Combustible Gas Issues in Nuclear Safety Panel Discussion

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Background & Purpose

- Worked at Savannah River Site (‘90-’99)
- Focus on flammability and explosion issues
- Consulted for other DOE sites, including Hanford issues (expert panels)
- At BakerRisk since ’99
  - Focus on commercial clients
  - Accident investigation and explosion testing
- Highlight several differences between DOE & commercial approaches for vapor cloud explosions

Outline

- Vapor cloud explosion (VCE) blast load modeling
  - Simplified methods
  - Computational fluid dynamics (CFD)
- Deflagration-to-detonation transition (DDT) in external VCEs
  - Testing and predictive methods
  - Detonation wave propagation and consequences
- Consequence vs. probabilistic methods
- Industry guidance (US)

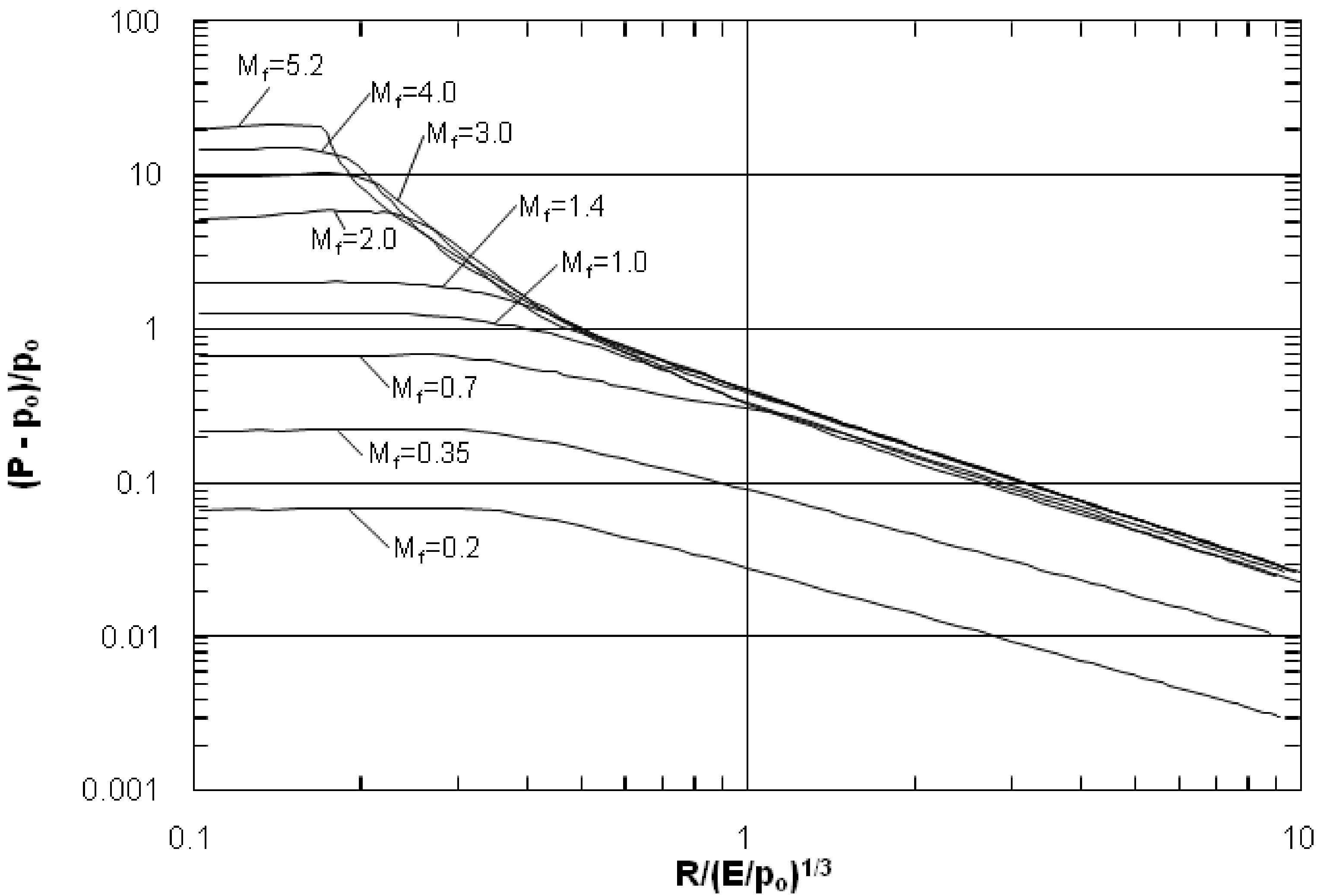
VCE Blast Load Modeling (1 of 7)

- Simplified VCE blast load modeling
  - Based on blast load curves (constant flame speed, hemispherical gas cloud)
  - Only congested/confined regions contribute
  - Main examples are Baker-Strehlow-Tang (BST) and TNO Multi-energy Method (TNO MEM)
- Advantages
  - Relatively easy to apply
  - Can provide acceptable accuracy, particularly outside congested volume (e.g., control rooms)
  - Can integrate into consequence assessment codes (dispersion, blast, building damage)

VCE Blast Load Modeling (2 of 7)

- Disadvantages
  - Assignment of flame speed subject to uncertainty
    - Need to tie back to relevant test data
    - Congestion and confinement levels
    - Gas mixture reactivity
    - Scale
  - Treatment of regions with multiple flame speeds
    - Actual plant geometries have variable levels of congestion and/or confinement
  - Criteria as to whether adjacent congested volumes constitute separate explosions

VCE Blast Load Modeling (3 of 7)



Ref: "Guidelines for Vapor Cloud Explosion, Pressure Vessel Burst, BLEVE and Flash Fire Hazards," Fig. 6.43, p. 190

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VCE Blast Load Modeling (4 of 7)

- Published BST flame speed table, scaled for typical processing plant dimensions

Confinement	Reactivity	Congestion		
		Low	Medium	High
2-D	High	0.59	DDT	DDT
	Medium	0.47	0.66	1.6
	Low	0.079	0.47	0.66
2.5-D	High	0.47	DDT	DDT
	Medium	0.29	0.55	1.0
	Low	0.053	0.35	0.50
3-D	High	0.36	DDT	DDT
	Medium	0.11	0.44	0.50
	Low	0.026	0.23	0.34

VCE Blast Load Modeling (5 of 7)

- Typical VCE test to derive flame speed
- Test for Explosion Research Cooperative (ERC)

VCE Blast Load Modeling (6 of 7)

- Computational fluid dynamics (CFD)
  - FLACS is most widely accepted commercial code (GexCon)
  - Others available in past & currently under development
- Advantages
  - More sophisticated approach
  - Can treat actual congestion and confinement present rather than approximating to “typical” values over large volumes
  - Directly treat flame acceleration / deceleration

VCE Blast Load Modeling (7 of 7)

- Disadvantages
  - Commercial codes capable of treating typical process units utilize large computational cell size (e.g., 1 meter) and utilize sub-grid models
    - Large dimensions & multiple scenarios
  - Uncertainty when applying to geometries and conditions not part of validation data base
    - Large flame travel distances can be problematic
  - Requires detailed solid model of congested volume (e.g., process unit)
    - All solid objects (> roughly one inch)

External VCE DDT (1 of 5)

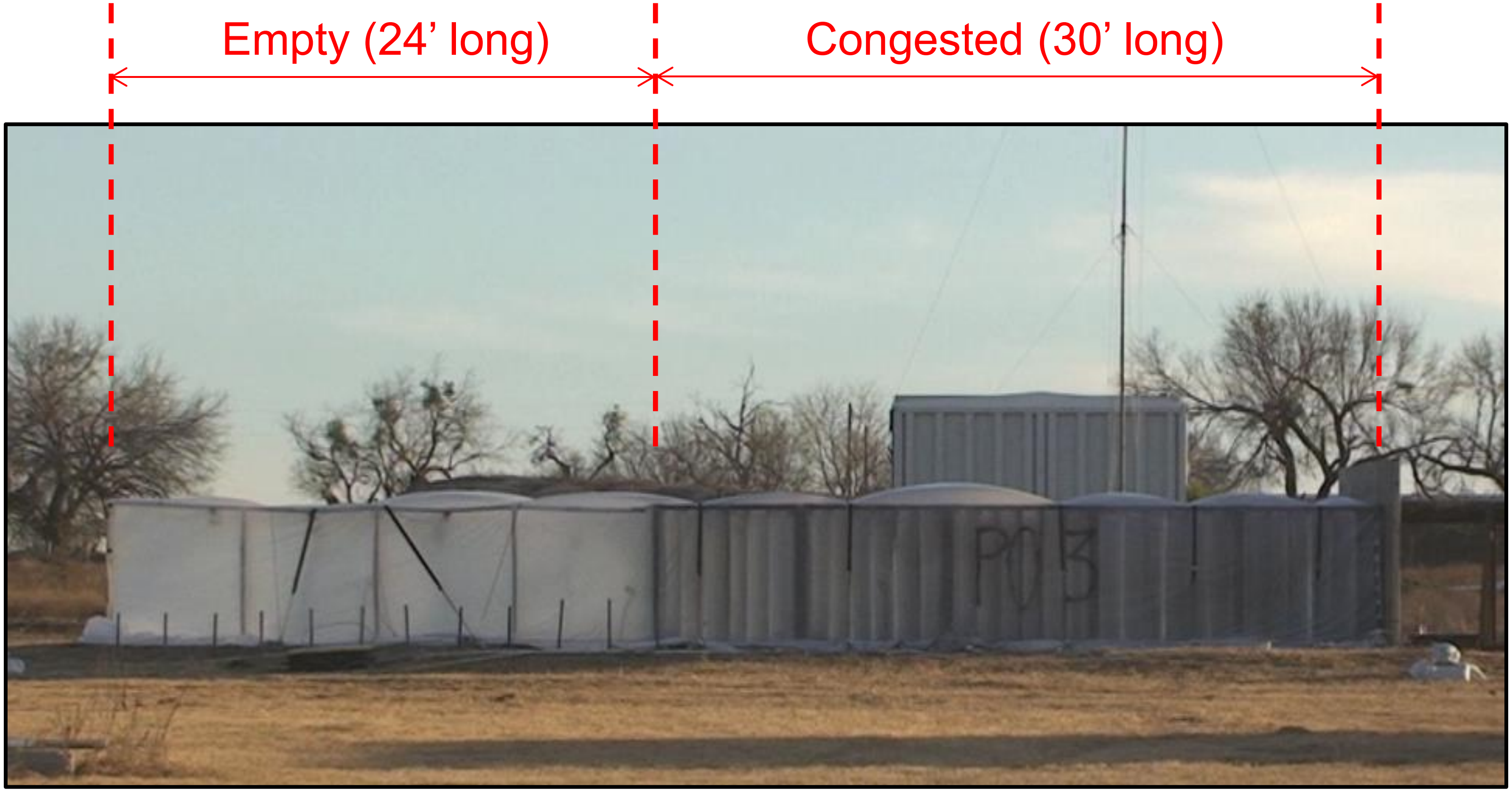
- DDT in external VCE can significantly increase blast load (very relevant for H_2)
  - Outside congested volume, significant only if cloud extends beyond congested volume
    - Deflagration > flash fire outside congested vol.
    - Detonation > propagates outside congested vol.
- Testing
  - Attempt to define conditions likely to trigger a DDT (congestion, confinement, reactivity)
  - Have shown would be expected with high reactivity fuels under relevant conditions

External VCE DDT (2 of 5)

- Lean (22%) hydrogen at medium congestion level without confinement (internal research)

External VCE DDT (3 of 5)

- Detonation propagation (normal speed video)
- Ethylene, medium cong., no conf. (internal research)



External VCE DDT (4 of 5)

- Detonation propagation (high speed video)
- Ethylene, medium cong., no conf. (internal research)

External VCE DDT (5 of 5)

- Predictive methods
  - Simplified methods
    - Definition of congestion / confinement / reactivity level combinations likely to trigger a DDT
  - CFD methods (commercial codes)
    - Definition of key parameters where exceeding critical value indicates DDT likely
    - Pressure gradient
    - Flame speed
  - Area of active development and debate within industry due to several recent accidental VCEs which may have involved DDT

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Consequence vs. QRA (1 of 2)

- Few QRAs for on-shore plants a decade ago
  - Availability of efficient tools and cost were main issues
  - Consequence-based studies used relatively small release sizes so that predicted blast loads were tolerable (i.e., could be accepted or mitigated)
  - QRAs gained acceptance for off-shore facilities
- QRAs now being routinely performed on-shore
  - Efficient and cost-effective tools
  - Push to use much larger release sizes in consequence studies yields significantly higher blast loads
  - Consideration of DDT can yield much higher blast loads
  - Pure consequence results may be difficult to mitigate

Consequence vs. QRA (2 of 2)

- Relative to VCE blast load, QRAs may consider:
  - Release scenario (release frequency, size & duration)
  - Meteorological conditions (class, wind speed & direction)
  - Ignition (conditional probability & location)
  - Explosion severity (e.g., likelihood of DDT, likelihood of propagation into cloud external to congested volume)
- QRAs can be used to:
  - Prioritize prevention and mitigation actions
    - Significant where consequence-based study identifies numerous such actions required
  - Ensure selected actions provide acceptable level of risk reduction (i.e., risk reduced to tolerable level)

Industry Guidance (1 of 5)

- AIChE CCPS Guideline
- API RP 752 for siting permanent buildings
  - API RP for general building siting
- API RP 753 for siting portable buildings
  - Developed following BP Texas City incident due to damage to light wood trailers (temporary buildings)
  - Resulted in fairly widespread use of blast resistant modular buildings (BRMs)
- API RP 756 for siting tents (2014)
  - Tents used as alternative to temporary portable buildings, support turn around activities, etc.
  - Example tests shown in following slides

Industry Guidance (2 of 5)

- Deflagration Load Generator (DLG) test rig
- 48’ x 24’ x 12’, vertical pipe congestion (3% C_3H_8)

Industry Guidance (3 of 5)

- Tent blast load response test (1.4 psi, 22 ms)

Industry Guidance (4 of 5)

- National Fire Protection Explosion (NFPA) Explosion Protection Committee
  - 69: Explosion prevention
  - 68: Deflagration venting
    - Accounts for congestion within vented enclosure
    - See example video next slide
  - 67: Protection for piping systems
    - First issued in 2013
- NFPA standards on combustible dust

Industry Guidance (5 of 5)

- Vented deflagration testing with obstacles (ERC test)
- This (and similar) tests now factored into NFPA 68 vented deflagration correlation