Shrapnel

Accounting for Blast Fragments in Facility Siting Studies

BLUEFIELD PROCESS SAFETY

Presented by

- **Corey A. Whelehon**
  - **Safety Consultant,**
    Bluefield Process Safety, LLC
    St. Louis, Missouri
- **Michael S. Schmidt**
  - **Principal, Bluefield Process Safety, LLC**
    St. Louis, Missouri
  - **Adjunct Professor, Missouri S&T**
    Rolla, Missouri

“Shrapnel” but NOT Shrapnel

- **Types of explosions**
  - **Boiling liquid expanding vapor explosions (BLEVEs)**
  - **Vapor cloud explosions (VCEs)**
  - **Pressure vessel explosions(PVEs)**
- **Fragments from industrial explosions**
  - **Missiles**
  - **Projectiles**
  - **Blast Fragments**

Impacts of Explosions

- **Explosion consequences**
  - **Blast waves**
  - **Release of contents**
  - **Thermal radiation**
  - **Projectiles**
- **Effects of projectiles in explosions are routinely mentioned in facility siting studies but rarely assessed**

Pressure Vessel Explosions

- **PVE released energy**
  - **Shockwave**
  - **Fragments**
- **Using TNT Equivalency Model to determine energy released**

PVE Explosive Energy

- **Isothermal expansion**
  - $E = P_2V[\ln(P_2/P_1)-(1-P_1/P_2)]$
    - V is the volume of the vessel
    - P_1 is the atmospheric pressure
    - P_2 is the burst pressure
- **Burst pressures**
  - 4 times MAWP, ASME Boiler and Pressure Vessel Code (BPVC)
  - 6 times MAWP, European pressure vessel code, EN13445

TNT Equivalency Model

- **Equivalent mass of TNT**
  - $m_{TNT} = E/\Delta H_{TNT}$
    (ΔH_{TNT} is the heat of explosion of TNT)

- **Combining gives**
  - $m_{TNT} = \{1/\Delta H_{TNT}\} \times \{P_2 V[ln(P_2/P_1) - (1 - P_1/P_2)]\}$

BLUEFIELD PROCESS SAFETY

Equation for Calculations

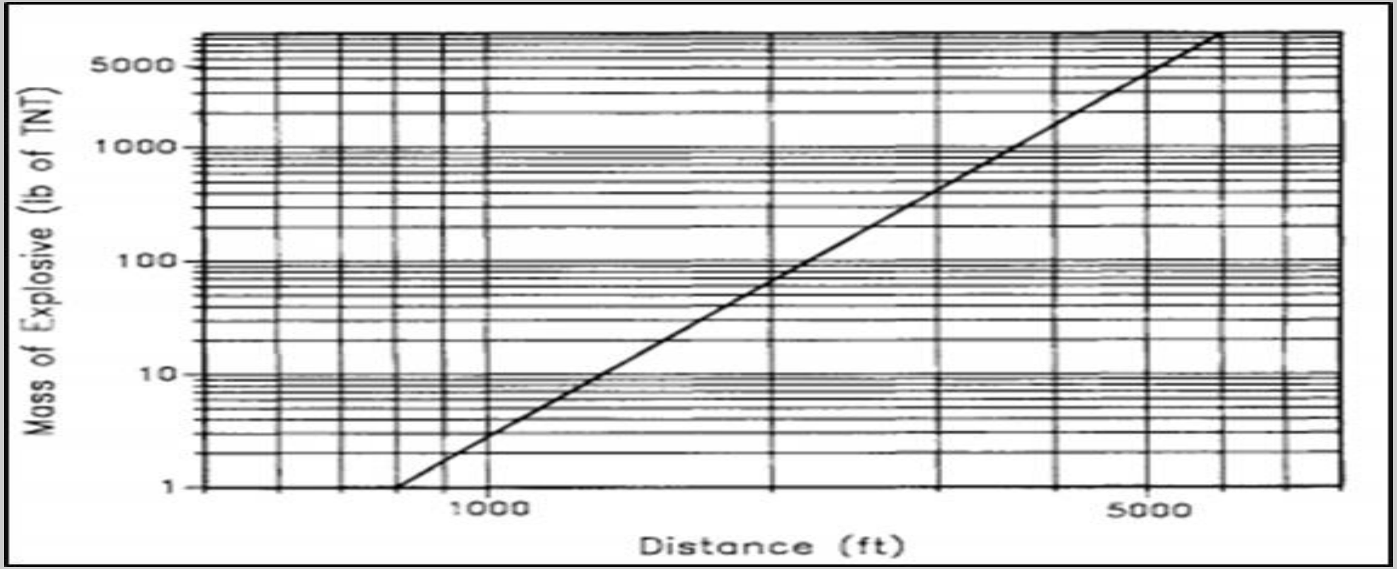
- $m_{TNT} = 9.21 \times 10^{-5} P_{BURST} V_{BURST}$
  $\times [ln (P_{BURST}/14.7)-(1-14.7/P_{BURST})]$
- **Where:**
  - m_{TNT} **is equivalent mass of TNT, in pounds,**
  - P_{BURST} **is vessel burst pressure, in psia,**
  - V_{BURST} **is gas volume of bursting vessel, in cubic feet**

Blast Fragments - Modeling

Six steps to modeling potential damage

- Determine maximum horizontal range
- Calculate fractional distance
- Estimate the probability of fragments traveling distance to target
- Estimate the probability of fragment going in the direction of target
- Estimate the surface target density of target
- Calculate the probability of damage by blast fragments

Horizontal Range



$$d_{MAX} = 800\ m_{TNT}^{0.22}$$

Fractional Distance

- **Impacts of fragments striking other processes**
  - **Determine distance to the target process, d**
  - **Calculate fractional distance, d_{FRAC}**
  - **$d_{FRAC}=d/d_{MAX}$**
- **When $d_{FRAC} > 1$, the blast fragment case may be ignored**

Probable Distance

Horizontal vessel- fractional distance, d_{FRAC}	Probability of reaching or exceeding fractional distance, P_{dist}
1.0	0.010
0.9	0.014
0.8	0.018
0.7	0.028
0.6	0.042
0.5	0.063
0.4	0.09
0.3	0.17
0.25	0.22
0.20	0.31
0.16	0.40
0.12	0.51
0.08	0.71
0.04	0.91
0.02	0.99

Vertical/Spherical fractional distance, d_{FRAC}	Probability of reaching or exceeding fractional distance, P_{dist}
1.0	0.010
0.9	0.016
0.8	0.027
0.7	0.045
0.6	0.079
0.5	0.137
0.4	0.23
0.3	0.39
0.25	0.53
0.20	0.69
0.16	0.80
0.12	0.92
0.08	0.985
0.04	0.995
0.02	0.999

Probable Direction, P_{dir}

- **Fragments traveling in direction of target processes, P_{dir}, depend on**
  - **Number of fragments**
  - **Size of fragments**
  - **Width of the target process**

Number of Fragments

- **Number of fragments…too many to count?**
- **Numbers typically reported range from 2-3 per incident to a couple dozen**
- **The assumption of 24 fragments is conservative and recommended for most cases**
- $N_{Frag} = 24$

Size of Fragments

- **Fragment size is related to the surface area of the vessel:**

  $$L = (A_{vessel} / N_{Frag})^{0.5}$$

- **Only half of fragments create impact areas beyond the overpressure zone:**

  $$N = N_{frag}/2$$

Target Point Direction

- **Probability of fragments hitting the target processes point distance:**

  $$P_{hit} = NxL/2\varpi r$$

- **Substituting the previous equations gives**

  $$P_{hit} = (A_{vessel} \times N_{Frag})^{0.5} / 4\pi d$$

- **The probability of not hitting:**

  $$P_{not\ hit} = 1 - ((A_{vessel} x N_{Frag})^{0.5} / 4\pi d)$$

Target Area Direction

- **Probability of fragments not hitting the target processes area**
  - **Number of sequential segments, n = W/L**
  - $P_{\text{target not hit}} = (1-((A_{vessel} x N_{Frag})^{0.5} / 4\pi d))^{n}$
- **Probability of a fragment going in the direction of a process target, P_{dir}**
  - $P_{dir} = 1 - (1-((A_{vessel} x N_{Frag})^{0.5} / 4\pi d))^{W/(Avessel /NFrag)^{\wedge}0.5}$

Process Density

- **Surface target density presented to a fragment is its process density, $P_{density}$**
  - **Low – coverage less than 2% and more than 6.5 ft between obstacles.**
  - **Medium – coverage of 2% to 6% and 1.5 to 6.5 ft between obstacles.**
  - **High – coverage greater than 6% and less than 1.5 ft between obstacles.**
- **$P_{density}$ of 5% is common**

Probability of Impact

- **The probability of impact by blast fragments, P_{impact}, is determined by the product of these probabilities**
  - **$P_{impact} = P_{dist} \cdot P_{dir} \cdot P_{density}$**
- **When P_{impact} is greater than 0.01, then the blast fragment case is a valid scenario for causing a catastrophic release**

Summary

- **Impacts of a blast fragments from a PVE should be considered in facility siting studies**
- **Blast fragments from PVEs are not shrapnel, but large pieces**
- **The number of blast fragments from a PVE is less than a couple dozen**
- **Estimating three probabilities can determine the impact from blast fragments following a PVE: $P_{impact} = P_{dist} \cdot P_{dir} \cdot P_{density}$**

Questions?

Email us!

Mike Schmidt:

bluefieldsafety@gmail.com

Corey Whelehon:

Corey.Whelehon.bluefieldsafety@gmail.com

Follow us!

LinkedIn

BLUEFIELD PROCESS SAFETY