Confined Explosion Hazards in Enclosed Process Buildings:
A Recognized Risk with Limited Guidance

Tuesday, June 9, 2026

12:00pm EDT
9:00am PDT

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Confined Explosion Hazards in Enclosed Process Buildings A Recognized Risk with Limited Guidance

Tuesday, June 9, 2026

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About AcuTech

Since 1994, AcuTech has been a global leader in providing best-in-class consulting, training, and software solutions to manage process risk.

With deep expertise in both the management and technical aspects of risk management, AcuTech is uniquely positioned to support clients ranging from the world's largest companies to specialized private companies to trade organizations and government agencies in improving safety, security, environmental, and operational performance.

This extensive experience across industries and in-depth knowledge of the tools and methods available for managing risk, allows our consultants to be responsive and flexible to meet client needs. In addition, they possess strong project management skills, broad technical expertise, and emphasize high-quality, on-time project work to support safer, more efficient, and, ultimately, more profitable operations.

Speakers

Ahmad Al-Douri, PhD

Assistant Professor, University of Oklahoma

Dr. Ahmad Al-Douri is an Assistant Professor in the School of Sustainable Chemical, Biological, and Materials Engineering at the University of Oklahoma. The Al-Douri group focuses on process systems engineering approaches to challenges in sustainable energy systems and decarbonized industrial processes. Before OU, he was a postdoctoral fellow at the Systems Risk and Reliability Analysis (SyRRA) Lab at the University of Maryland. His research at UMD focused on quantifying and addressing uncertainties in the risk assessment of a diverse set of energy systems critical to national and global energy transition efforts, with a focus on hydrogen technologies.

Andrés Ruiz-Tagle, PhD

Senior Associate Engineer, Quantitative Risk Services

Dr. Andres Ruiz-Tagle was formerly a researcher and postdoctoral fellow in the fields of Quantitative Risk Assessment and Reliability Engineering at the University of Maryland and GTI Energy. In these positions, he developed innovative methods for enabling quantitative risk assessment for complex engineering systems, such as natural gas pipeline networks and emerging hydrogen technologies. Before his doctoral studies, Dr. Ruiz-Tagle was a Reliability Engineering researcher at the University of Chile and a Data Science consultant for the Chilean State Railway Company (EFE), where he developed EFE's track quality index for supporting the integrity management of Chile's state-owned railway network.

Colin Armstrong, CCPSC

Group Lead & Principal Engineer, Quantitative Risk Services

Colin Armstrong brings years of experience in the areas of quantitative risk analysis and facility siting, including hazard identification, consequence modeling, development of frequency data, and risk analysis. He serves as a member of the API Facility Siting Committee, responsible for the development of API RPs 752, 753, and 756. He has been the technical lead and manager for 100+ successful quantitative risk analyses and risk-based facility siting studies for facilities in the oil, gas, LNG, specialty chemical, and alternative energy industries worldwide. In his work he has provided instruction and training in QRA and facility siting techniques to operating companies and university students.

Webinar Objectives

- **Objective:** Call attention to the need for a systematic evaluation of confined explosion hazards during hazard identification and risk assessment activities, including facility siting and PHAs.

- **This presentation**: 1st step towards objective
  - Explains confined explosions
  - Identifies common causes
  - Reviews current hazard identification and risk assessment practices

  Main data source: Review of U.S. CSB accident reports documenting confined explosion incidents in the U.S. since 1998

CSB Report – AB Specialty Silicones, 2019

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Confined Explosions

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Confined Explosions

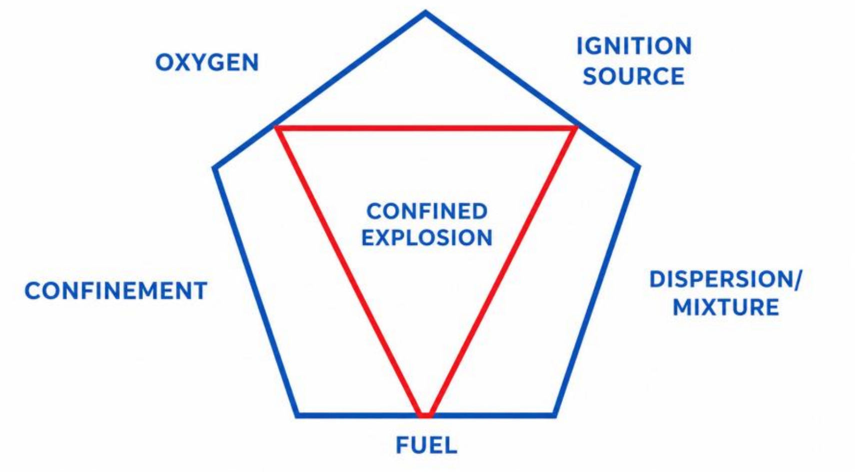
- Hazardous processes in enclosed processing areas are common in the chemicals industry
- Confined explosions present severe safety and economic risks
- Documented impacts include:
  - Fatalities and serious injuries
  - Catastrophic damage to facilities and surrounding communities
  - Long-term business interruption and closure
- Multiple incidents have occurred across industries

Davis and Hansen, 2010

Confined explosions are not rare, isolated events, but a persistent and cross-industry hazard with catastrophic outcomes

Confined Explosion Characteristics

- Flammable vapor accumulation in enclosed space
- Delayed ignition leading to high overpressure events (7-20X pressure rise)
- Catastrophic damage to original building. Extended impacts to the site and, potentially, beyond the fenceline



NBC - ConAgra Slim Jim Explosion, 2009

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Confined Explosions Incidents Investigated by the US CSB

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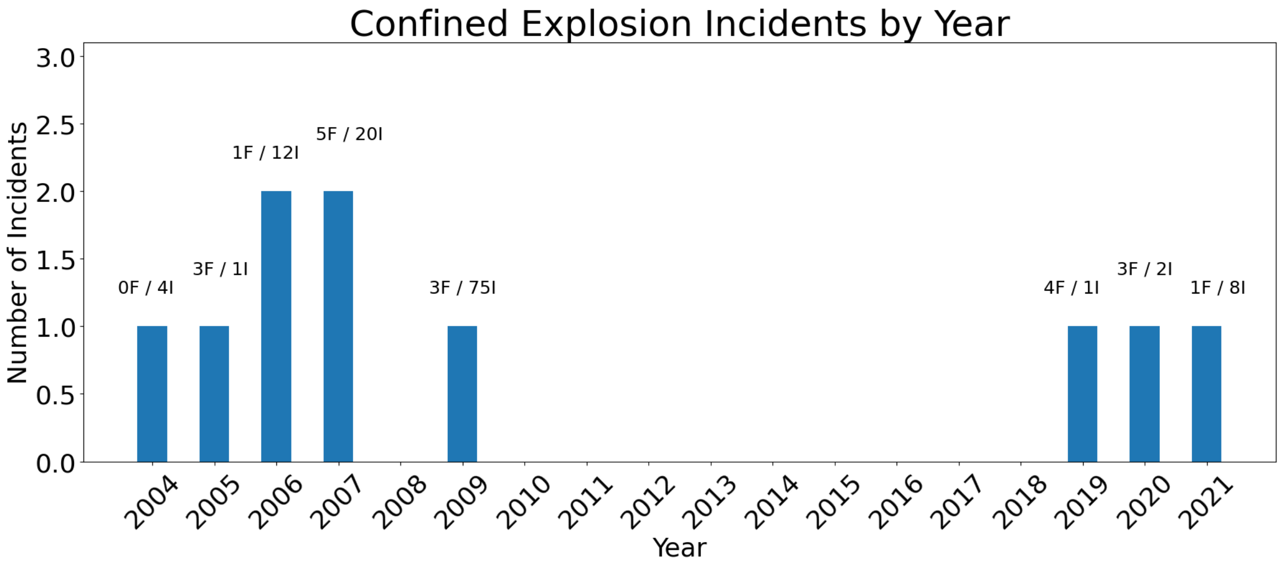
CSB Summary Statistics

- Since 2004, CSB has investigated **10 confined explosion incidents**
- **Total Fatalities**: 20
- **Total Injuries**: 123
- **Total Permanently Closed Facilities**: 6

- In the past 27 years, there has been an average of 1 catastrophic confined explosion every 3 years
- 10% of fatalities and injuries reported by CSB since 1998 were caused by confined explosions



Watson Grinding 2020 – 3 Fat., 2 Inj., Closed

AB Specialty Silicones 2019 – 4 Fat., 1 Inj., Closed

Yenkin Majestic 2021 – 1 Fat., 8 Inj., P. Closed

CAI, Inc and Arnel Company, Inc 2006 – 0 Fat., 10 Inj., Closed

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Causes of Confined Explosions

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Examples of Confined Explosions from US CSB

- **Yenkin Majestic 2021** – 1 Fat., 8 Inj., Partially Closed
  - Closed kettle + naphtha (no mixing) → vapor buildup → agitation →overpressure → seal failure → vapor release into process building →ignition → explosion & fire
- **Watson Grinding 2020** – 3 Fat., 2 Inj., Closed
  - Poorly crimped propylene hose → leak → vapor accumulation overnight→ ignition on entry → explosion
- **AB Specialty Silicones 2019** – 4 Fat., 1 Inj., Closed
  - Wrong chemical added → incompatible reaction → foaming/overflow →flammable fog formation within process building → ignition → explosion &fire
- **CAI, Inc and Arnel Company, Inc 2006** – 0 Fat., 10 Inj., Closed
  - Steam valve left open → tank overheating during mixing → solvent vaporization → vapor release into building → ignition → explosion

Yenkin Majestic, 2021

- Inadequate industry guidance for pressure vessels not exceeding 15 psig

→

- Stakeholders outreach

- YM's mechanical integrity procedures did not have QA requirements for vessel alterations
- Kettle 3 was considered atmospheric because it operated at <15 psig
- Company did not document engineering standards for Kettle 3
- Agitator solvent addition interactions not covered in hazard reviews
- VCE hazards not covered in operator training

→

- Asset integrity and reliability
- Process knowledge and management
- Compliance with standards
- Hazard identification and risk analysis
- Training and performance assurance
- Operating procedures

- LEL detectors not configured with audible alarms
- Flame-resistant PPE not available

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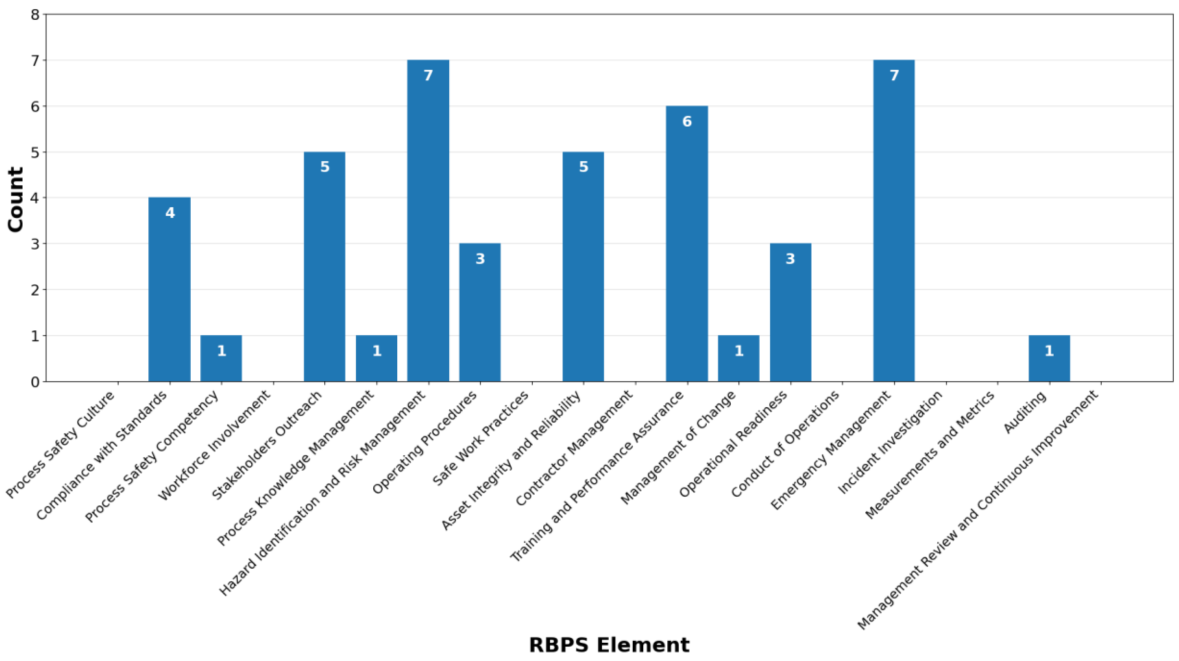
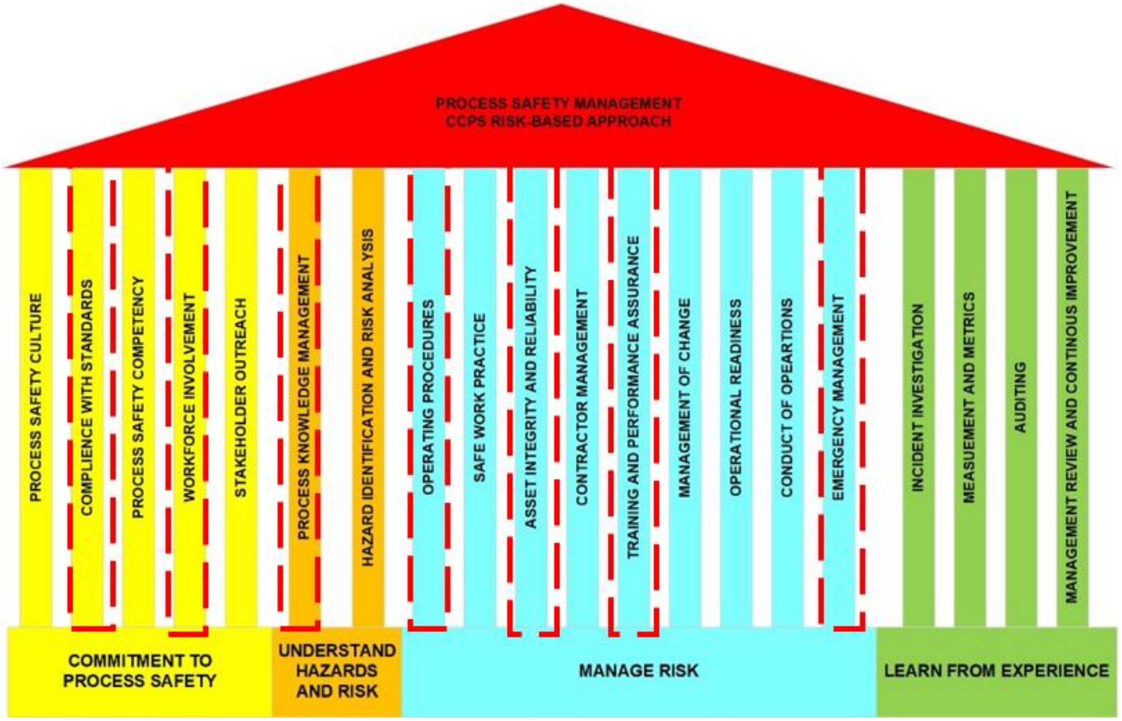
- Emergency management

RBPS Elements Failing in Confined Explosion Events





The following elements of RBPS were observed as characteristic in confined explosion incidents:

- Hazard Identification and Risk Analysis
- Training and performance assurance
- Emergency management

Insights from Confined Explosions Reported by CSB

- **Limited PHAs and Comprehensiveness:** only 6/10 analyzed facilities had PHAs. Only 2 of them had identified the scenario leading to the confined explosion. 2 facilities not covered by OSHA PSM (below inventory threshold)
- **Recurring Initiating Event:** Human Error leading to flammable vapor release. E.g.,
  - poorly crimped welding (Watson Grinding),
  - mixing of incompatible materials (AB Silicones),
  - improper valve action (CAI & Arnel and Little General Store), and
  - unfit instructions during operations/ maintenance (Synthron, Sterigenics)
- **Recurrent Issues:** forced ventilation not present / disconnected. E.g.,
  - Forced ventilation disconnected (Watson Grinding, CAI and Arnel Company, Inc)
  - Ventilation design worsened confined explosion impacts (AB Specialty Silicones)
- **Recurrent Materials Involved in Confined Explosions:** solvent and highlyreactive materials (e.g., hydrogen, acetylene, etc)

These failures are not random: they reflect a systematic gap in how confined explosion risks are identified, evaluated, and managed

Human Errors

- Human error was a recurring initiating event in several incidents:
  - **Synthron**: Personnel did not have reactive hazards training appropriate for polymer operations.
  - **ConAgra Slim Jim**: Worker installing a gas-fired water heater purged a gas line into an interior utility room.
  - **Yenkin-Majestic**: Operator did not recognize in a timely manner the agitator in the kettle had turned off.
  - **ASCO**: Operator closed city water supply valve prior to starting up the recycled water system, thus leaving generator without pressurized water source to prevent acetylene backflow.
- In most cases, the *operating procedures* for the units involved in the incidents were *either insufficient or undocumented*.

- Increase the implementation of **structured human reliability analysis (HRA)** methods such as SPAR-H or ATHEANA as part of risk assessments for enclosed process buildings
- These methods begin with task decomposition, highlighting necessity of well-documented, complete procedures.

Ventilation Deficiencies

- Several accidents were also caused by a lack of, insufficient, or badly designed ventilation:
  - **Watson Grinding**: Gas detection system was disconnected from PLC which did not automatically trigger emergency exhaust fans.
  - **ConAgra Slim Jim**: Utility room to which NG was purged into had an exhaust fan, but it was insufficient compared to gas release rate.
  - **AB Specialty Silicones**: Ventilation design promoted flammable gas dispersion throughout the room.
  - **CAI and Arnold**: Ventilation system was turned off during nights due to neighbors' complaints
- None of these facilities showed consideration of deflagration venting strategies

Insufficient attention to flammable cloud prevention and explosion protection safeguards in enclosed areas contribute to catastrophic confined explosions

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Hazard Identification and Risk Assessment Practices

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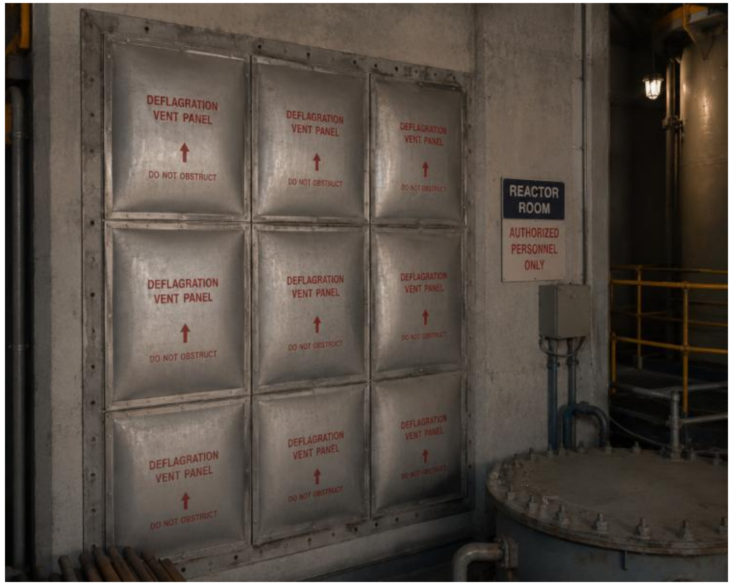
Hazard Identification: PHAs

- Methods: What-If, HAZOP, LOPA

Years of audit findings indicate that PHAs frequently:

- Underestimate the severity of confined explosion scenarios
- Rely on safeguards whose effectiveness for confined explosion events has not been demonstrated through design basis documentation.

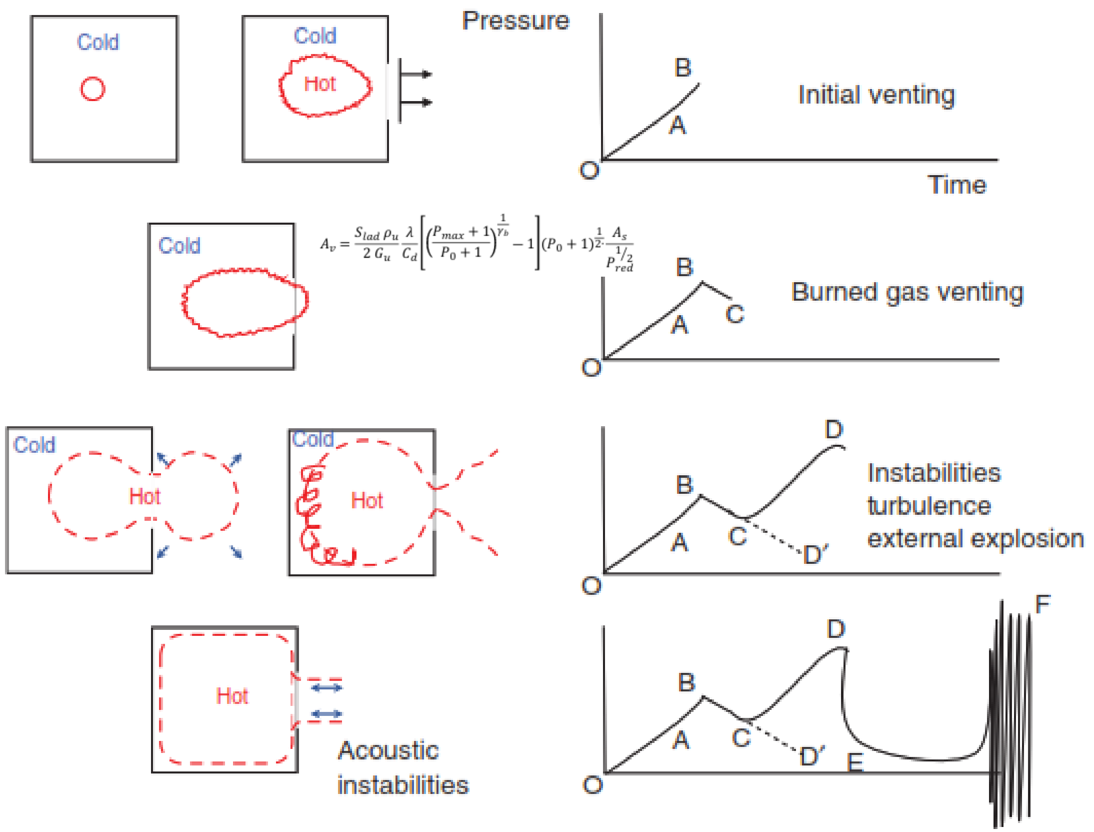
No.	DEVIATION / HAZARD	CONSEQUENCE	INITIAL RISK	EXISTING SAFEGUARDS	RESIDUAL RISK	RECOMMENDATIONS	FINAL RISK
1	DISPENSING GUN BLOCKAGE	EO flow continues until cylinder depletion, resulting in vapor release into the work area. Potential explosion and single fatality.	4 / 4	• Ventilation System	5 / 4	Implement a preventive inspection and maintenance program for the dispensing gun.	6 / 4



Detailed Risk Assessments: QRA and Facility Siting

- **Methods**:
    - **Multiphysics**: Computational Fluid Dynamics
    - **Empirical**: Pressure rise calculation methodologies (e.g., NFPA 68; BS EN 14994) and Blast Curves (TNO, BST)

- **Main requirement**:
    - Explosion venting (structural characteristics, vent dimensions, etc.)
    - Other effects: turbulence, vent ducts, enclosure pressure, interconnected enclosures, etc.



Rangwala and Zalosh, 2023; NFPA 68

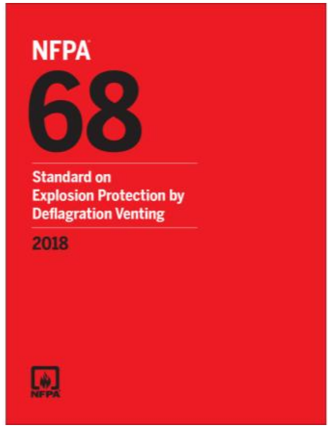
Guidance mostly focus on Pressure Rise and Reduction within an enclosure, not pressure developed outside of it

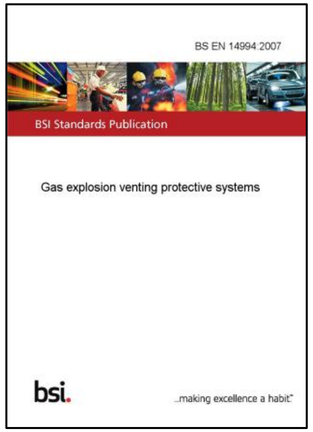
Detailed Risk Assessments: QRA and Facility Siting

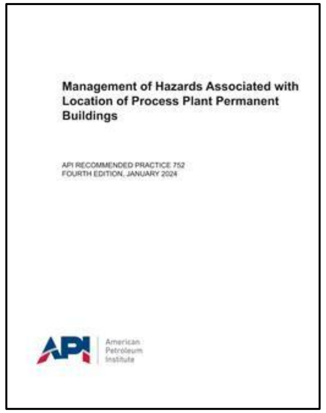
Substantial evidence exist on confined explosion events impacting, severely, sensitive receptors at significant distances

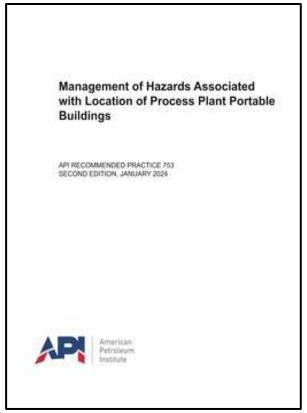
Estimating External Impacts

- Typically addressed during Facility Sitings
- **Current guidance from RAGAGEPs:**
  - **NFPA 68**: only provides hazard distance from vented fireball
  - **EN 14994**: provides vented overpressure vs distance under restrictive conditions:
    - Enclosures without obstructions (turbulence); L/D < 2; limited vent static pressure, no detonation
  - **API 752:** performance-based. Occupied buildings should be sited for internal VCEs using a similar methodology to external VCEs (E.g., Blast Curves or CFD)
  - **API 753:** portable buildings should not be sited using Method A (VCE Standoff Distance Table Approach) – *acknowledges confined explosion unique characteristics compared with external explosions*









RAGAGEPs assumes deflagration venting protection or suggest use of typical VCE models (e.g., TNO ME, BST, CFD) for confined explosions

What to do when lacking design basis for deflagration protection

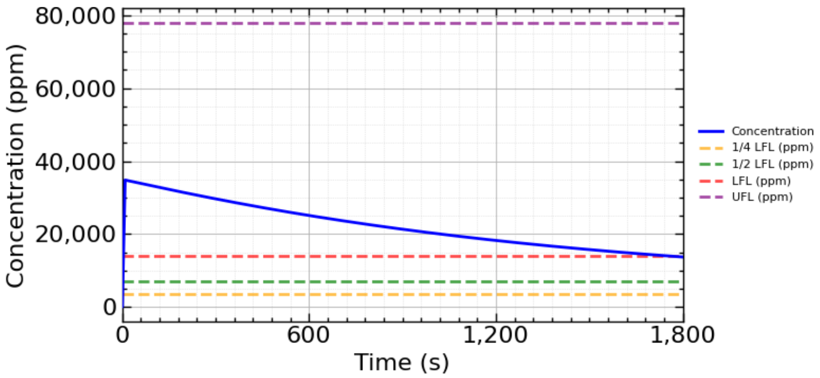
- RAGAGEPs recommend use of typical VCE modeling (Blast Curves; CFD)
- CFD provides the most accurate results, but requires expertise, time, and is costly
- What is typically done:

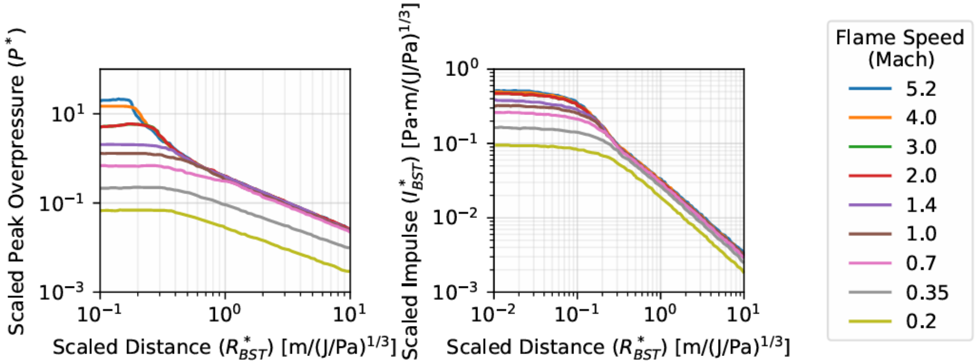
Homogeneous mixing assumption

- Assumes a flammable volume concentration within a volume (process building)
- **CAUTION**: Results are highly dependent on selection of volume size, specially in large buildings

Blast Curve Modeling

- Select blast curve based on confinement, congestion, and material reactivity
- **CAUTION**: confinement based on industrial site (e.g., refinery), not process building (e.g., RX building)





Guidelines from practitioners

Pitbaldo et al. 2014

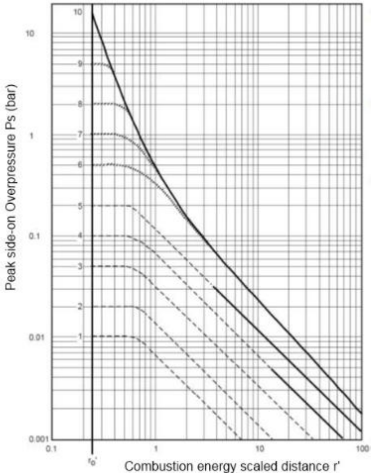
- TNO ME
- Strength 4 to 6
- Fully enclosed buildings:
  - Separate congested volume
  - Max height cut-off 7.6m
  - Propane-air with $\phi = 1$ and energy density of 3.5 MJ/m3

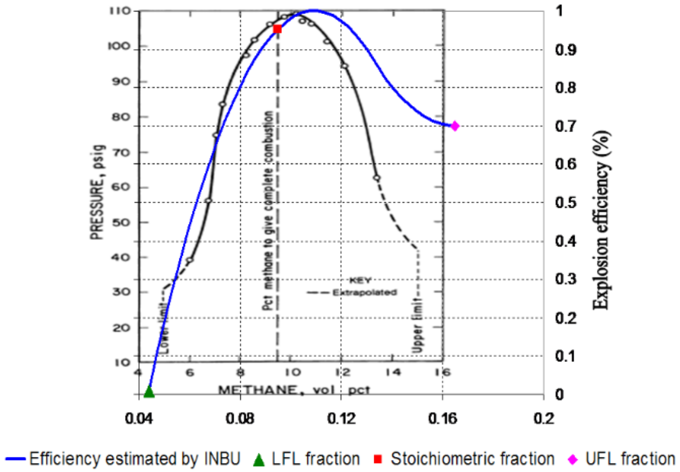
DNV PHAST, 2026

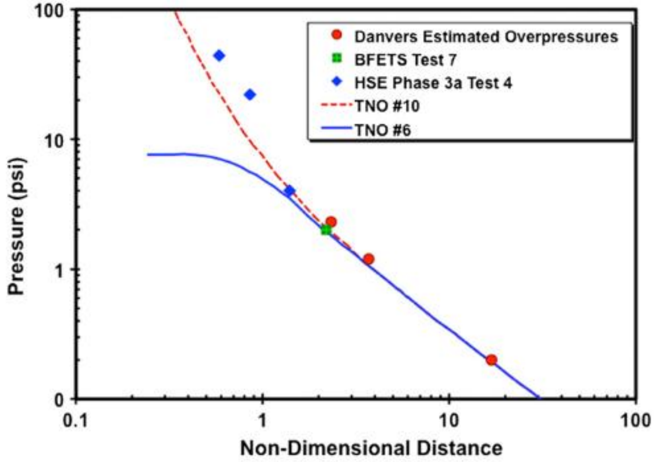
- INBU Model
- Assumes TNT detonation behavior and equivalency model
- Estimates explosion efficiency based on indoor concentration of a homogeneously mixed volume

Davis et al. 2014

- Investigation into the 2006 CAI/Arnel explosion
- Shows that TNO models do not predict observed overpressures (strengths 6-10)
- Advocates for CFD





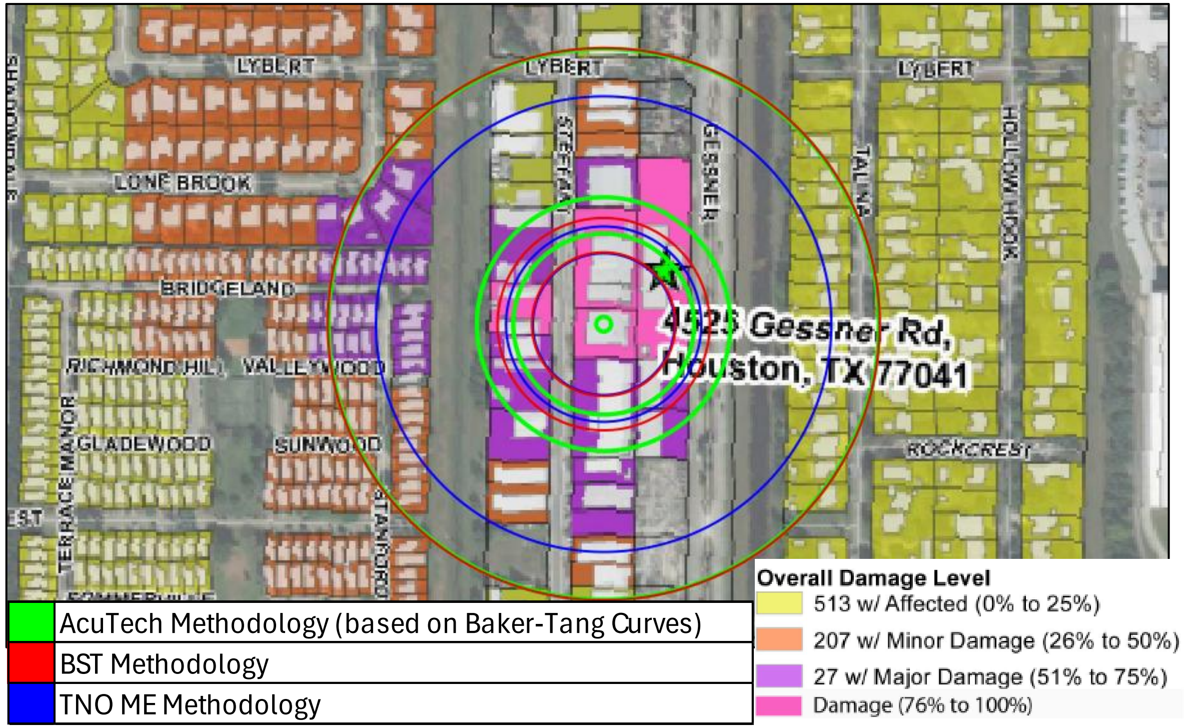


Guidance from practitioners

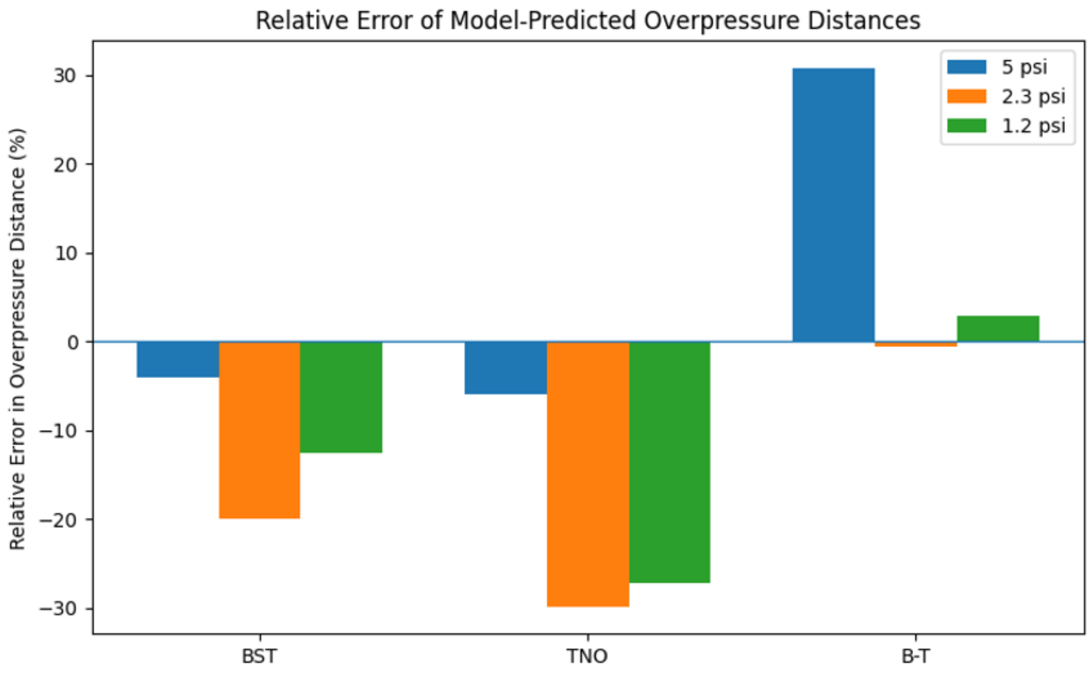
- Consider the Brode's Energy as a conservative explosion energy approximation (Ineris, 2026; AcuTech, 2025)

$$E = \frac{\Delta P.V}{\gamma - 1}$$

Watson Grinding, 2020



CAI Inc and Arnel Company, Inc. 2006



Limited methodologies tailored for evaluating confined explosions hinder accurate PHAs, QRAs, and facility siting analyses

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Conclusions

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Conclusions

- Confined explosions remain a frequent, high-consequence hazard across multiple industries.
- PHAs are not capturing the potential catastrophic impacts of confined explosions
- There is a clear need for systematic methodologies to evaluate confined explosion risk.
- While QRAs and facility siting studies can support impact assessment, existing modeling approaches have critical limitations:
  - Many modeling approached are not designed or validated for confined explosion scenarios
  - Others rely on internal pressure/venting assumptions that are impractical or unavailable in real applications

Call for action: Confined explosions are not rare, isolated events, but a persistent and cross-industry hazard with catastrophic outcomes and limited guidance for evaluation

Thank you!

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HEADQUARTERS
1750 Tysons Blvd, Suite 200
McLean, VA 22102
USA

EMAIL ADDRESS
contact@acutech-consulting.com

WEBSITE
www.acutech-consulting.com