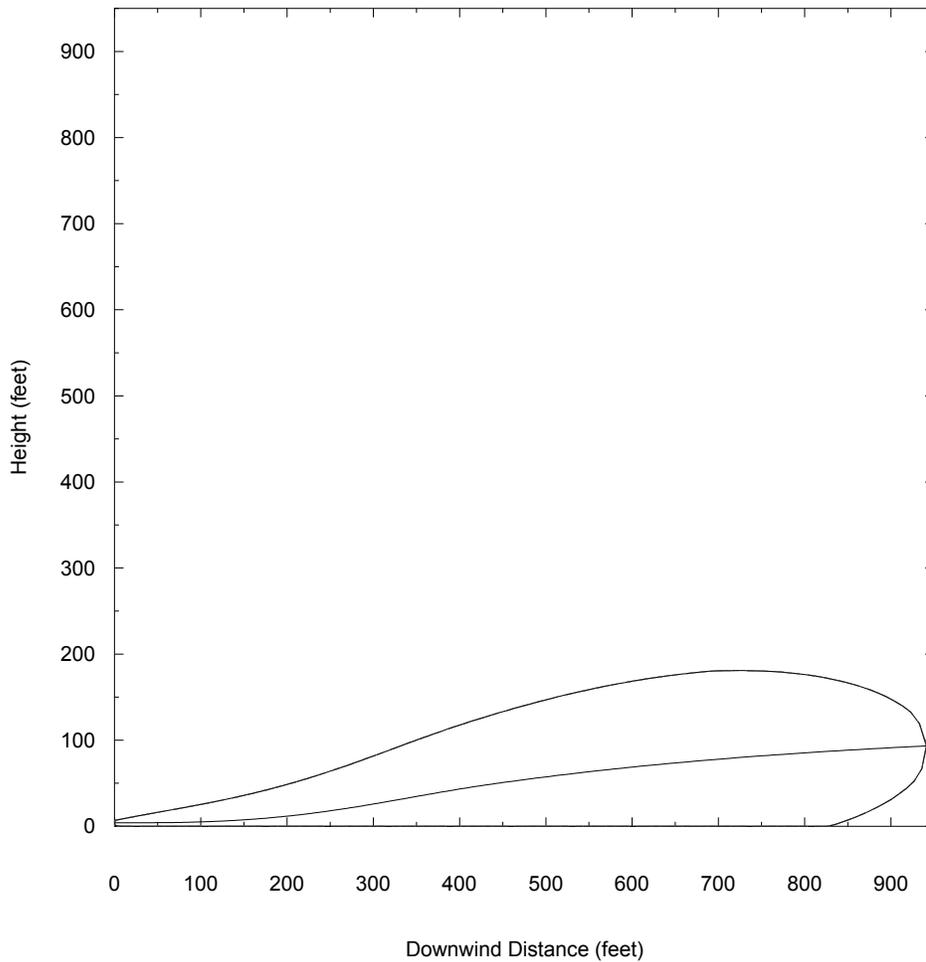
CANARY by Quest

Fri Nov 07 15:24:09 2003

CONCENTRATION CONTOURS: SIDE VIEW

Momentum Jet Cloud

ULSD Reactor Release - Modified Design



- 30.0 ppm Hydrogen Sulfide
- 30.0 ppm Hydrogen Sulfide
- - - - 30.0 ppm Hydrogen Sulfide

casename=rx_m_vt

windspeed = 3.4 mph

F stability

CANARY by Quest

Fri Nov 07 15:13:16 2003