Realistic Assessment of Hazard Division 1.3 Events

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Agenda

- Review of current QD methodology
- NATO AASTP-1 vs. US DOD 4145.26-M
- IBD comparisons from AASTP-1
- Accident and test review/comparison
- Practical implications
Current QD Methodology

- HD 1.1 and HD 1.3 based on NEWQD
- Primary hazard for HD 1.1
  - Detonation resulting in overpressure and fragmentation
  - All energetic material consumed in milliseconds
- Primary hazard for HD 1.3
  - Mass fire resulting in high levels of heat flux
  - Accidents and testing show that with adequate venting (no «choked flow»), propagation of fire takes minutes to hours
- Does weight-based QD provide a realistic assessment of the hazard from HD 1.3 materials?
Not a new idea...

- Papers sponsored by the DDESB in 2010 and 2013 discuss the shortcomings of weight-based QD for HD 1.3 materials.
- Both discuss the importance of choked flow:
  - Proper construction with consideration for adequate venting to prevent an event similar to detonation.
- Disparities in current weight-based QD calculation methods for HD 1.3 materials...
Weight-based QD does not account for...

- Initiation energy
- Reaction rate
- Article in which the HD 1.3 material is embedded
- Energy density of the substance
- Critical diameter or total mass of the substance
- Confinement of buildings or technical equipment due to inadequate venting area (choked flow)
- Cause of fatalities (burns to personnel)
Subcategories of HD 1.3 within AASTP-1

• HD 1.3.1: Explosives producing a mass fire effect
  • fireball with intense radiant heat
  • firebrands
  • some fragments where the firebrands may be massive fiery chunks of burning propellant

• HD 1.3.2: Items other than propellants that produce a moderate fire with moderate projections and firebrands
  • projections include fragments but these are less hazardous than those which characterize HD 1.2
AASTP-1 vs. DOD 4145.26-M

- Both are weight based (NEWQD)
- AASTP-1 uses cube root
- 4145.26-M uses exponential function
- AASTP-1: 41% longer QD
Disparities within AASTP-1

- Four models in AASTP-1 from NATO, Norway/Sweden, Switzerland, and the Netherlands
- Four different answers...
0.5 kg of black powder injured a Norwegian EOD officer due to failure to secure the fuze
- Event occurred ~0.7m (arms length) away
- Resulted in superficial burns to his face
- Is the 60m IBD required by AASTP-1 or the 22.9m IBD required by DOD 4145.26-M warranted based on this accident?
- Black powder has a relatively low energy density (~3MJ/kg)
  - Weight-based QD does not account for the energy density of different HD 1.3 materials
Finnish Test

- Finnish Ministry of Defense tested behavior of HD 1.3 propellant in two 40-foot ISO containers
- Observed the flame jet and fireball resulting from ignition of propellant in one of the containers
- Measured the time for the contents of the second container to ignite
16 tons of HD 1.3 propellant

Flame jet formation
Fireball formation
Comparison of calculations for IBD and fireball diameter

<table>
<thead>
<tr>
<th>NO-SW 1% lethality</th>
<th>SUI 1% lethality</th>
<th>NL 1% lethality</th>
<th>US DOD 4145.26-M</th>
<th>NATO AASTP-1</th>
</tr>
</thead>
<tbody>
<tr>
<td>117m</td>
<td>94m</td>
<td>49m</td>
<td>66m</td>
<td>161m</td>
</tr>
</tbody>
</table>

- Fireball diameter prediction model calculations for 16 tons of propellant according to AASTP-4 Part II
- Again, four different answers...
- IBD for 16 tons of propellant
- Five different answers...most conservative model yields a QD 328% longer than the least conservative model
Between 2011-2013, the DDESB conducted a series of tests to evaluate choked flow effects.

**Test Structure for Current Project**

- Similar Construction to Kasun
  - Door modified to ensure seals and insertion of vent
    - 79 cm (vent area ratio – 0.06)
    - Unchoked Flow
    - 39 cm (vent area ratio – 0.01)
    - Choked Flow
- HD 1.3 Material
  - M1 gun propellant
    - NC
  - Large Surface Area
- 4 Tests
  - Loading Densities
    - 0.01 g/cc
      - 2 Unchoked Flow
    - 0.05 g/cc
      - 2 Choked Flow
Fireball/flame jet calculations from AASTP-4 Part II

<table>
<thead>
<tr>
<th>Test 1 - Unchoked flow</th>
<th>Test 2 - Unchoked flow</th>
<th>Test 3 - Choked flow</th>
<th>Test 4 - Choked flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>130kg propellant</td>
<td>533kg propellant</td>
<td>120kg propellant</td>
<td>503kg propellant</td>
</tr>
<tr>
<td>Predicted flame jet 21.5m</td>
<td>Predicted flame jet 32.2m</td>
<td>Predicted flame jet 21m</td>
<td>Predicted flame jet 31.5m</td>
</tr>
<tr>
<td>Predicted fireball* 3.8-20m</td>
<td>Predicted fireball* 7.1-33m</td>
<td>Predicted fireball* 3.7-20m</td>
<td>Predicted fireball* 7.0-32m</td>
</tr>
</tbody>
</table>

Predicted fireball and flame jet from DDESB tests, (* the range of predicted fireball diameters represents different models given in AASTP-4 part II for different reaction rates)
- Choked flow, 503kg
- Rupture of structure
Realistic Hazard Assessment

- Rocket motor production facility at Nammo Raufoss AS
- Building 108 is sited for 9500kg HD 1.3
- IBD with weight-based QD is 55.5m
- Building is constructed with reinforced concrete walls/roof with a light venting wall to prevent choked flow
- Building is divided into numerous rooms/cells
  - Not possible for all 9500kg to ignite simultaneously
Building 108 layout

Light walls for venting in event of accident
### Weight-based QD vs. flame jet and fireball calculations

<table>
<thead>
<tr>
<th>Room</th>
<th>HD 1.3 NEWQD</th>
<th>Required IBD, 4145.26-M QD value</th>
<th>Calculated Flame Jet total length (length along ground: 2/3 total length)</th>
<th>Calculated Fireball Diameter, $D_{FIRE}=3.97*(NEW*1.2)^{1/3}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room 4</td>
<td>1700</td>
<td>32,8</td>
<td>44,1 (29,4)</td>
<td>50,4</td>
</tr>
<tr>
<td>Room 5</td>
<td>1900</td>
<td>33,9</td>
<td>45,5 (30,4)</td>
<td>52,3</td>
</tr>
<tr>
<td>Room 6</td>
<td>2100</td>
<td>35,0</td>
<td>46,8 (31,2)</td>
<td>54,1</td>
</tr>
<tr>
<td>Room 9</td>
<td>650</td>
<td>24,7</td>
<td>33,7 (22,5)</td>
<td>36,6</td>
</tr>
<tr>
<td>Room 10</td>
<td>700</td>
<td>25,2</td>
<td>34,4 (23,0)</td>
<td>37,5</td>
</tr>
<tr>
<td>Room 11</td>
<td>2800</td>
<td>38,1</td>
<td>50,7 (33,8)</td>
<td>59,5</td>
</tr>
<tr>
<td>Room 14</td>
<td>3200</td>
<td>39,7</td>
<td>52,7 (35,1)</td>
<td>62,2</td>
</tr>
<tr>
<td>Room 15</td>
<td>1500</td>
<td>31,6</td>
<td>42,6 (28,4)</td>
<td>48,3</td>
</tr>
<tr>
<td>Room 20</td>
<td>125</td>
<td>22,9</td>
<td>21,3 (14,2)</td>
<td>21,1</td>
</tr>
<tr>
<td>Room 23</td>
<td>1300</td>
<td>30,3</td>
<td>40,9 (27,3)</td>
<td>46,1</td>
</tr>
<tr>
<td>Total</td>
<td>9500</td>
<td>55,6</td>
<td>71,4 (47,6)</td>
<td>84,1</td>
</tr>
</tbody>
</table>

*Flame jet/fireball* > weight-based QD*
Safety zones vs. weight-based QD
«A building with marked asymmetry of construction such as an igloo or building with protective roof and walls, but with one relatively weak wall or a door, induces very directional effects from the flames and the projection of burning packages.»

Unfortunately, there is no specific quantitative guidance in the form of calculations.
Conclusions

- Comparison of QD calculation methods shows high variability
- Engineering analysis should be conducted to produce a more realistic picture of the risk associated with the quantity and type of HD 1.3 materials
- Sufficient ventilation to prevent choked flow and consideration for hazard zones associated with directional flame jets/fireballs and ejected burning material is critical
- Reliance purely on weight-based QD tables can lead to being both overly conservative in some cases and overconfidence in others
- Assessing the risks associated with HD 1.3 materials requires further study