Consequence Modeling and PSM

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Consequence Modeling

The use of models to assess the potential for injury to persons and damage to buildings and equipment that could result from a Loss of Containment.

Potential Hazards from Loss of Containment

- Explosions
- Fire
- Flammable Cloud
- Toxic Cloud

Potential 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)

Potential Hazards from Loss of Containment

- Toxic Release
  - Hydrogen Sulfide
  - Ammonia
  - Chlorine
  - Combustion Byproducts
  - Particulate Matter
  - Air Quality – SOx, NOx

Consequence Models & Methodology

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

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 potential risks to personnel in occupied buildings that could result from releases in process units
  - Possible 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
- Aerosol Effects
- Weather Conditions
- Pool Evaporation
- Surface Roughness

Model Capabilities & Considerations

- Possible 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
  - Potential 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-ft^2: Continuous exposure for personnel
  - 1500 Btu/hr-ft^2: Personnel Exposure only for several minutes
  - 2000 Btu/hr-ft^2: Personnel Exposure only for 1 minute

Example of Dispersion Modeling, (Canary 4.4)

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

Example of Dispersion Modeling, (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

Example of Dispersion Modeling, (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**

Example of Dispersion Modeling, (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, Propane at 200 psig	**Sunny Day 10 mph wind**	**20**	**130**

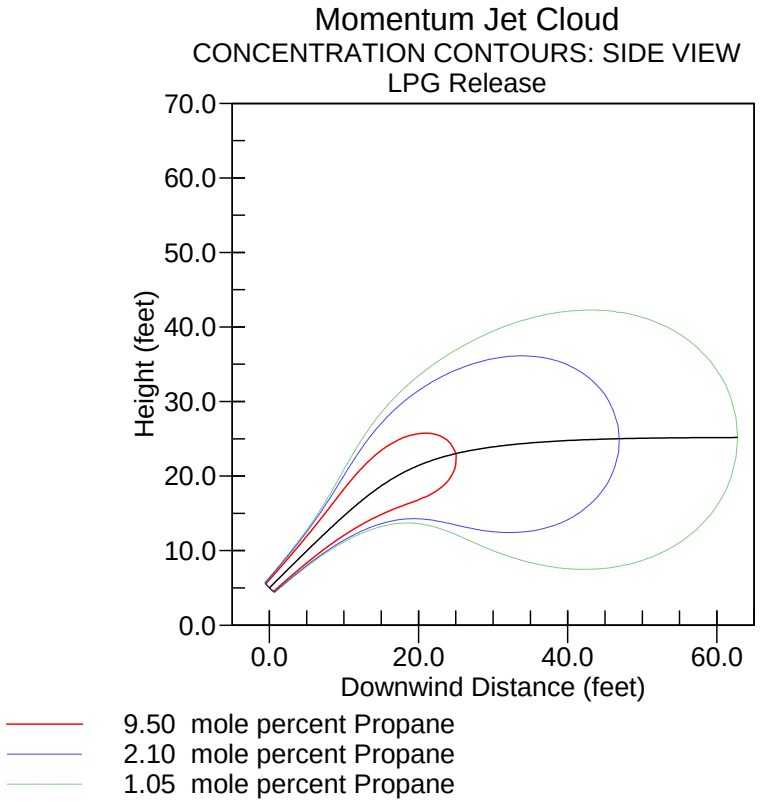
Example of Dispersion Modeling, (Canary 4.4)

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, Propane at 200 psig	Sunny Day 10 mph wind	20	130
2” Hole, Propane at 200 psig	**Sunny Day 10 mph wind**	**500**	**1100**

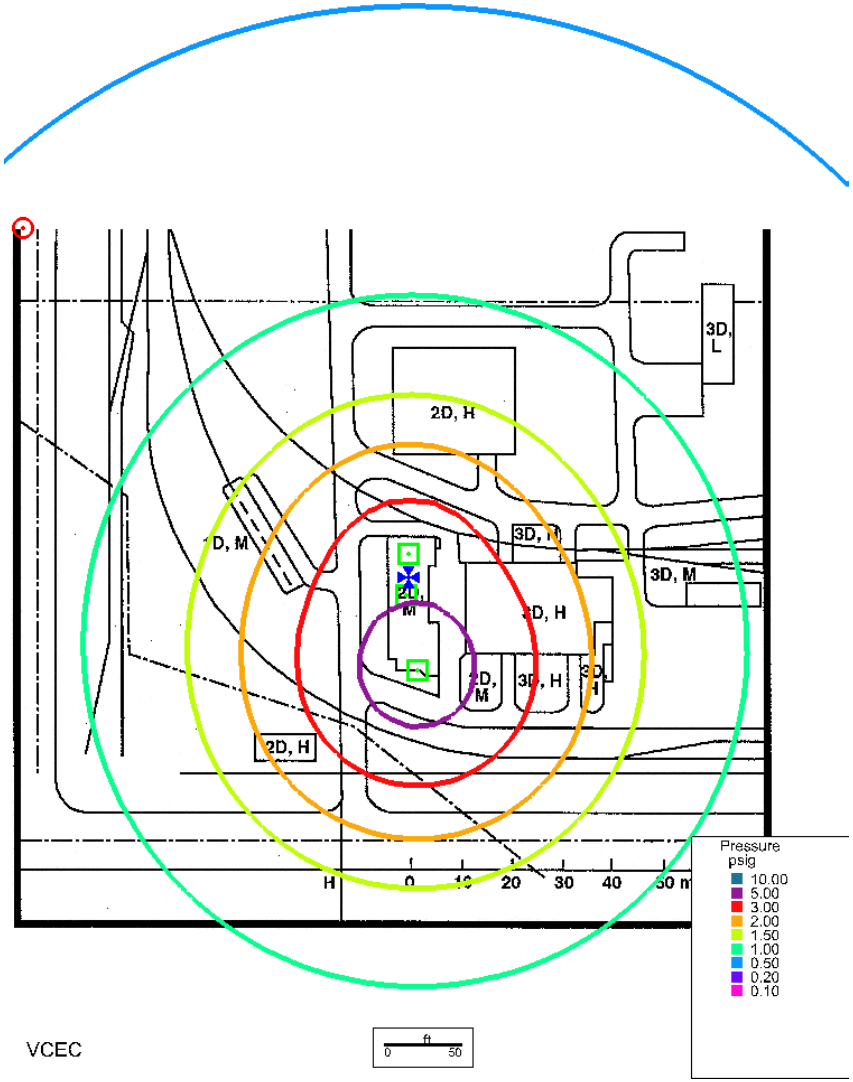
Example of Dispersion Modeling, (Canary 4.4)

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, 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	**Night 5 mph wind**	**900**	**2000**

Example of Dispersion Model Output



Example of Explosion Model Output



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

CCPS: "Guidelines for Consequence Analysis of Chemical Releases" - Equations, Graphs & Excel Spreadsheets

- Liquid Discharge through a Piping System
- Gas Discharge through a Hole
- Pool Evaporation
- Vapor Cloud Explosion Model
- Overpressure from a Ruptured Vessel
- Range of a Fragment in Air

CCPS: "Guidelines for Consequence Analysis of Chemical Releases" - Equations, Graphs & Excel Spreadsheets

- BLEVE Thermal Flux
- BLEVE Blast Fragments
- Overpressure from a Combustion in a Vessel
- Radiation from a Burning Pool
- Radiant Flux from a Jet Fire
- Thermal Flux Dosage Fatality Estimate

Use of Consequence Modeling in PSM: Summary

- Identify Potential Hazards:
  - PHA's
  - Review of plant & drawings
- Estimate Potential Impact & Hazard
- Understand why modeling is needed
- Use to improve/determine design basis
- Mitigation Options
- Procedures and Emergency Response

Use of Consequence Modeling in PSM: Other Issues

- Know what models and methods are available
- Understand limits & boundaries of models
- Understand accuracy and sensitivities of model
- Understand what data is needed to run analysis
- Determine most appropriate model to use
- Understand that models only provide estimates

Questions ?