Updated Blast Effects and Consequences Models in DDESB TP-14 Revision 5

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• The U.S. Department of Defense Explosives Safety Board (DDESB) has established an approved quantitative risk assessment methodology (QRA) for evaluating and accepting risks associated with explosives storage and activities
  – Equivalent alternative to Quantity-Distance (QD) siting
  – Approved QRA model defined in DDESB Technical Paper (TP) 14

• This brief provides details of the explosion effects and consequence algorithms of TP 14, focusing on recent updates to the methodology
What is DDESB Technical Paper 14?

• DDESB TP 14 presents the underlying logic and algorithms used in the DDESB approved QRA methodology for risk-based explosives safety siting
  – Method is implemented in the approved QRA tool SAFER v3.1
  – Current approved version is Revision 4, but a draft Revision 5 has been developed and improvements shall be briefed herein
  – In future years, the DDESB-approved QRA tool will be the Risk Based Explosives Safety Siting (RBESS) tool within the DDESB’s Automated Site Planning software ESS

• Within the context of TP 14, risk is defined as follows:
  – Risk = Likelihood * Consequence * Exposure
  – Risk = P_f = P_e * P_{f|e} * E_p

• This presentation shall focus on the $P_{f|e}$ term of the equation, which can also be termed as “the probability of fatality given the event occurs and a person is present”
TP 14 Architecture

- TP 14 employs a 26-step process
  - The first step is to admit that you have a QD violation…
- The architecture is defined by a logical flow that starts at the scenario input, accounts for all of the potential harmful effects generated by an explosion, and quantifies both the individual and group risk
- The individual Steps are bunched into a series of six Groups
- Focus of this brief is the “Science” Groups, 2 through 5
TP-14 Revision 5 Update

• Since the publication of TP-14 Revision 4 in 2009, there have been numerous updates to blast effects modeling
  – Improved numerical simulation techniques
  – Multiple explosives safety tests conducted

• Many of these improvements have been incorporated into TP-14 Revision 5, with the more critical ones being:
  – Window response and glass injury/fatality models
  – Secondary debris mass distribution
  – Explosion produced debris effects
  – Explosion produced debris consequences

• This briefing details the Revision 5 methodology, including many of these algorithm enhancements
Group 2 Steps: Pressure & Impulse Branch

• The Group 2 steps calculate the pressure and impulse acting upon exposed persons and the resulting consequences from these primary blast effects.

• Blast wave parameters at a given distance are baselined as a function of Kingery-Bulmash TNT based equations, but then require modification to account for the different explosive material, casing effects, and attenuation provided by the structure the explosive event occurs.

• Blast wave prediction methodology of DDESBL TP-17 Revision 3 is implemented in TP-14 Revision 5.
Group 2: Direct Blast Effects

• Pressure and impulse calculated at distance of exposed site (ES)
  – If person in the open blast effects are directly applied to calculate consequences
  – For persons in buildings, attenuation by structure is calculated

• Leakage pressure into building calculated using methodologies prescribed in UFC 3-340-02, “Structures to Resist the Effects of Accidental Explosions”

• Injury and fatality mechanisms due to direct blast are then calculate for each system vulnerability
  – Fatality: lung rupture, whole body displacement, & skull fracture
  – Major & Minor Injury: soft tissue damage, whole body displacement, & skull fracture
    • Soft Tissue Damage: lung, gastrointestinal tract, larynx, ear drum rupture
Group 3 Steps: Structural Response Branch

- Pressure-Impulse (PI) diagrams are used to quantify building damage.
- Composite PI diagrams were developed for each of the 21 ES structure types by analyzing component response and then averaging over the entire structure.
- Damage is then equated to injury and fatality as a function of ES type.
Group 3: Window Hazard Models

• Determination of hazards from windows is a multi-step process
  – Determine pressure and impulse from Group 2 steps
  – Calculated breakage probability as a function of window type (annealed, tempered, dual pane, & laminated annealed)
  – Determination of internal hazard area
  – Scale from nominal glass hazard (11.11%)

• Additional factors such as emergency response and presence of curtains are considered, as well as multi-hit effects that can elevate the consequence
Group 3: Window Model Background

- Window models are an engineering fit to the physics-based analysis used to develop them.
- Statistical distribution of glazing properties set and breakage probabilities established.
- Shard mass distribution and velocity profile at breakage determined.
- Shard flight and impact location on target calculated.
- Based on impact area (e.g., artery, eye, head, etc.), probability of minor injury, major injury, and fatality established.

* Laminated windows treated as blunt force trauma.
Group 4 Steps: Debris Branch

• End goal of quantification of debris effects is to discretize arriving debris into one of 10 kinetic energy (KE) bins
  – Injury and fatality from debris is defined as a function of KE
• Essential first step is to discretize all primary and secondary mass into one of ten mass bins

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Group 4: Mass Distribution

• The primary fragment (munition casing) mass distribution has been developed from generic munition types; is a function of size of the item
• Improvements in secondary debris (donor structure) mass distribution has been greatly aided by vast test data generated over the past decade
• Mass distribution is dynamic, in that it is a function of explosive weight
  – Higher explosive weight ➔ larger number of smaller pieces
Group 4: Initial Velocity

- Initial velocity for secondary debris is defined as a function of loading density for each PES type
  - Initial velocity increases with loading density
- Primarily use DLV formula with adjustments in TP-14 Rev 5
- Velocity functions developed via numerical simulation and analysis of test data

Klotz Group ISO container tests

NAVFAC EXWC
Group 4: Improved PDF Methods

- The approach is to perform drag-corrected trajectory simulations based on the TP14 fragment mass bin definitions:
  - Each simulation involves many trials; each trial varies key fragment parameters.
  - After each trial, the wall and roof impacts on an ES at various downrange distances are recorded.

- After a simulation, the wall/roof trial impacts are used to develop FRMs as a function of distance:
  - Probability of wall impact per lineal foot & mean KE
  - Probability of roof impact per lineal foot & mean KE
Group 4: Sample Problem – Concrete Building

- Potential Explosion Site (PES) = concrete building; wall & roof fragments
- Constant fragment parameters
  - Considered 10 average values defined by TP14 “concrete” mass bins
  - Takeoff Velocities $\geq 100 - 3,000$ ft/sec
- Random parameters
  - Fragment shape = box with aspect ratio ranging from 1 to 2 (between its 3 sides)
  - Drag Coefficient = based on tumbling box as a function of velocity
- Wall-Specific Parameters
  - Fixed Takeoff Height = 7.5 feet
  - Takeoff angle distribution = normal
    - Mean = +5 deg (upwards)
    - Standard Dev = 6 deg
  - Number of Monte Carlos = 5,000
- Roof-Specific Parameters
  - Fixed Takeoff Height = 15 feet
  - Takeoff angle distribution = normal
    - Mean = 90 deg (upwards)
    - Standard Dev = 6 deg
  - Number of Monte Carlos = 20,000

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- ES-Specific Parameters
  - ES Height = 15 ft
  - PES to ES distance (X) = variable

ACTA, Inc.
• Fast Running Models (FRMs) are developed based on simulated fragment impact data from a software program developed for this specific purpose.
  - Internally the trajectories are computed using the same integration algorithm in TRAJ_CAN

• Each FRM is in the form:
  \[ f(x) = \exp(a + bx + cx^2 + dx^3) \]
  where \( a, b, c \) and \( d \) are model parameters, \( x \) is the distance, and \( f \) is either impact probability or kinetic energy ratio.

• The parameters are determined through least-squares fitting to data generated by Monte Carlo simulations.
Group 4: PDF Technical Approach

- For each combination of the discrete parameters, FRM curves are generated for a series of takeoff speeds (up to 8,000 ft/s for primary fragments).

- FRM results are interpolated between two speeds.

- 320 tables are generated, corresponding to the combinations of 2 outputs × 8 debris source/types × 10 mass bins × 2 impact surfaces.

- Each table will have sufficient number of speed data points to ensure interpolation quality (typically about 15).
Group 4: Results Example

PES Wall PDF on ES Wall vs. Velocity ($M = 5.61 \text{ lb}$)

PES Wall PDF on ES Wall vs. Mass ($V = 1,000 \text{ ft/s}$)
Group 4: Results Example

PES Wall KE on ES Wall vs. Velocity \((M = 5.61 \text{ lb})\)

PES Wall KE on ES Wall vs. Mass \((V = 1,000 \text{ ft/s})\)
Group 4 Steps: Debris Branch

- Once the debris density distribution at the ES for all debris sources and types is determined, the protection afforded by conventional wall and roof construction must be determined.
- Perforation resistance/reduction in debris velocity is defined as a function of kinetic energy for each component (delta KE).
  - Values have been determined by extensive testing (SPIDER series) and modeling efforts to approximate delta KE values.
Group 4: Debris Impact Injury and Fatality

- Probabilities of injury and fatality are computed as a function of KE and hit area
  - Head, thorax, abdomen, and limbs
- Distributions of personnel size, orientation, and location assumed

Exposed Impact Areas in the Standing Position

Probability of Major Injury+

Probability of Fatality
Group 5 Steps: Thermal Branch

- The thermal effects and consequence routine in TP-14 Revision 5 is only intended for HD 1.3 material and is quite simplistic.
- Effects models are largely based on gun propellant.
- Three step process for determining thermal effects:
  - Quantify protection provided by PES and/or ES.
  - Determine injuries and fatalities due to radiant heat effects as a function of quantity of material and distance.
  - Perform final check of fireball radius to determine fatalities.
- Thermal consequences are not calculated for HD 1.1 material; only thermal consequences are calculated for HD 1.3 material.
Conclusions and Way Forward

• TP-14 Revision 5 is currently being finalized
• The QRA methodology will be officially released when the corresponding tool (RBESS) is fully implemented within ESS
• While TP-14 has been developed specifically for quantitative risk assessments associated with risk-based explosives safety siting, the consequence algorithms, $P_{f/e}$, can be used independently to support qualitative risk assessments, strictly consequence assessments, or other comparative studies to support optimization of funding allocation to support safety enhancements