Combustion Behavior and Quantity Distance (QD) Siting

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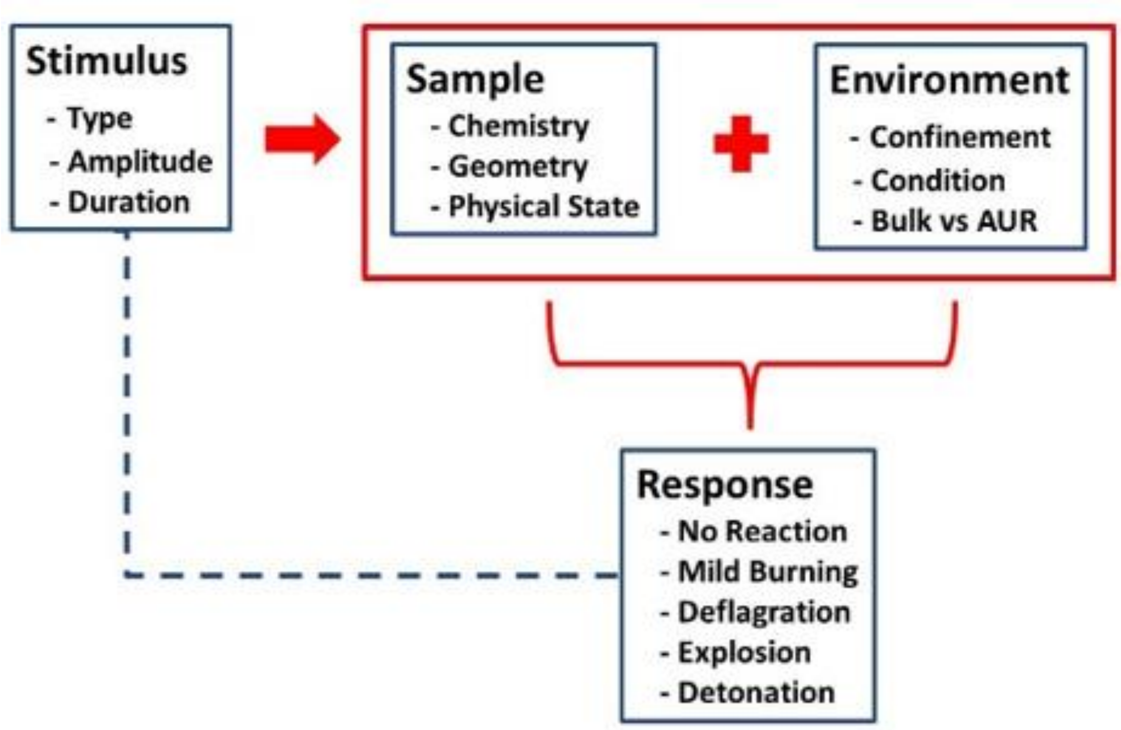
Outline

- Quantity Distance (Explosives Safety Separation Distance) for HD 1.3 Tables in DODM-6055.09-M Onset of 2nd degree burns **
- Background and motivation for current program ~ 75% of large mishaps initiate by fire
- Overview of Test results
- Modification of HD 1.3 tables to include heat flux requirement
- Conclusions and way-ahead

$$2R = D_{FIRE} = 10 \text{ x } W_{EFF}1/3$$

**Society of Fire Prevention Engineers, “Engineering Guide: Predicting 1st and 2nd Degree Skin Burns From Thermal Radiation,” SFPE, Maryland (2000).

Hazard Threat



$$Risk = Probability\ of\ Event \times Consequences \times Exposure$$

$$Risk = P_f = P_e \times P_{f|e} \times E_p$$

Class 1 Hazard Divisions

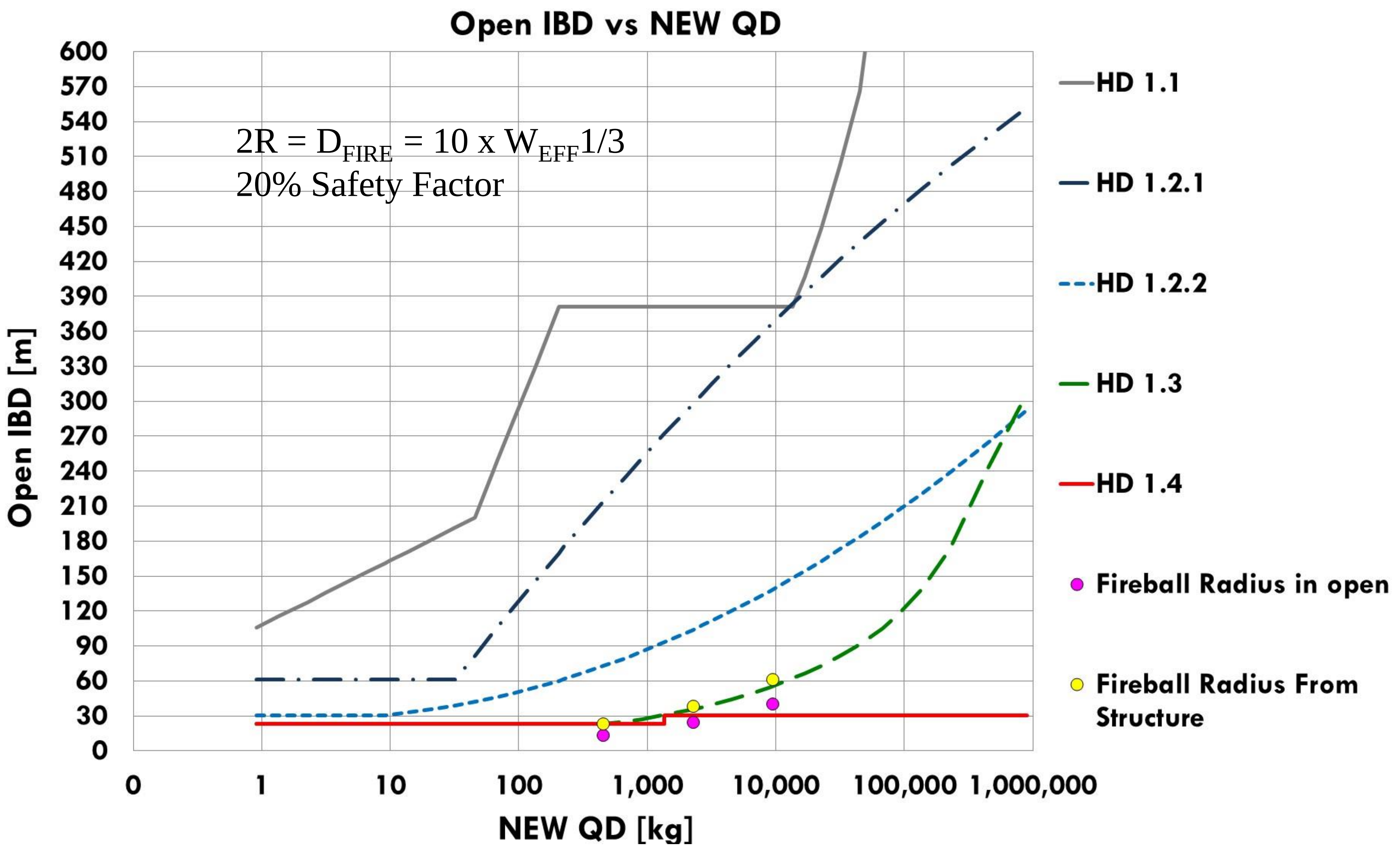
TB-700-2 49 CFR 173

Hazard Division	Hazard Type
1.1	Mass explosion
1.2.x	Non-mass explosion, fragment producing
1.3	Mass fire, minor blast or fragment
1.4	Moderate fire, no significant blast or fragment
1.5	Explosive substance, very insensitive (with mass explosion hazard)
1.6	Explosive article, extremely insensitive (no mass explosion hazard)

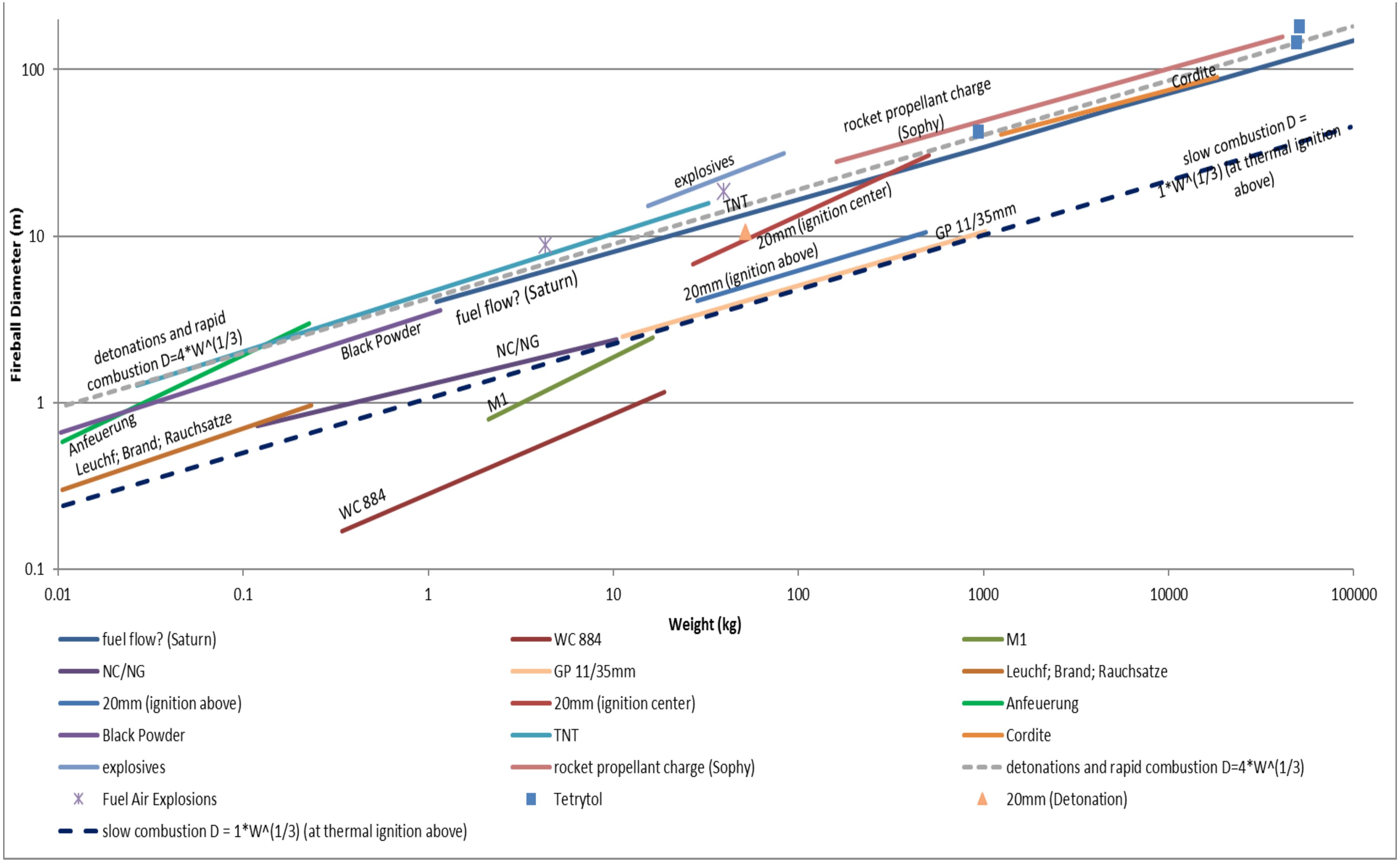
Hazards Not Considered

Electrostatic and electromagnetic influence
Rough handling and vibration
Effects of exposure to hot or cold environments
Mechanical defects
Solar radiation
Temperature shock
Abnormal functioning
Combat exposure

Current QD Tables



Fire Ball Diameters for Various Propellants and Explosives



*Thermische Wirkunge bwei Pulverabbranden und-detonationen, B 3113-23 Ueberarbeitete Fassur, December 1984. Partial English Translation.

Motivation for Current Efforts

- **Milan AAP, 2004***
  - Magazine contained Comp A-5, M2 propellant, and M9 propellant
  - While returning 3 drums a drum tipped and propellant ignited
  - Fire spread to other materials in magazine
  - Two fatalities and one critical injury
  - Huge debris fragments at distances greater than the 1,250-foot IBD arc. One 6 x 8-feet fragment found at 3,100 feet away and other debris found approximately 2,050 feet away
- All fragments were secondary fragments originating from the structural elements of the ECM
- Majority of the secondary fragments were hazardous
- Current QD tables may need to be re-examined in light of the large number of hazardous fragments, and the high hazardous fragment density (greater than 1 hazardous fragment/600 square feet) that occurred outside of the 1,250-foot IBD arc."

- *T. L. Boggs, K. P. Ford, and J. Covino, "Realistic Safe-Separation Distance Determination for Mass Fire Hazards," NAWCWD TM 8668, Naval Air Warfare Center Weapons Division (2013).

Objectives

- Understand QD (explosives safety-separation distance) criteria for HD 1.3 materials
  - Effects of loading density on structural response
  - Pressure rupture of the structure under choked flow
  - Fireball/plume dimensions
- Determine influence of structural design and venting
- Understand rupture and propagation of debris
  - Rapid pressurization vs detonation
- Obtain data showing transitions from unchoked to choked conditions- for diferent configurations
- Validate pressurization and fragmentation predictions from existing models

- **M1 Gun Propellant**

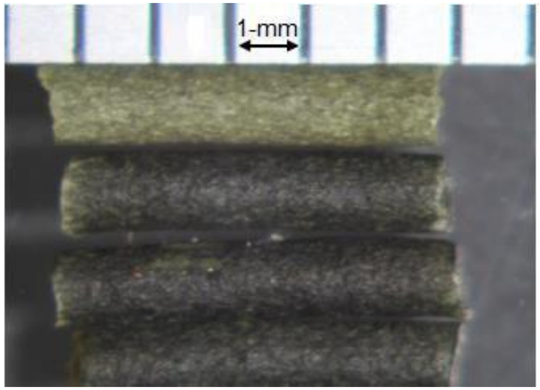
Ingredient	Weight %
Nitrocellulose	85.00 ± 2.00
Dinitrotoluene (DNT)	10.00 ± 2.00
Dibutylphthalate (DBT)	5.00 ± 1.00
Diphenylamine (DPA)	1.00 ± 0.10
Lead carbonate	1.00 ±0.20
Potassium sulfate	1.00 ±0.30

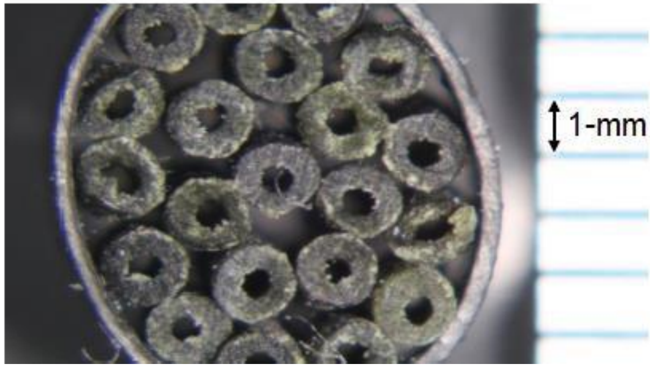
Tests 1 & 2: Single Perforation – Higher Surface area

OD: 1.22 mm

L: 5.03 mm

Perf: 0.514 mm



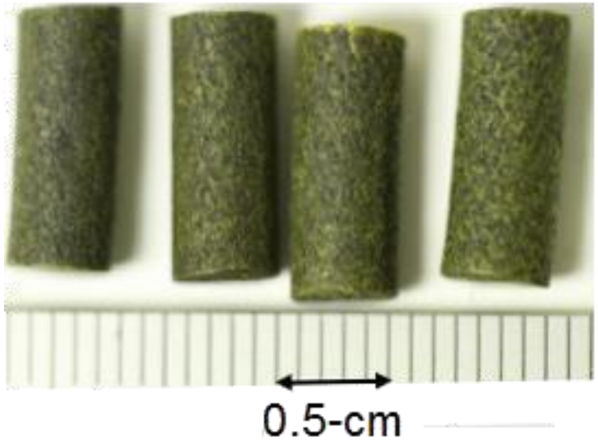


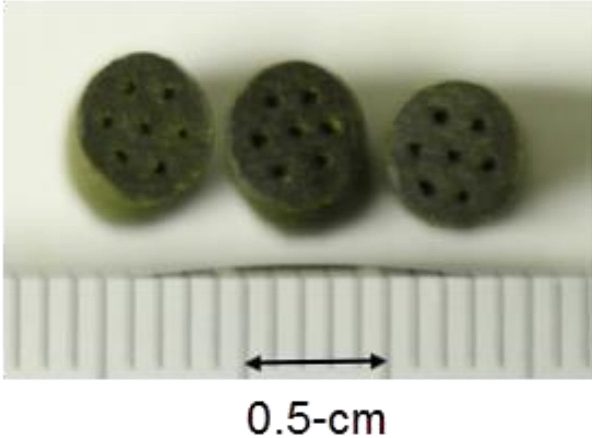
Tests 3 -7: Seven Perforation – Longer Burn time
[Note: Difference in scales]

OD: 4.77 mm

L: 10.765 mm

Perf: 0.451 mm

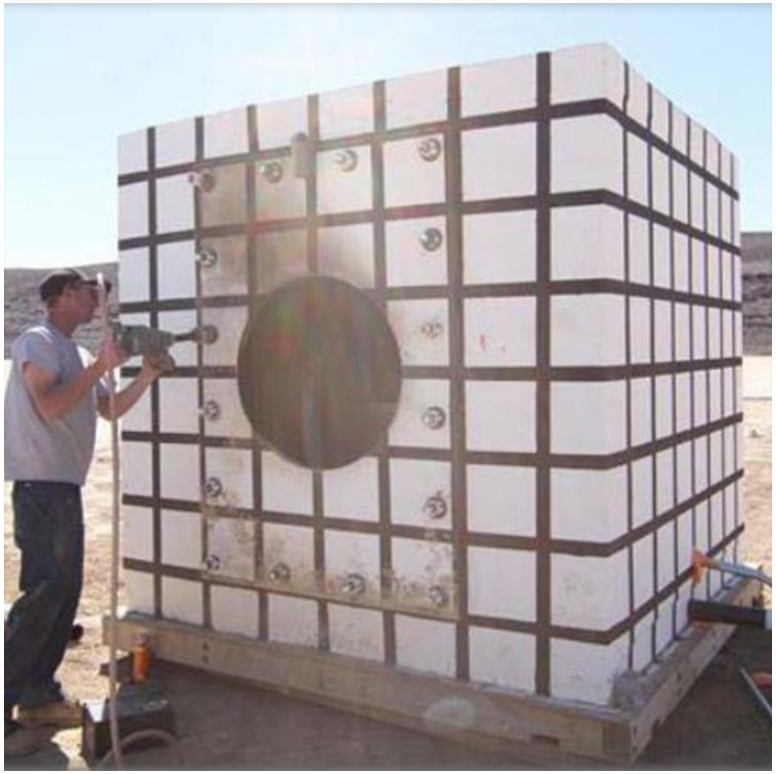


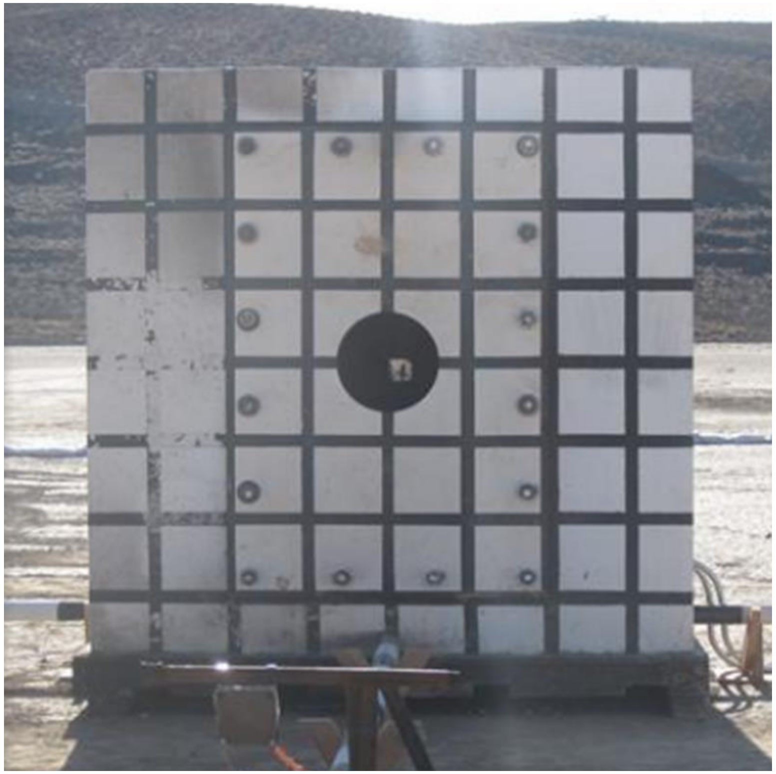


Test Structure

Tests 1, 3 & 5: 79-cm

Tests 2, 4, 6 & 7: 39-cm



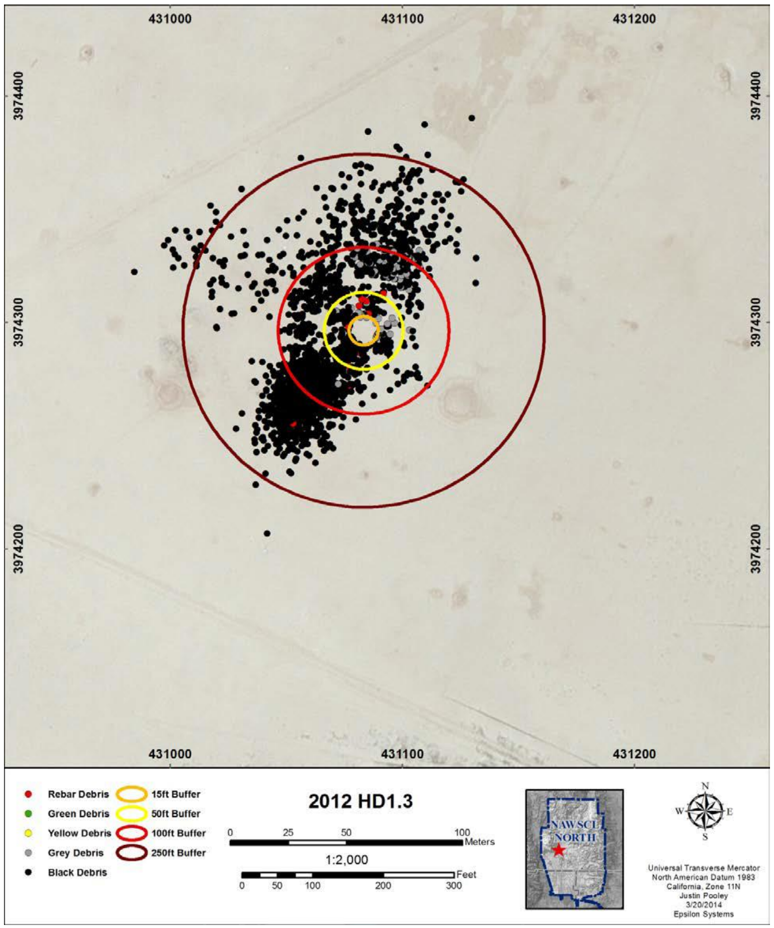


Test Summary

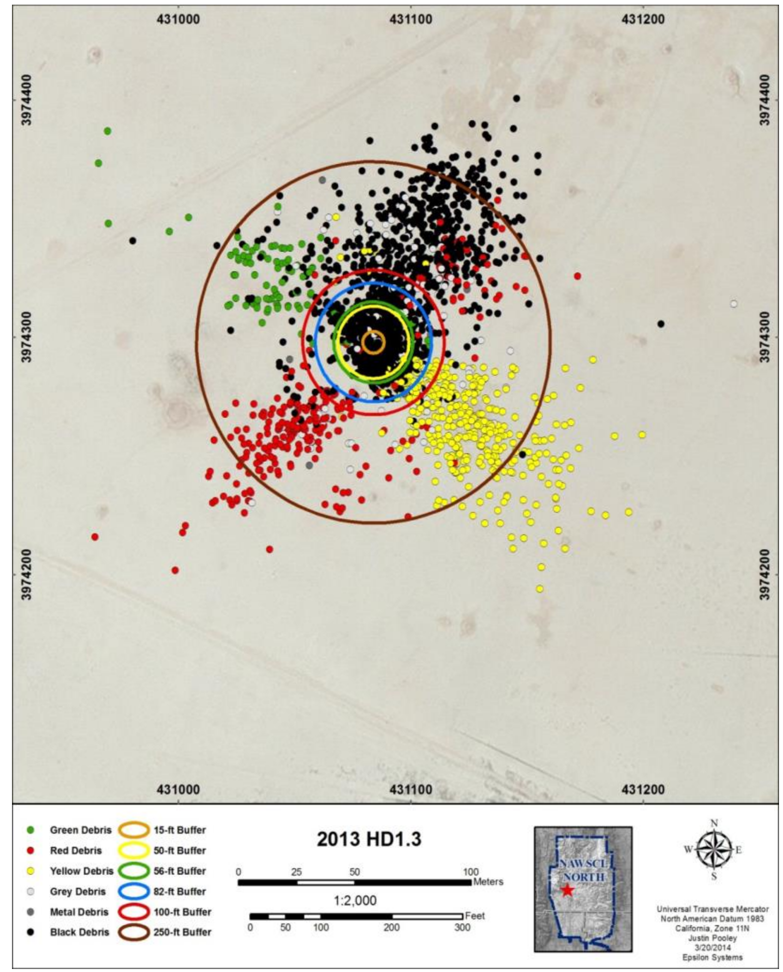
Test Number	Grain Type	Propellant Weight (kg)	Loading Density (g/cm^3)	Number of Barrels	Structural Failure Observed
1	1P	134.55	0.017	3	No
2	1P	534.55	0.067	8	Yes
3	7P	120.00	0.015	3	No
4	7P	503.64	0.063	8	Yes
5	7P	120.00	0.015	3	No
6	7P	534.82	0.063	7	Yes
7	7P	240.55	0.030	3	Yes

Propellant Surface Area Differences

Test 2* - 1P



Test 4 - 7P



* Not all fragments < 200 grams collected

Surface Area Differences

- Test 2-Higher Surface Area
  - 2609 collected*
    - 2177 outside IBD
      - ~83 percent of collected
  - Largest = 8.4 kg
  - 32 @ distance> 76.2 m
    - Furthest at 105 m

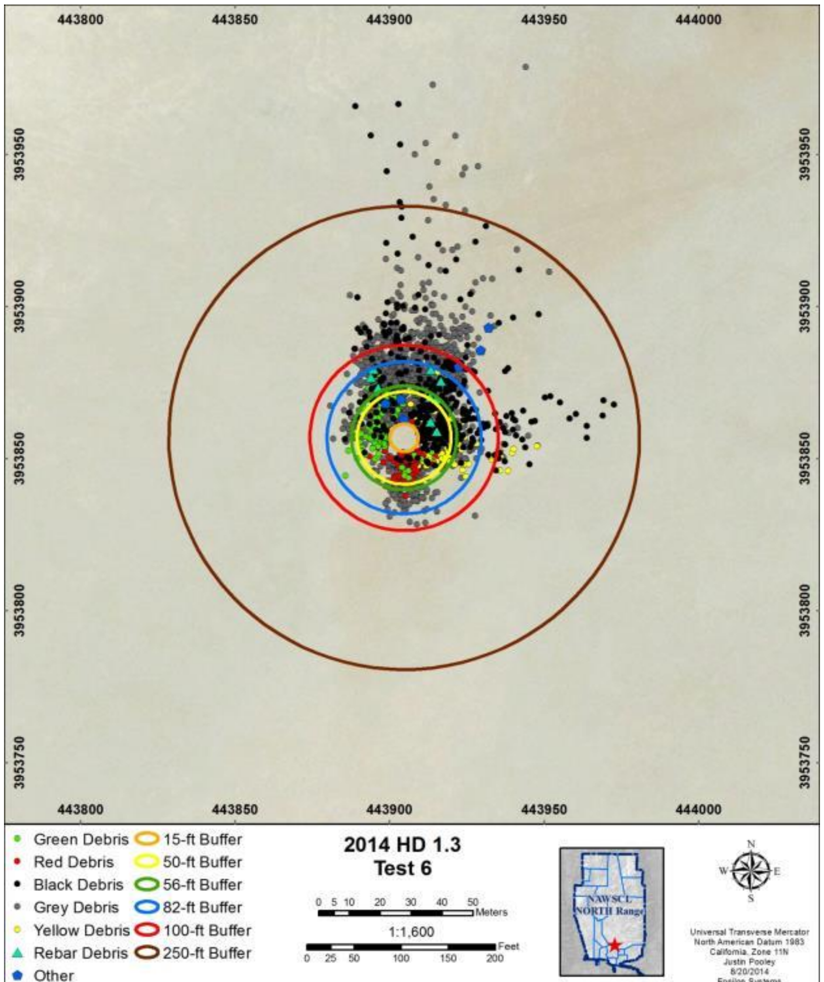
* Not all fragments 5-200 grams collected

- Test 4 – Lower Surface Area
  - 3244 collected
    - 1458 outside IBD
      - ~45 percent of collected
  - Largest = 11.56 kg
  - 162 at distance > 76.2 m
    - Furthest at 156 m

Secondary Fragments

Loading Density Differences

Test 6-0.063 g/cc



Test 7-0.030 g/cc

Loading Density Differences

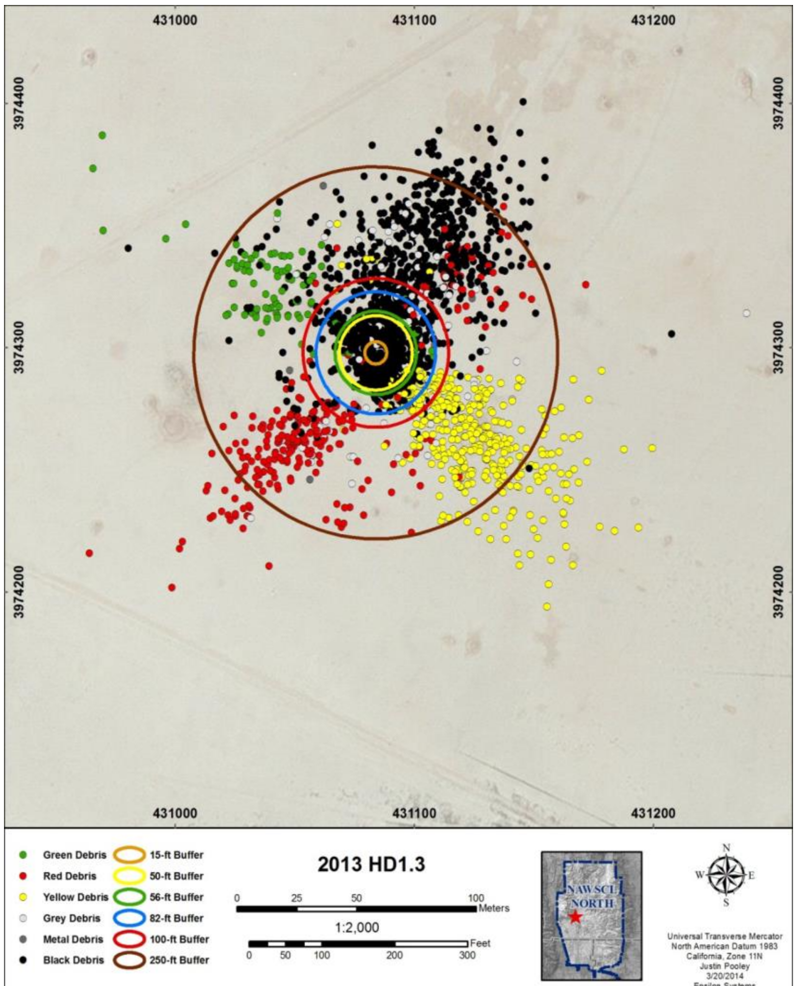
- <u>Test 6 - 0.063 g/cc</u>
  - 3415 collected
    - 546 outside IBD
      - ~16 percent of collected
  - Largest = 19.01 kg
  - 19 at distance > 76.2 m
    - Furthest at 128 m

- <u>Test 7 - 0.030 g/cc</u>
  - 778 collected
    - 293 outside IBD
      - ~38 percent of collected
  - Largest = 3.48 kg
  - 16 at distance > 76.2 m

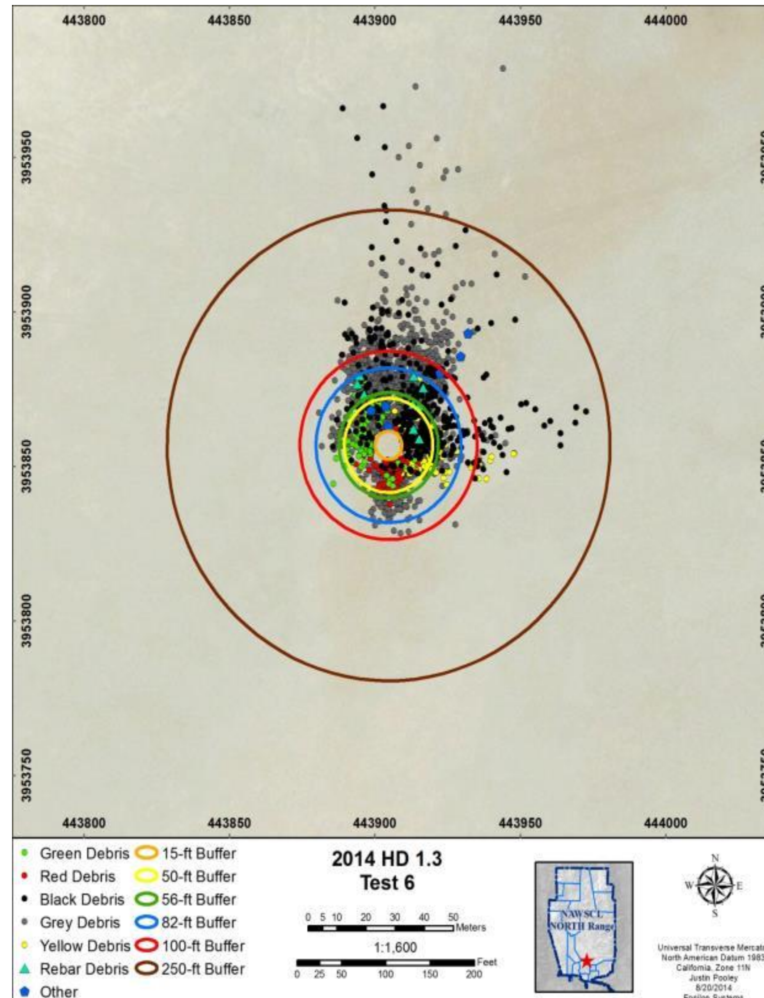
Secondary Fragments

Structural Differences

Test 4-fails at roof



Test 6-fails at floor

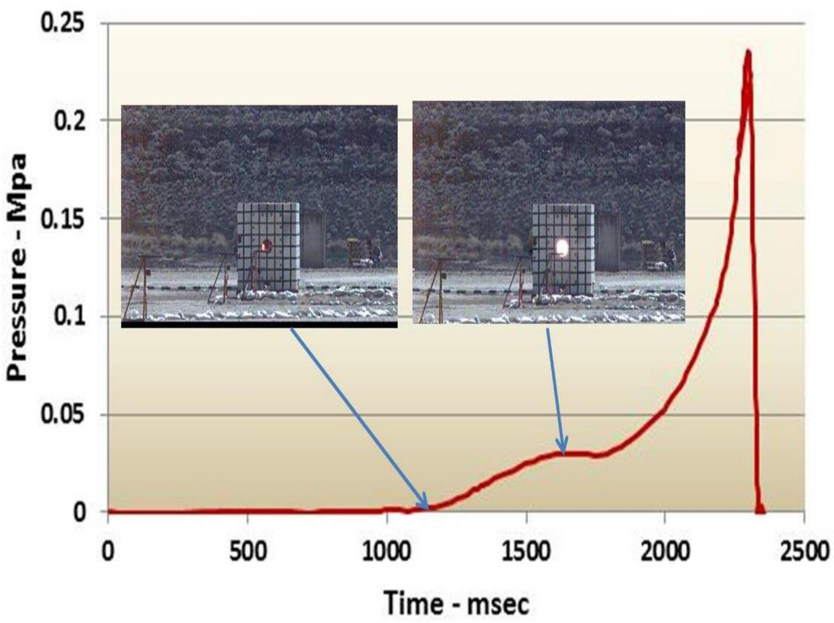


Structural Differences

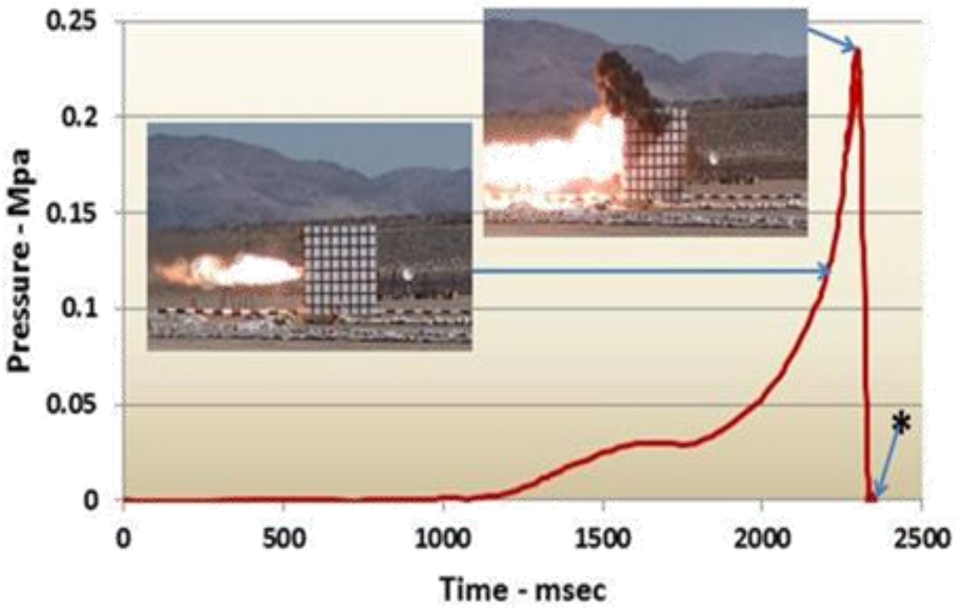
- <u>Test 4 - fails at roof</u>
  - 3244 collected
    - 1458 outside IBD
      - ~45 percent of collected
  - Largest = 11.56 kg
  - 162 at distance > 76.2 m
    - Furthest at 156 m

- <u>Test 6 - fails at floor</u>
  - 3415 collected
    - 546 outside IBD
      - ~16 percent of collected
  - Largest = 19.01 kg
  - 19 at distance > 76.2 m
    - Furthest at 128 m

Combustion and Structural Response



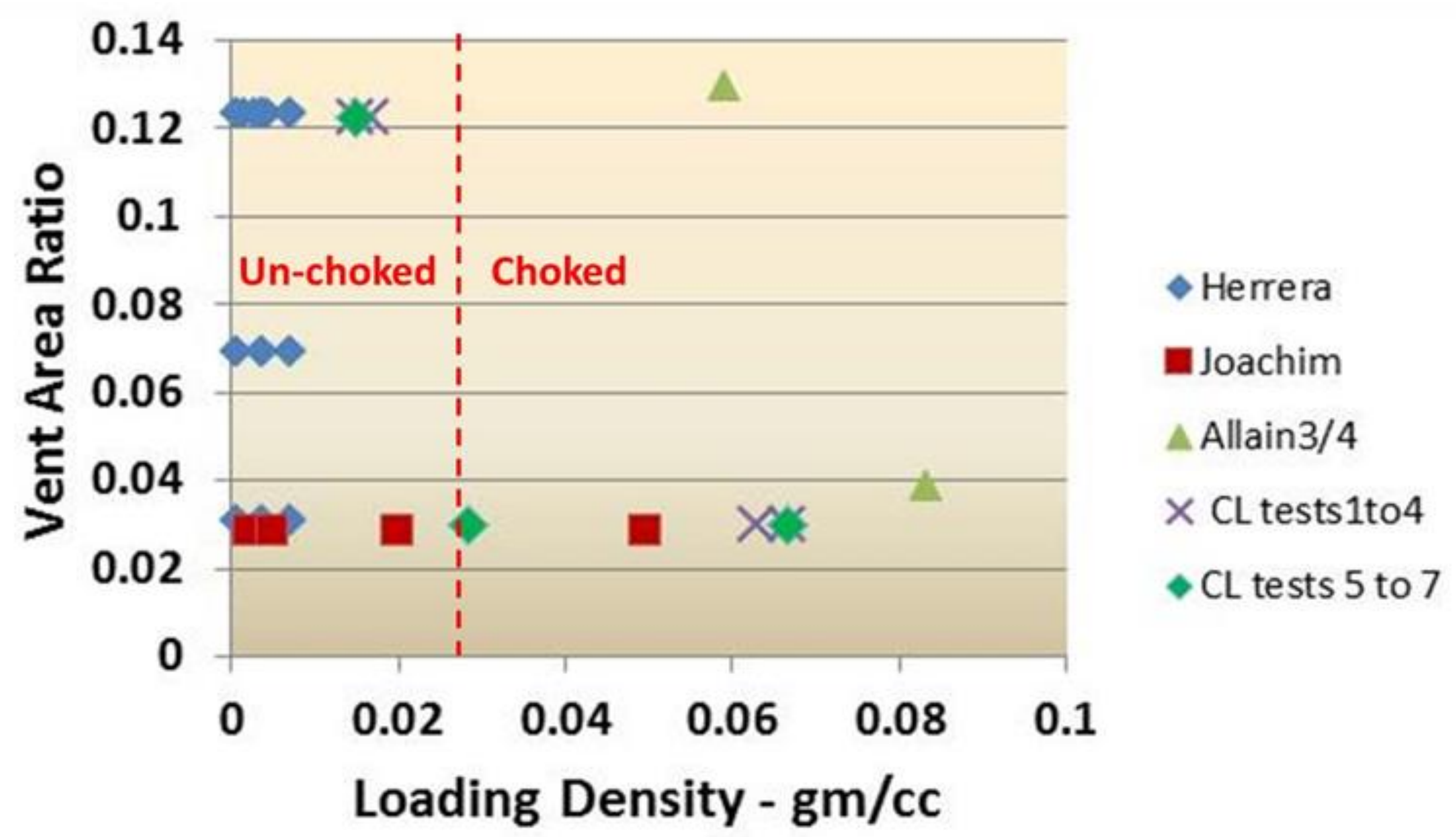
Relating the Plume/Fireball Formation With Internal Pressure, Test 4.



Plume Formation and Structural Failure, Test 4.

HD 1.3 Test 4 at Pressure Drop

M1 Vent Area Ratio versus Loading Density



$VAR = A_v / (V_{ch})^{2/3}$

What about a real magazine?

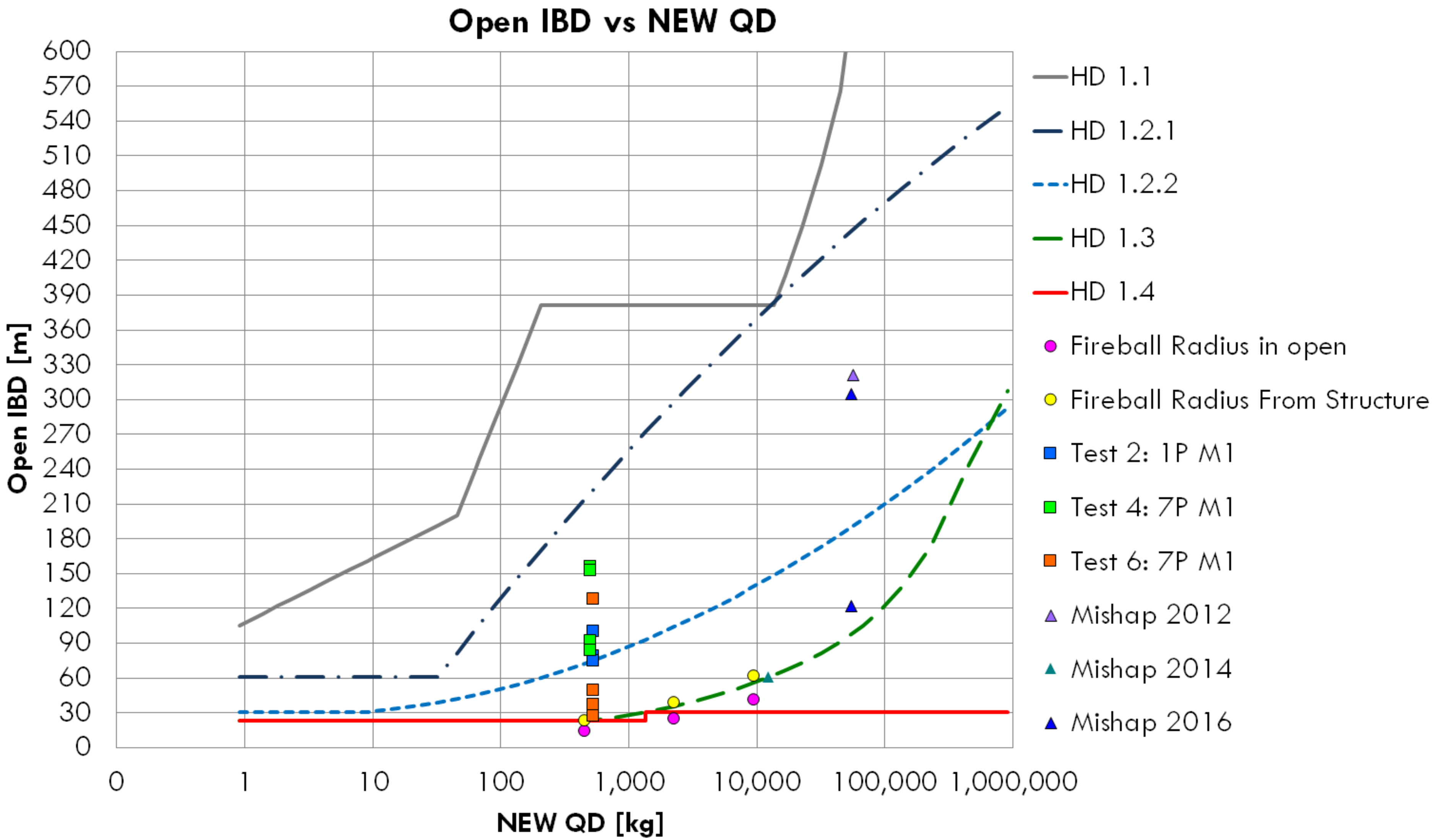
Assume loading to

500,000 lbs (226,796 kg)

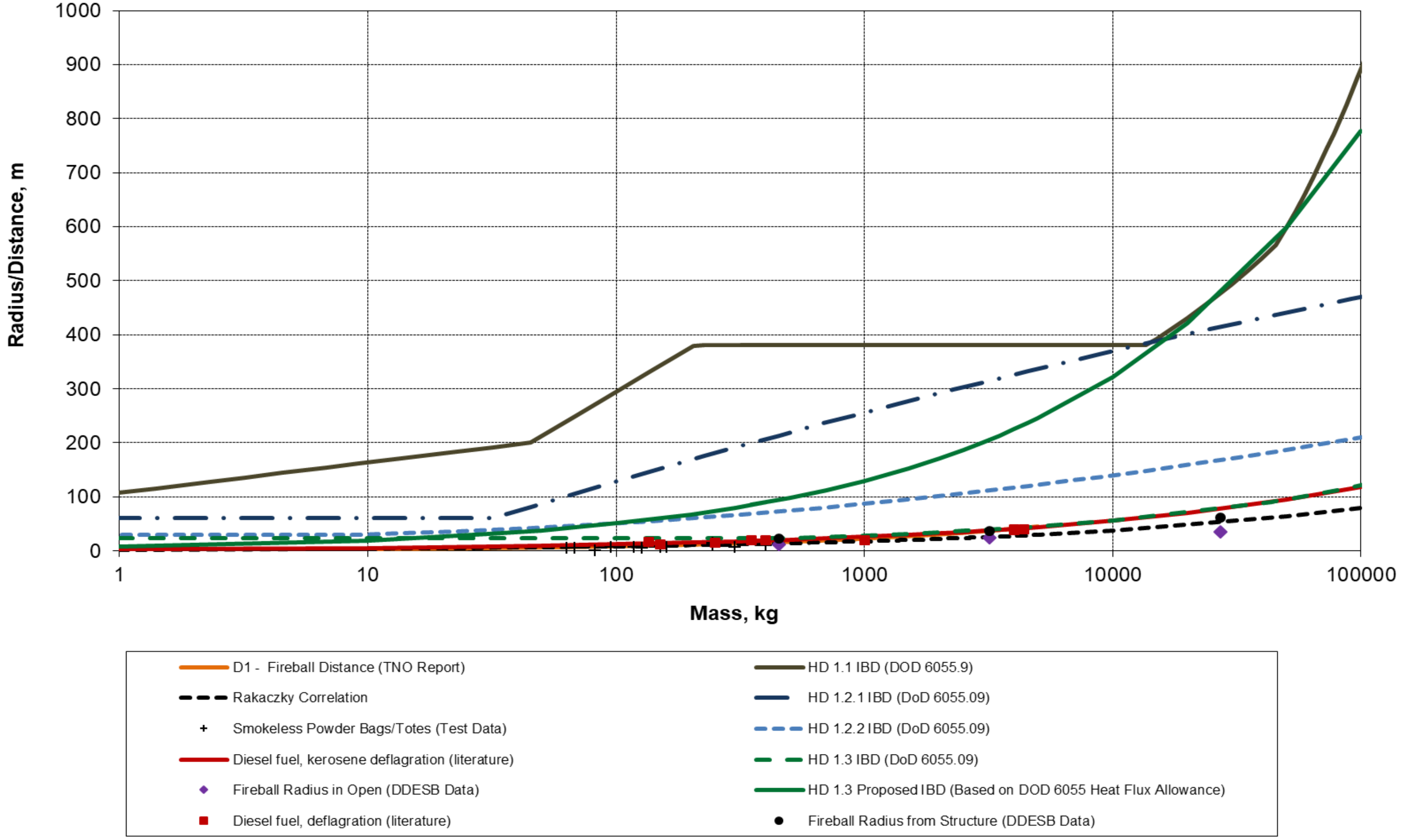
Magazine

Magazine Type and Dimensions	Maximum Loading Density Assuming 226796 kg NEW (g/cm^3)	VAR $A/V^{2/3}$
RC Box 421-80-06	0.364	0.316
RC Circular Arc, NAVFAC 1404310-1404324		
24.38 m long, door area 9.29 m^2	0.43	0.1423
24.38 m long, door area 14.86 m^2	0.43	0.228
RC Arch 421-80-05		
27.43 m long, door area 5.95 m^2	0.3	0.0725
27.43 m long, door area 9.29 m^2	0.3	0.113
24.38 m long, door area 5.95 m^2	0.338	0.0785
24.38 m long, door area 5.95 m^2	0.338	0.122
18.29 m long, door area 5.95 m^2	0.45	0.0951
18.29 m long, door area 9.29 m^2	0.45	0.148
Steel Arch 421-80-01		
27.13 m long, door area 5.95 m^2	0.309	0.073
27.13 m long, door area 9.29 m^2	0.309	0.114
Lone Star, 18.29 m x 8.08 m x 3.89 m	0.252	0.0691
Indian Head, 24.99 m x 7.62 m x 3.35 m	0.226	0.0691
Radford, 25.04 m x 7.62 m x 3.96 m	0.191	0.0299

Current QD Tables



IBD Vs. Mass (kg) With 2012 Proposed IBD Based on Heat Flux to Protect Personnel From 2nd Degree Burns



Conclusions

- Thermal stimuli account for over 75% of large mishaps
- IBD based on thermal flux to *prevent the onset of second-degree burns (heat fluxes and exposure times experienced by personnel should be less than that given by the equation* $t=200q^{-1.46}$ *where "t" is the time in seconds that a person is exposed and "q" is the received heat flux in kilowatts (kW) per* m^2*)*".
- A step-by-step risk assessment based on hazards should be considered for explosives storage facilities–choked vs un-choked, directional effects, structural and instrumentation debris, impulse, and blast
- Experiments and modeling efforts should be synergistic and consider hazards during the entire system life cycle
- Combustion properties of the HD 1.3 substances should be used to gain an understanding of the potential hazard response
  - Propellant surface area and it's role in pressurization
  - Confinement and structural effects are significant.
  - Tests where structure ruptured significant debris was found beyond IBD.

References/ Acknowledgements

C. P. Romo, et al. The 6th International Symposium on Energetic Materials and their Applications 6-10 Nov., 2017, Tohoku University, Sendai, JAPAN; "Science and Technology of Energetic Materials, Vol. 79, No. 1 (2018)".

NAWCWD TM 8668 Realistic Safe-Separation Distance Determination for Mass Fire Hazards

NAWCWD TM 8742: Combustion of Hazard Division 1.3 M1 Gun Propellant in a Reinforced Concrete Structure

NAWCWD TM 8764: Combustion of Hazard Division 1.3 M1 Gun Propellant in a Reinforced Concrete Structure. Part 2. Tests 5 Through 7

Acknowledgements

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