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Mr. Frank has more than 35 years of experience in the chemical process industries, with the last 20 years as a risk, reliability, and safety consultant. He spent 24 years with DuPont where he held assignments in the areas of plant technical support, manufacturing supervision, research and development, design, project start-up, and process safety consulting. His last ten years with DuPont were in the Process Safety and Fire Protection group in the DuPont Engineering Services Division. During this time, he specialized in consulting in explosion hazards evaluation and control, and contributed to the development of the fire and explosion module for the Safer Trace™ consequence modeling software. After DuPont, he was a process safety consultant with ABS Consulting for ten years, leaving to form Frank Risk Solutions in 2007.

In addition to his work in explosion hazards evaluation and control, Mr. Frank provides support to industry in the areas of process safety management system application and enhancement, auditing, regulatory compliance, and safety culture evaluation and growth.

Mr. Frank has co-authored four books on process safety topics for the American Institute of Chemical Engineers (AIChE), Center for Chemical Process Safety (CCPS), and was a contributing author for the process safety section of the new edition of Perry's Chemical Engineer's handbook.

Mr. Frank received a B.S. degree in Chemical Engineering from Rose-Hulman Institute of Technology in 1973. He is a registered Professional Engineer in the state of Delaware and an AIChE Fellow. He is an emeritus member of CCPS and is a CCPS Staff Consultant. He is also a member of the National Fire Protection Association (NFPA) and chairs the Technical Committee on Handling and Conveying of Dusts, Vapors, and Gases.

WHY VAPOR CLOUD EXPLOSIONS ARE UNLIKELY IN LIQUID FUEL TANK FARMS

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Case Study

- An isobutane and ethylene release from a polyethylene reactor occurred at a plastics plant in Pasadena, Texas in 1989. The resulting *vapor cloud explosion* destroyed the facility.

Pasadena - 1989



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Afterwards



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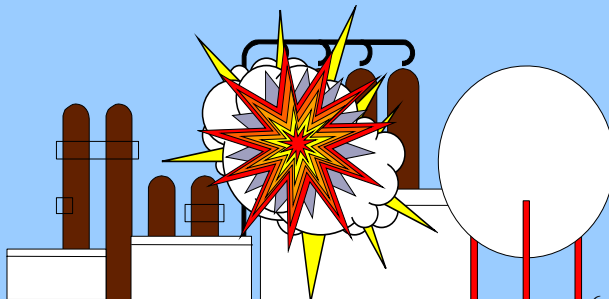
This Presentation...

- ... seeks to explain what conditions are required for such events
- ... and why an intentional attack on a tank farm would not provide those conditions

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Vapor Cloud Explosions

- A *vapor cloud explosion (VCE)* results from the ignition of a cloud of flammable vapor, gas, or mist in which flame speeds are high enough to produce significant overpressure.



Flash Fires

- A *flash fire* results from the ignition of a cloud of flammable vapor, gas, or mist in which flame speeds are too low to produce significant overpressure.

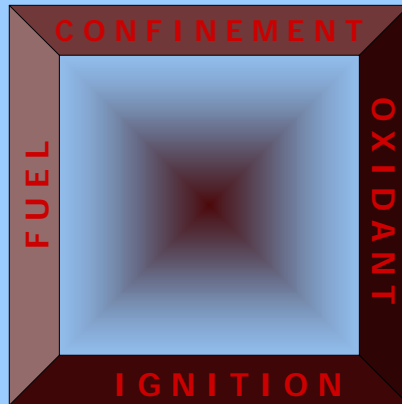
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What Is the Difference?

- Flames in the open require special circumstances to transition from *flash fires* to *vapor cloud explosions*
- The release environment must accelerate the flame to produce damaging pressures.

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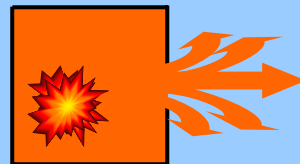
Explosion Quadrangle



Burning fuel/air mixtures do not produce damaging pressures unless somehow confined.

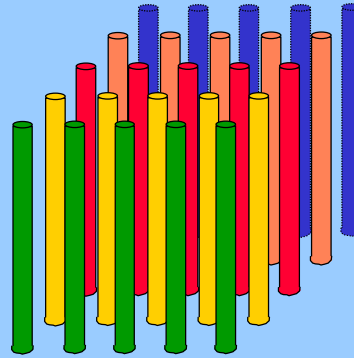
Confined Explosions vs. VCEs

- Burning fuel/air mixtures inside enclosures build pressure until the enclosure bursts (*confined explosions*).
- Burning fuel/air mixtures outdoors require congested environments
 - to provide confinement
 - and to accelerate the flame speed to cause a *VCE*



Congestion

- Congestion (obstacles, such as a row of pipes) confines the burning cloud and increases the flame speed... increasing the explosion pressure.



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Factors Needed for A Damaging VCE

- Mechanism for creating cloud of vapor, gas, or mist in air
- Cloud with a favorable fuel concentration... within flammability limits, uniform concentration
- Ignition source, but not too soon

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Factors Needed for Damaging VCE

- Fuels that burn more rapidly generate more pressure
- Confinement and/or congestion of the flammable cloud

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Creating a Cloud of Fuel

- By definition, combustible liquids do not produce flammable vapor at ambient temperature
 - Class II & III liquids, NFPA 704 "2" & "1"
 - Entire tank contents would have to be heated to above the flash point
 - ...or dispersed as a mist

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Creating a Cloud of Fuel

- Storage tanks are not pressurized so release rate would be low... no sprays
- Flammable liquid fuels produce flammable vapors, but vaporization rate is relatively low
 - Especially NFPA 704 "3" materials
 - Normal dispersion by the wind tends to limit size of flammable cloud

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Favorable Fuel Concentration

- Fuel must mix with enough air to burn, but not enough to make mixture too lean
 - Between *LFL* and *UFL*
- Pockets outside flammable limits stifle flame propagation

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Finding An Ignition Source

- Cloud must “avoid” ignition long enough to accumulate considerable mass within flammable region... then find ignition source
 - If the event causing the release provides an ignition source... no accumulation... minimal pressure produced

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The Nature of the Fuel

- Fuels that naturally burn more rapidly produce more pressure

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Fuel Burning Rate

- Fast burners (NFPA 704 rating)
 - Acetylene ("4")
 - Ethylene ("4")
 - Hydrogen ("4")
 - Ethylene Oxide ("4")
 - Propylene Oxide ("4")

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Relative Fuel Reactivity

- Medium Burners (NFPA 704 rating)
 - n-Butane ("4")
 - Propane ("4")
 - Cyclohexane ("3")
- Slow Burners
 - Gasoline, 100 octane ("3")
 - Jet Fuel, JP-5 ("2")

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Confinement/Congestion

- Tank farms typically do not provide either the confinement or congestion associated with damaging VCEs

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Congested



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Not



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Confined Explosions Unlikely

- Head space in tanks holding combustible liquid too lean to burn
- Head space in tanks holding flammable liquid typically too rich to burn
 - If head space is flammable, vapor inventory is limited
 - Damage to tank, and local explosion effects likely... but no off-site catastrophic potential
 - Tank liquid not involved in explosion, but subsequent fire likely

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Tank Fire



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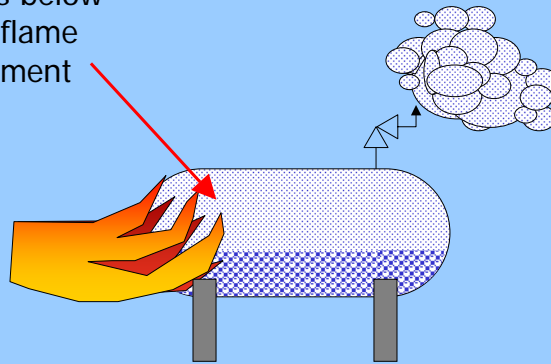
BLEVEs Not An Issue

- BLEVE = *Boiling Liquid Expanding Vapor Explosion*
- Explosion that results when pressurized vessel ruptures, releasing accumulated energy
 - Typically accompanied by fireball

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Common BLEVE Scenario

Fire-exposed wall overheats and weakens when liquid level drops below point of flame impingement



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ASTs Will Not BLEVE

- Atmospheric storage tanks (ASTs) are too weak to accumulate pressure required for explosive rupture
 - Many are floating roof tanks
 - Or, fixed roof tanks with wall to roof seam designed to fail at low pressure (fraction of psi)

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Summary

- Physical and chemical properties of hydrocarbon liquid fuels not conducive to VCE formation
- Physical arrangement of tank farm not conducive to VCE formation

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Summary

- Scenarios needed to cause catastrophic loss of containment likely to introduce ignition source
 - Prompt ignition and fire
 - No accumulation of vapor cloud required for explosion
- AST explosions with off-site consequences not likely to occur

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