



Consequence Modeling and PSM



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Consequence Modeling

The use of models to predict the nature and extent of injury to persons and damage to buildings and equipment that could be caused by a loss of Containment.

Consequence Models & Methodology

- Equations and calculations
- Graphical
- Computer Programs
 - Excel Based
 - Integrated Program, with Subroutines
 - Single Hazard Program
- Dispersion
 - Accidental Release
 - Air Quality, (Gaussian)

Hazards from Loss of Containment

■ Explosions

- Vapor Cloud Explosion
- Pressure Vessel Burst
- Dust
- Confined Explosion
- Chemical

■ Fire

- Jet Fire
- Pool Fire
- Flash Fire
- Flares
- BLEVE , (Boiling Liquid Expanding Vapor Explosion)

Hazards from Loss of Containment

- Toxic Release
 - Hydrogen Sulfide
 - Ammonia
 - Chlorine
 - Combustion Byproducts
 - Particulate Matter
 - Air Quality – SO_x, NO_x

Use & Purpose of Consequence Modeling

■ Project Design

- Risk management and reduction
- Plant Layout:
 - ▶ Vents and PSV's
 - ▶ Flares
- Building Siting

■ Risk Assessments

- Qualitative
- Quantitative, (QRA's)

Use & Purpose of Consequence Modeling

- Regulatory:
 - EPA Risk Management Plan, (RMP)
 - OSHA PSM – Facility Siting
 - UK, Europe, & Australia Safety Case
- Inherently Safer Design
- Emergency Response Procedures
- Operating Procedures
- Maintenance Procedures
- Company Policy

Use & Purpose of Consequence Modeling: Facility Siting Assessments



- API RP-752 & RP-753, (Permanent & Portable Buildings)
 - Refineries, Gas Plants, and Chemical Plants
 - Methodology for managing risks to personnel in occupied buildings that could result from releases in process units
 - Hazards Include:
 - ▶ Explosion
 - ▶ Fire
 - ▶ Toxic Releases
 - Consequence or Risk Based Analysis

Potential Sources of Releases

Rupture, puncture, leak or hole in:

- Pressure Vessels
- Equipment:
 - Pipes
 - Pumps
 - Compressors
- Flares, Vents, PSVs
- Valves, Gaskets, Seals, Flanges, Bleeders

Potential Sources of Releases

■ Transportation Vehicles:

- Trucks
- Railcars
- Ships

■ Pipelines:

- Above ground
- Below ground
- Subsea

Model Capabilities & Considerations

- Thermodynamics
 - Multi-Component
- Release Rate Prediction
- Aerosol Effects
- Weather Conditions
- Pool Evaporation
- Surface Roughness

Model Capabilities & Considerations

- Hazards:
 - Explosion
 - Fire
 - Dispersion – Toxics & Flammables
 - Flares: Radiant Heat
- Model Validation
- Accidental versus Air Quality Model

Explosion Modeling: Factors

- Energy Term
- Congestion
- Confinement
- Fuel Reactivity
- Ignition Strength
- Shielding and Channeling Effects
- Venting of Overpressure Buildup
- Deflagration versus Detonation

Explosion Models

- Baker Strehlow
- TNO Multi-Energy
- TNT
- CAM
- SCOPE
- Computation Fluid Dynamics, (CFD)
 - FLACS
 - EXSIM
 - AutoReaGas

(Note: Some models are proprietary)

Dispersion Models

- Accidental Releases:
 - Canary, (Quest Consultants)
 - PHAST, (DNV)
 - SAFER TRACE, (SAFER Systems)
- Air Quality:
 - AERMOD
 - Screen3
 - ISCST3
 - Many Others
- First Responders:
 - ALOHA
 - CAMEO

Endpoint or Concentration Criteria

■ Flammable Gas Dispersion

- Lower Flammable Limit, (LFL)
- Upper Flammable Limit, (UFL)

Substance	LFL	UFL
Methane	5%	15%
Propane	2.1%	9.5%
Hydrogen	4%	75%

■ Criteria to Keep From Potential Ignition Sources:

- 20-50% LFL

Toxic Endpoint Criteria

- ERPG: Emergency Response Planning Guidelines
 - ERPG-1, 2, 3: (1) Hour Exposure
 - ▶ Minor Health Effects, (max)
 - ▶ Serious Health Effects, (max limit, without experiencing)
 - ▶ Life-Threatening Effects, (max limit, without experiencing)

- AEGL: Acute Exposure Guideline Levels
 - AEGL 1, 2, 3
 - (10) min to (8) hr Exposure Duration
 - Similar to ERPG Health Effects Definitions

Toxic Endpoint Criteria

- IDLH: Immediate Dangerous Limit or Health
- TLV & STEL: Worker Exposure
 - Threshold Limit Value, Short-Term Exposure Limit
 - 8 hour and 15 min
- Dosage & Probits
 - Exposure Time & Concentration
 - Fatality rates
 - Can be used in QRA's

Hydrogen Sulfide Endpoint Criteria, (ppm)

- ERPG-1: 0.1ppm
- ERPG-2: 30 ppm
- ERPG-3: 100 ppm

- AEGL-1: 0.51ppm, (1 hour)
- AEGL-2: 27 , (1 hour)
- AEGL-3: 50 , (1 hour)

- IDLH:100 ppm
- TLV:1 ppm
- STEL:5 ppm
- 1% Fatality for (1) Hour Exposure:160 ppm*

* - Perry and Articola - CCPS 1980

Radiant Heat Endpoint Criteria

- Jet, Pool Fires, & Flares
- API 521 Flare Design Criteria: (max)
 - 500 Btu/hr-ft²: Continuous exposure for personnel
 - 1500 Btu/hr-ft²: Personnel Exposure only for several minutes
 - 2000 Btu/hr-ft²: Personnel Exposure only for 1 minute

Example of Dispersion Modeling Predictions, (Canary 4.4)



Scenario	Weather Conditions	Distance to LFL, (ft)	Distance to 20% LFL, (ft)

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Scenario	Weather Conditions	Distance to LFL, (ft)	Distance to 20% LFL, (ft)
1/2" Hole, Methane at 50 psig	Sunny Day 10 mph wind	3	7

Example of Dispersion Modeling Predictions, (Canary 4.4)



Scenario	Weather Conditions	Distance to LFL, (ft)	Distance to 20% LFL, (ft)
1/2" Hole, Methane at 50 psig	Sunny Day 10 mph wind	3	7
1/2" Hole, Methane at <u>200 psig</u>	Sunny Day 10 mph wind	5.6	13

Example of Dispersion Modeling Predictions, (Canary 4.4)



Scenario	Weather Conditions	Distance to LFL, (ft)	Distance to 20% LFL, (ft)
1/2" Hole, Methane at 50 psig	Sunny Day 10 mph wind	3	7
1/2" Hole, Methane at 200 psig	Sunny Day 10 mph wind	5.6	13
1/2" Hole, <u>Propane</u> at 200 psig	Sunny Day 10 mph wind	20	130



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Scenario	Weather Conditions	Distance to LFL, (ft)	Distance to 20% LFL, (ft)
1/2" Hole, Methane at 50 psig	Sunny Day 10 mph wind	3	7
1/2" Hole, Methane at 200 psig	Sunny Day 10 mph wind	5.6	13
1/2" Hole, Propane at 200 psig	Sunny Day 10 mph wind	20	130
<u>2" Hole, Propane at 200 psig</u>	Sunny Day 10 mph wind	500	1100

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Scenario	Weather Conditions	Distance to LFL, (ft)	Distance to 20% LFL, (ft)
1/2" Hole, Methane at 50 psig	Sunny Day 10 mph wind	3	7
1/2" Hole, Methane at 200 psig	Sunny Day 10 mph wind	5.6	13
1/2" Hole, Propane at 200 psig	Sunny Day 10 mph wind	20	130
2" Hole, Propane at 200 psig	Sunny Day 10 mph wind	500	1100
2" Hole, Propane at 200 psig	<u>Night</u> <u>5 mph wind</u>	900	2000

References for Information

- CCPS: "Guidelines for Consequence Analysis of Chemical Releases"
- CCPS: "Guidelines for Vapor Cloud Explosions, Pressure Vessel Burst, BLEVE and Flash Fire Hazards"
- CCPS: "Guidelines for Chemical Process Quantitative Risk Analysis"
- API 752: "Management of Hazards Associated with Location of Process Plant Permanent Buildings"
- API 521: "Guide for Pressure-relieving and Depressuring Systems"
- Lee's Loss Prevention in the Process Industry

Questions ?