Siting Assessment for Sounding Rocket Missions

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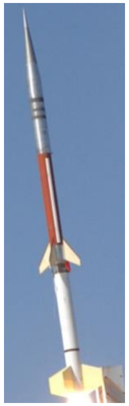
Outline

- Problem Description
- Generic Sounding Rocket
  - *Propellant Summary*
- Physics-based Analyses
  - *Detonation*
  - *Pressurized Burst*
- Comparison of IBD
  - *Explosives Standards vs. Physics-based Analyses*

Problem Description

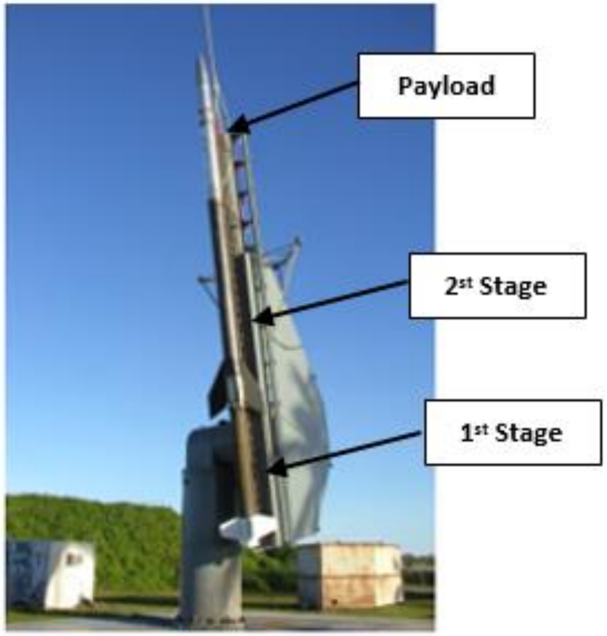
- **The U.S. sounding rocket program has been active for 50+ years using a variety of rocket configurations/stages/sizes/propellants**
- **The hazardous propellants can have multiple Hazard Divisions (HD's)**
  - ***HD 1.1 (mass detonating); HD 1.2 (fragment producing); HD 1.3 (mass fire)***
- **For pre-launch operations (e.g., processing, testing, integration), an Explosives Safety Site Plan (ESSP) must be developed and approved by the DDESB and/or the responsible Organization/Service**
  - ***Quantity-Distance (QD) safe separation distances must be met:***
    - **Intermagazine, Intraline, Public Traffic Route, Inhabited Building Distance**

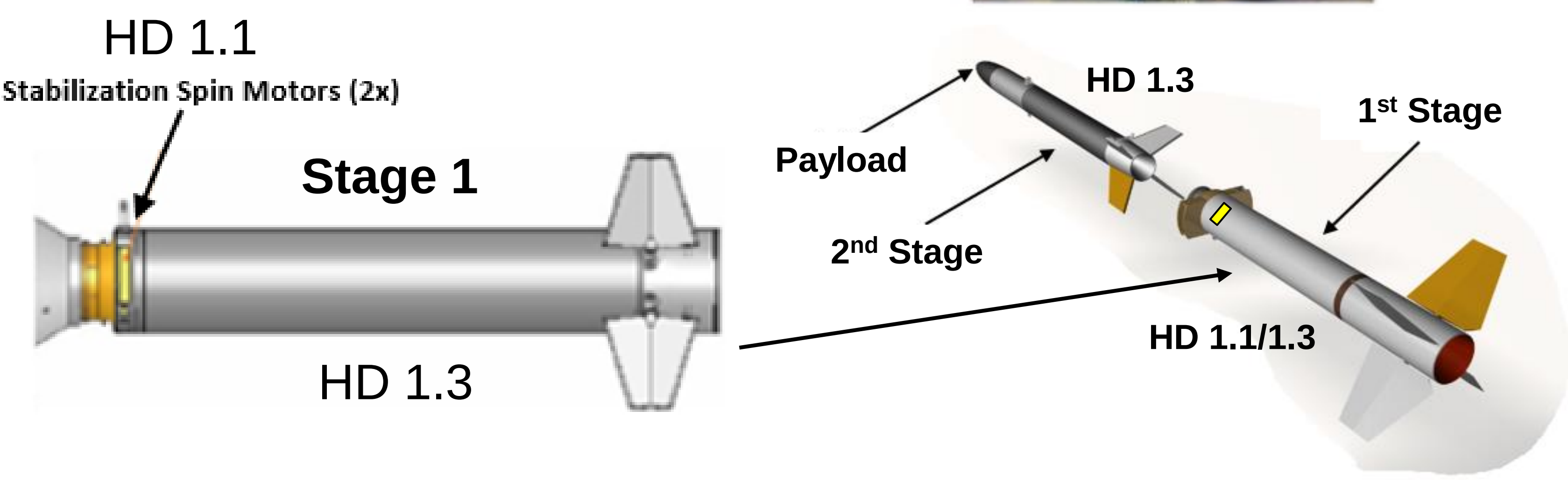


- **If a sounding rocket uses a combination of HD 1.1 propellant in close proximity to other HD's, the DoD Explosives Standard "mixing rule" requirements state:**
  - ***The Net Explosive Weight (NEW) is the sum of all HD's and shall be considered HD 1.1 "unless technical justification is provided to reduce the amount".***
  - ***This requirement can lead to violations of QD distances & affect operations***

Generic Two-Stage Sounding Rocket

- **To demonstrate this issue, we will look at a generic two-stage sounding rocket**
  - ***Stage 1*****: HD 1.3 solid rocket motor w/ two small HD 1.1 spin stabilization motors**
  - ***Stage 2*****: HD 1.3 solid rocket motor**
  - ***Payload*****: no hazardous propellant**





Summary of Propellant Weights

- **The propellant weights shown below for the "generic" sounding rocket are approximate but representative**

Rocket Stage	Component	Hazard Division	Approx. Propellant Weight (lb)
Stage 1	Propellant	HD 1.3	1,500
	Spin Motors (2)	HD 1.1	2 each
Stage 2	Propellant	HD 1.3	1,000
		Total	~2,504

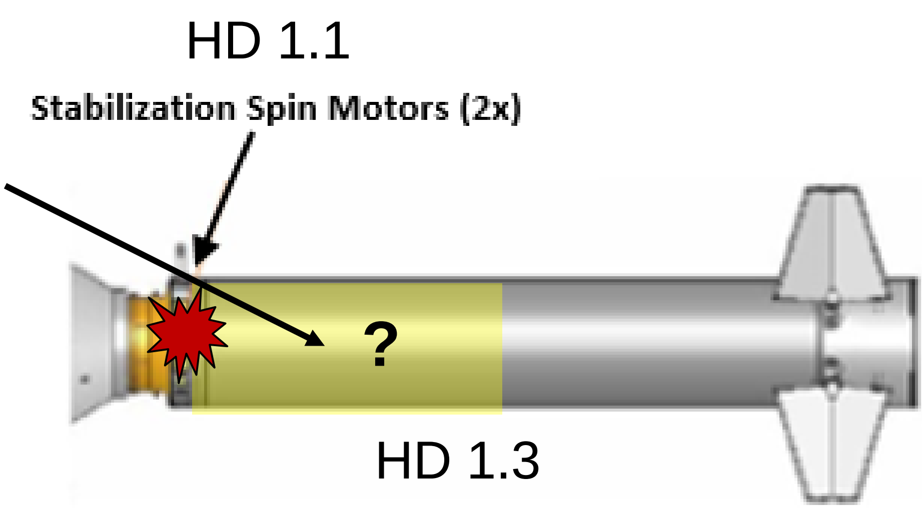
Based on DoD "mixing" rules, the NEWQD would be 2,502 lbs, TNT and considered HD 1.1. And, inhabited Building Distance (IBD) is:

IBD (air blast) = 543 ft
IBD (fragmentation) = 1250 ft

Detonation Analysis (1)

- Since the DoD Explosives Standard allows for "technical justification to reduce the NEWQD", a shock physics analysis was performed

- The focus was on an HD 1.1 spin motor detonation & how much of the HD 1.3 Stage 1 propellant would promptly react and contribute to the spin motor NEWQD

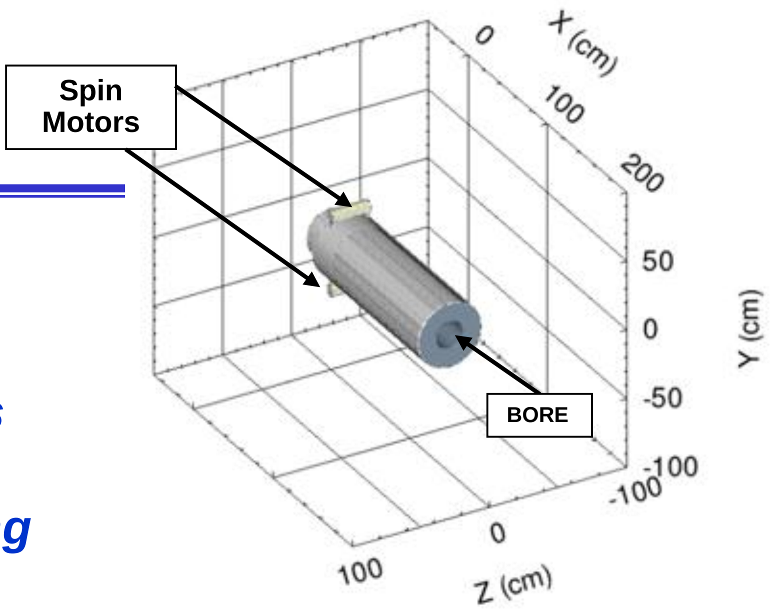


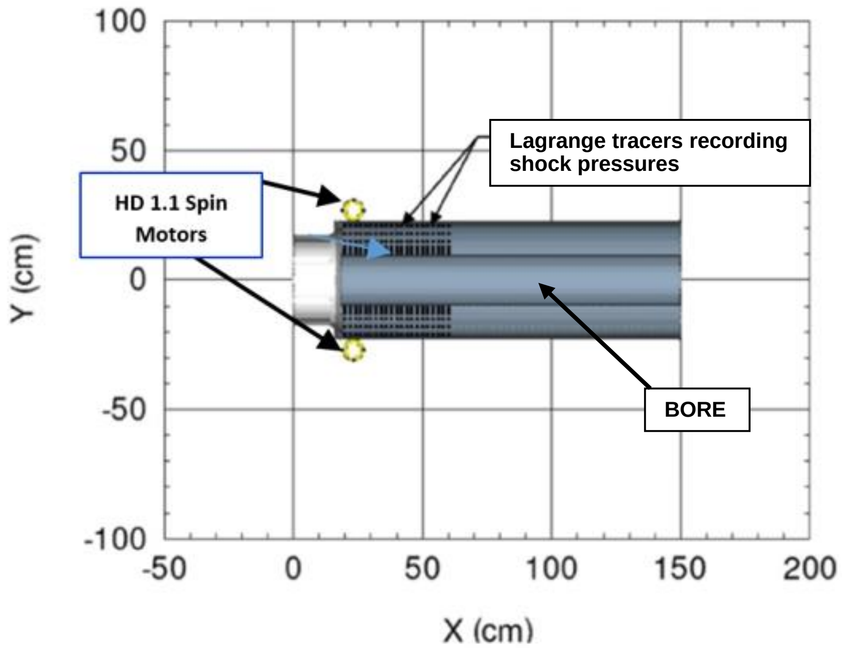
- The Stage 2 motor is sufficiently separated from the Stage 1 motor by an interstage so that it will not participate sympathetically

Detonation Analysis (2)

- **A CTH Model was used to perform a shock physics analysis**
  - ***Their PMOD propellant reaction models were used to represent the Stage 1 HD 1.1 & HD 1.3 equations of state including both solid- & gas-phase***

- **A grid of Lagrangian tracers were placed along the top portion of the Stage 1 propellant**
  - ***Tracers were located on the surface as well as radially inward to the propellant bore***
  - ***The tracers monitored the pressure as a function of time***

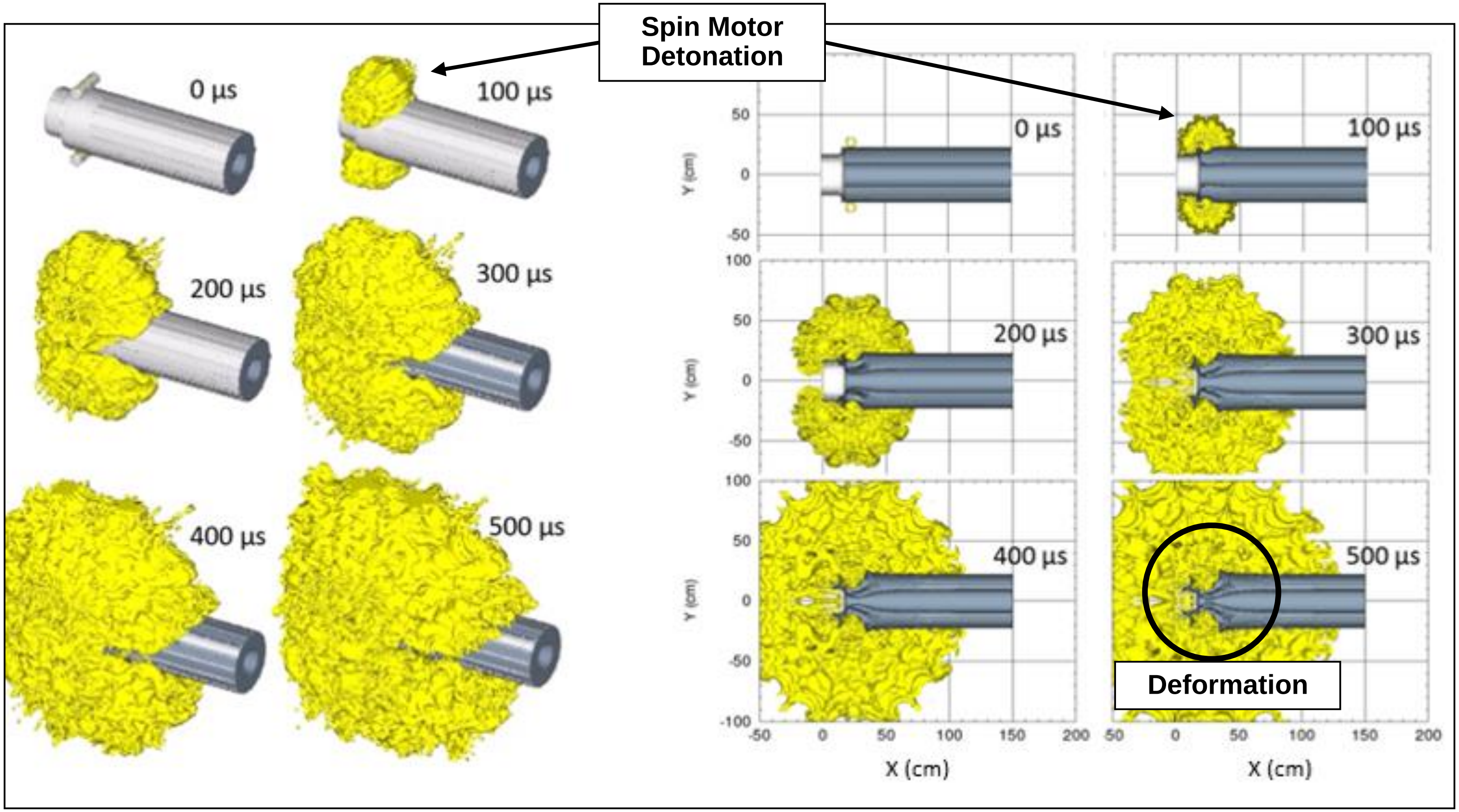




CTH is a family of codes developed at Sandia National Laboratories (SNL) for the purpose of modeling complex multi-dimensional, multi-material problems that are characterized by large deformations and/or strong shocks.

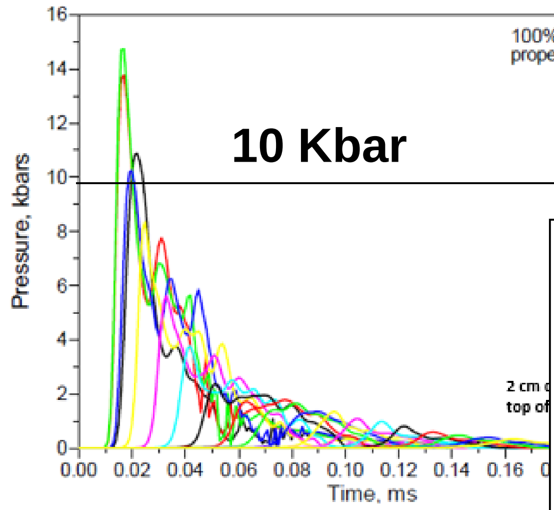
Detonation Analysis (3)

- **The CTH simulation is seen to severely deform the forward end of the Stage 1 propellant where peak pressures occur due to the spin motor detonation**



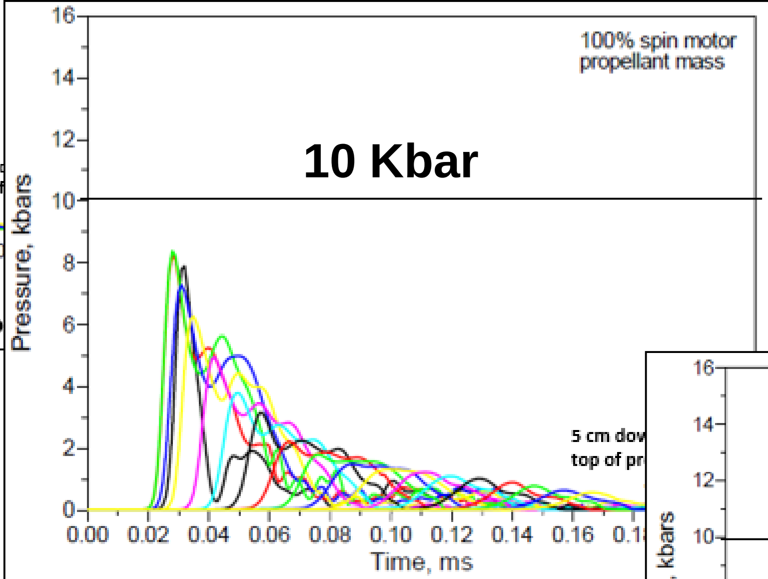
Detonation Analysis (4)

- **Shock pressure decays rapidly w/ distance from spin motor detonation**



a) 2-cm intervals, 2-cm down from top o

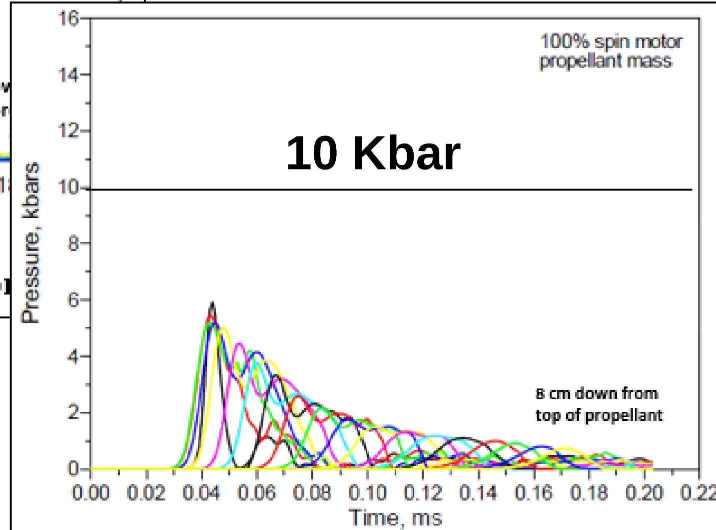
2 cm from top



b) 2-cm intervals, 5-cm down from top of pr

5 cm from top

8 cm from top



c) 2-cm intervals, 8-cm down from top of propellant

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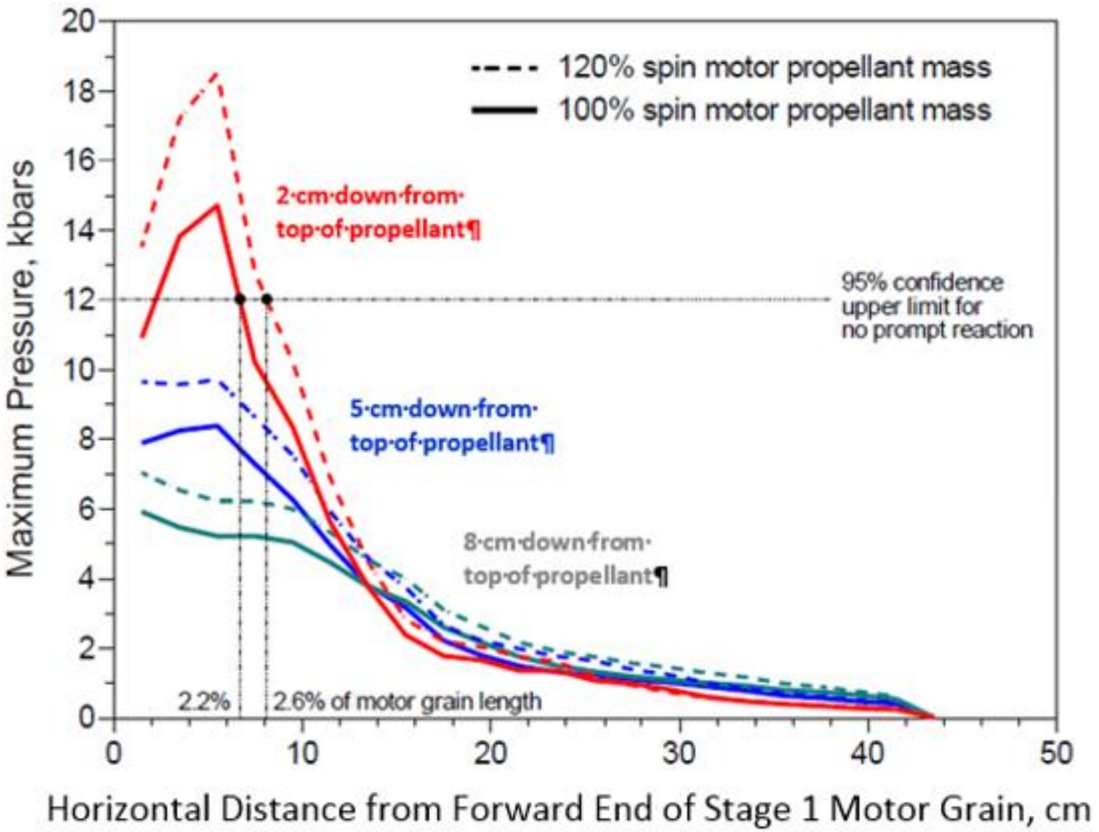
Detonation Analysis (5)

- **Analyses using shock Hugoniot (i.e., shock pressure versus shock velocity) data and 60-inch critical diameter data for an HTPB composite propellant very similar to the Stage 1 propellant showed the:**
  - ***95% confidence lower limit of the shock pressure threshold for prompt reaction was estimated to be 12 kbars.***
- **Using 12 Kbars as the conservative threshold:**
  - ***Only about 2.2% of the propellant on the forward end of the Stage 1 HD 1.3 propellant would promptly react or 34 lb, TNT***
- **NEWQD (including spin motors) = 45 lbs, TNT**

Maximum Pressure vs Distance from Forward End of Stage 1



Includes yield factors of 1.2 for HD 1.3 propellant & 1.25 for HD 1.1 spin motors

Stage 1 Burst Analysis

- If a motor stage ignites it may quickly build up internal pressure due to a clogged nozzle and burst
- A conservative estimate of the energy released from a motor burst was performed:
  - *Internal volume = 0.54 m^3*
  - *Max operating pressure = 1500 psia*
  - *Gamma (specific heat ratio) = 1.2* ***(based on Cheetah)***
- Stored Energy (U) = 110 MJ

$$U = \frac{PV}{\gamma - 1}\left[1 - \left(\frac{P_{atm}}{P}\right)^{\left(\frac{\gamma-1}{\gamma}\right)}\right]$$

- **Equivalent TNT = 46 lb**
- This is a conservative estimate

Comparison of NEW and IBD

<table>
<tr><th rowspan="2">Blast Hazard</th><th colspan="2">Based on DoD Mixing Rules</th><th colspan="2">Based on Shock Physics Analysis</th><th colspan="2">Based on Gas Physics Analysis</th></tr>
<tr><th>NEW (lb)</th><th>IBD (ft)</th><th>NEW (lb)</th><th>IBD (ft)</th><th>NEW (lb)</th><th>IBD (ft)</th></tr>
<tr><td>Overpressure</td><td rowspan="2">2504</td><td>543</td><td rowspan="2">45</td><td>142</td><td rowspan="2">46</td><td>143</td></tr>
<tr><td>Fragmentation</td><td>1250</td><td>593</td><td>595</td></tr>
</table>

- **Clearly, using the DoD “mixing” rule results in an over-estimation of the NEWQD and the required separation distances**
- **The shock and gas physics analyses indicate that technical justification can be made to reduce:**
  - ***Air Blast IBD by ~75%***
  - ***Fragmentation IBD by ~50%***
- **Such distance reductions can have a significant impact on being able to perform pre-launch sounding rocket operations while still ensuring personnel safety**


The End