



TYING EXPLOSIVES HAZARD CLASSIFICATION AND INSENSITIVE MUNITIONS TESTING TO EXPLOSIVE QUANTITATIVE RISK ASSESSMENT MODELING

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OVERVIEW

- Introduction
- Purpose of Explosive Hazard Classification (HC) and Insensitive Munitions (IM) Testing and what data are obtained from them
- Technical Paper 14 (TP-14) Rev 4 explosive models
- Incorporating HC and IM Test Data to the TP-14 Architecture
- How this could be done in Risk Based Explosives Safety Siting (RBESS)
- Benefits and limitations of using HC and IM tests to model an explosive in TP-14

INTRODUCTION

- TP-14 Rev 4 is the Department of Defense Explosives Safety Board (DDESB) approved methodology for calculating risk associated with explosives operations and storage.
- TP-14 includes models that estimate explosive effects and consequences. These models are anchored by various tests and years of research.
- Currently TP-14 uses generic HC and weapon types to define all possible scenarios.
- There are cases that using the generic models will cause overly conservative risk results.
- To more accurately model an Ammunition and Explosives (AE), data can be used from HC and IM tests.
- This paper looks at the various data obtained from the HC and IM tests of a AE and how that data can be applied to the TP-14 architecture to more accurately model the risk associated with that AE.

WHAT ARE HC TESTS AND WHAT DATA CAN BE OBTAINED FROM THEM?

- The main goal of HC and IM testing is to characterize the hazards of an AE. HC testing will indicate if an AE is detonable, creates fragments, is susceptible to sympathetically detonating, thermal hazards, etc.
- The HC testing protocol is defined in TB 700-2.
- There are 3 groups of testing that answer the following questions: Is the new substance an explosive? Is the substance or article too dangerous to transport? And what HC does the AE fall under?

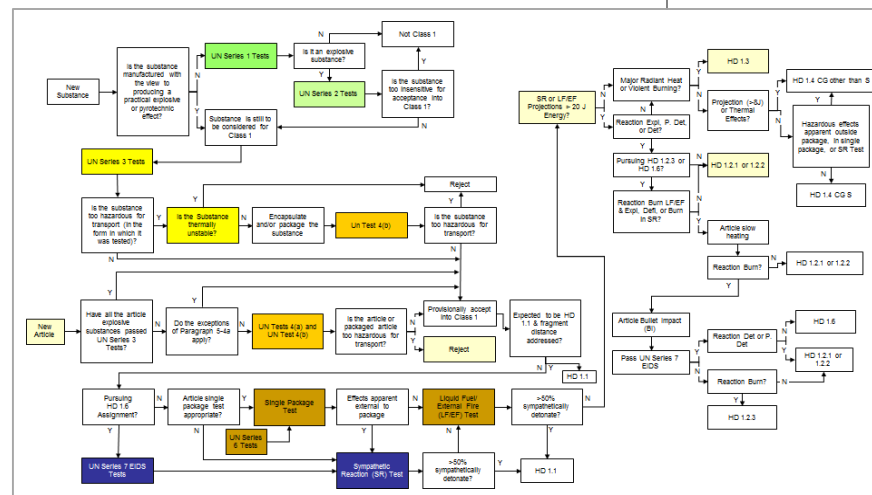
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WHAT ARE HC TESTS AND WHAT DATA CAN BE OBTAINED FROM THEM?

- For the purposes of modeling AE in TP-14, UN Test Series (TS) 6 tests provide the best data.
 - ▶ UN TS 6(a): Single Package (SP) Test – Demonstrates if hazardous effects are apparent outside the package when a single AE within the package is detonated. This test is conducted unconfined (UN TS 6(d)) and/or confined.
 - ▶ UN TS 6(b): Stack Test (ST) – Determines whether an explosion is propagated from one package to another or from an unpackaged article to another. This test is usually conducted unconfined and confined.
 - ▶ UN TS 6(c): Liquid Fuel/External Fire (FCO) – Demonstrates if reaction occurs when AE is exposed to liquid fuel/external fire.
- For all tests described above, debris recovery, blast measurements, thermal readings, and use of high-speed video are used.
- After the tests, data such as number of fragments generated, velocity of the fragments, maximum distance of fragments, overpressure, and thermal hazards can be generated for that specific AE.







WHAT ARE IM TESTS AND WHAT DATA CAN BE OBTAINED FROM THEM?

- IM testing determines the AE probability of an inadvertent initiation and severity of subsequent collateral damage to weapon platforms, logistic systems, and personnel when subjected to unplanned stimuli.
- MIL-STD-2015C has the IM testing and criteria requirements for the Department of Defense (DoD).

IM Threats

<u>FUEL FIRE</u> Such as a truck or an aircraft on a flight deck	<u>NEARBY HEAT</u> Such as fire in adjacent magazine, store or vehicle.	<u>BULLETS</u> Such as small arms from terrorists or combat	<u>FRAGMENTS</u> Such as from bombs, artillery, or IEDs	<u>SYMPATHETIC REACTION</u> Such as detonation of adjacent stores	<u>SHAPED CHARGE JET</u> RPG, Bomblets, ATGMs: Combat or terrorists
					

IM Tests

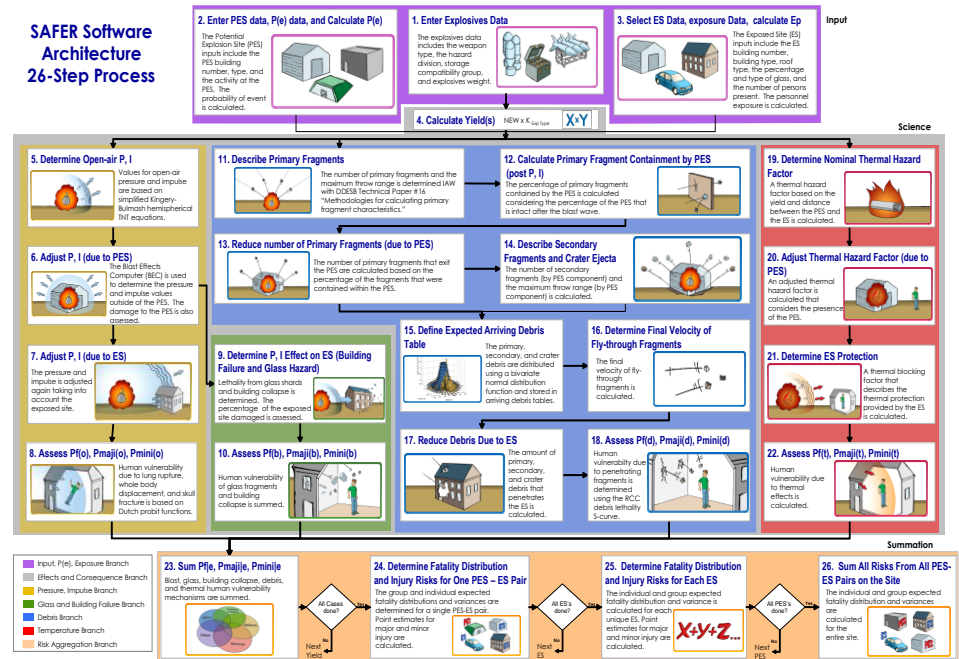
Fast Cook-off	Slow Cook-off	Bullet Impact	Fragment Impact	Sympathetic Detonation	Shaped Charge Jet
FCO	SCO	BI	FI	SD	SCJ
					

WHAT ARE IM TESTS AND WHAT DATA CAN BE OBTAINED FROM THEM?

- IM tests are evaluated by response of the AE
 - ▶ Type I (Detonation Reaction): Most violent type of explosive event
 - ▶ Type II (Partial Detonation): Some, but not all the energetic material, reacts as in a detonation
 - ▶ Type III (Explosion Reaction): Ignition and rapid burning of the confined energetic material builds up high local pressures leading to violent pressure rupturing of the confining structure
 - ▶ Type IV (Deflagration Reaction): Ignition and rapid burning of the confined energetic material leads to nonviolent pressure release
 - ▶ Type V (Burning Reaction): The energetic material ignites and burns, non-propulsively.
 - ▶ Type VI (No Reaction): No reaction of the energetic material without a continued external stimulus
- As with HC tests, IM tests also record a lot of data from the tests to determine the reaction of the AE. Pressure, impulse, debris, and thermal data are obtained with all the IM tests for that specific AE

TP-14 EXPLOSIVES CONSEQUENCE AND EFFECT MODELS

- TP-14 defines the models and logic associated with determining explosive effects and consequences for an explosive event
- A 26-step architecture is followed to model explosive consequences and associated effects
 - Steps 1 – 4: Situation definition, define explosive, event and exposure analysis
 - Steps 5 – 8: Pressure/Impulse branch
 - Steps 9 – 10: Building Failure/Glass Branch
 - Steps 11 – 18: Debris Branch
 - Steps 19 – 22: Thermal Branch
 - Steps 23 – 26: Risk results aggregation



TP-14 EXPLOSIVES CONSEQUENCE AND EFFECT MODELS

If HC and IM tests are used to define an explosive in TP-14 logic, the following steps are used:

- **Step 1:** Enter explosive data. The user enters explosive data, which includes net explosive weight (NEW), compatibility group (CG), and if needed, number of containers. The user also defines the specific AE to model using the HC and IM tests.
- **Step 4:** Calculate yields of the explosive. The yield is calculated for both maximum and expected NEW and maximum and expected % contribution. Currently, generic HC is used to calculate both maximum and expected yield. TNT conversation factors are also used to calculate the equivalent NEW.
- **Step 5:** Determine open-air pressure and impulse. Uses the yield in Step 4 and Kingerly-Bulmash hemispherical TNT equations to calculate the unmodified, or open-air pressure and impulse.
- **Step 11:** Describe primary fragments. To characterize fragments, TP-14 uses KE/mass bins. Step 11 begins the characterization of the primary fragments produced by the AE by performing two functions in TP-14. In Step 11a, TP-14 determines the number of primary fragments distributed over the 10 mass bins. Currently, TP-14 uses predefined weapon types to define the mass bins. In Step 11b, TP-14 determines the maximum throw range of the primary fragments.

TP-14 EXPLOSIVES CONSEQUENCE AND EFFECT MODELS

- **Step 14c and d:** Describe crater ejecta. The ejecta is also defined by the 10 mass bins. Characterization of crater ejecta is based on the type of soil around the PES. Currently there are predefined ejecta mass bins for rock or hard clay, looser soils, and concrete. The crater radius and maximum throw range are estimated in this step.
- **Step 19:** Determine nominal thermal hazard factor. TP-14 considers the effects and consequences due to heat if the explosive is a HD 1.3. Currently if a HD 1.3 is used, TP-14 does not consider any other consequence mechanisms (overpressure, debris, glass, etc.). The thermal hazard factor is a function of yield and distance between the PES and ES.

INCORPORATING HC AND IM TEST DATA INTO DEFINING THE AE IN TP-14

- HC and IM tests can obtain pressure, impulse, and debris information.
- Each test can provide different results, because of the different testing stimulus and if they are under confinement or not.
- It is up to the user to decide what data to use for each TP-14 step.
 - ▶ Use the worst-case data from all the tests. For example, the SCO test provided the greatest pressure and impulse, the FI test had the furthest fragment and initial velocity, the SD test had the largest crater, and the FCO test had the largest amount of debris generated. This option will be the most conservative.
 - ▶ Determine the most likely threat that can cause an explosion of the AE. If a study is shown that a fire is the only credible event causing an explosion of the AE, the FCO test results should be used to model the AE in TP-14.

EXAMPLE SCENARIO

Data From HC and IM Tests

- A weapon went through the following testing – Single Package (SP) (confined), Single Package (unconfined), Sympathetic Detonation (confined), FCO, SCO, BI, FI, and SCJ
- Pressure and impulse measurements, full debris recovery, and high-speed video were done for each test
- The table below summarizes the data taken from each test

Test	TNT EQ	Primary Fragments Mass Bins - # pieces										IV (ft/s)	MFR (ft)
		Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10		
Single Package – Confined	0.8	0	0	0	1	3	1	2	3	4	5	800	300
Single Package – Unconfined	0.6	0	0	0	3	5	12	15	17	30	45	3000	800
Sympathetic Detonation – Confined	1.2	0	0	1	10	26	30	40	60	93	167	3500	1200
Fast Cook-off	0.9	0	0	0	3	15	21	36	45	65	97	2800	750
Slow Cook-off	1.1	0	0	2	4	26	32	48	70	45	120	2980	1150
Bullet Impact	0.9	0	0	0	5	20	16	38	58	75	123	2850	930
Fragment Impact	1.1	0	0	1	5	15	36	25	68	83	110	2759	650
Shape Charge Jet	1.1	0	0	0	3	39	45	32	36	80	134	3156	1159

TNT Equivalence (TNT EQ)

Initial Velocity (IV)

Maximum Fragment Range (MFR)

EXAMPLE SCENARIO

What Data To Use

- The user will need to make a decision on which data to use to define the weapon using TP-14. They can either use the maximum from each tests, an average of all the tests, or the user can just choose the threat that is most credible.

Scenario	TNT EQ	Primary Fragments Mass Bins - # of pieces										IV (ft/s)	MFR (ft)
		Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10		
Maximum	1.2	0	0	2	10	39	45	48	70	93	167	3500	1200
Average	0.9625	0	0	0.5	4.25	18.6	24.1	29.5	44.6	59.4	100.1	2730.6	867.375

- The data will than be entered in the appropriate TP-14 architecture steps to model the weapon and calculate the explosive effects and consequences associated with that weapon

USER-DEFINED WEAPON TYPES

- SAFER does not have the capability to enter user-defined weapon types, but it is expected that RBESS will have an ability to enter a user-defined weapon type. The method has not been determined yet.
- IMESAFR currently has the ability to enter a User Defined Explosive Article (UDEA).
- IMESAFR uses a UDEA wizard to help the user enter the necessary information to define the explosive article. It walks the user through multiple steps to enter the necessary information.
- RBESS may incorporate something similar.

The image displays four sequential screenshots of the 'User Defined Explosive Article Wizard' software interface:

- Step 1: Yield Adjustments** - Shows options to define % contribution and TNT equivalence factors, a TNT Equivalence Factor input field, and radio buttons to map yield equations to an existing article type or fill in values. The 'Weight of one explosive article' is set to 1.0 lbs.
- Step 2: Pressure And Impulse Adjustment** - A table for defining Z ranges and equations.

Z	Equation	
< 40.00	BEC Line fit	Edit
40.00 - 150.00	BEC Line fit	Edit
- Step 3: Equation Editor** - Shows the 'Pressure And Impulse Equations' section with a 'Z Range' of 40.00 - 150.00 ft/lb^{1/3}. The chosen equation is 'BEC Line fit', and the displayed formula is:

$$Effective\ Yield = C1 * \left(\frac{Yield}{C2} \right)$$
 The 'Effective Yield Coefficients' are C1: 3.0 and C2: 1.0.
- Step 4: Primary Fragment Distribution Bin Values** - Shows two options: 'Map the primary fragment table to an existing article type' (selected) and 'Fill in bins for primary fragment values'. The 'Metal-cased' article is selected for mapping. Below, 10 fragment bins are defined with their respective Z ranges (e.g., 1: 122.1 - 53.60, 2: 53.60 - 21.74, etc.). Initial velocity is set to 4000.0 ft/s and the highest maximum throw range is 1870.0 ft.

BENEFITS AND LIMITATIONS OF USING HC AND IM TESTS

■ Benefits

- ▶ The explosive effects and consequence outputs will reflect the AE, not a generic weapon type
- ▶ The AE can have directional effects associated with its design
- ▶ Calculate the explosive consequences and effects relative to the specific threat. For example, users can specify that they want to see the effects and consequences from a fire event. The model will use the data from the FCO test and apply it to that scenario.

■ Limitations

- ▶ HC and IM tests are conducted with limited quantities of explosives. Scale up may be needed to accurately determine the consequences and effects.
- ▶ If the user is evaluating mixed AE. The specific AE, HC, and IM results may not be valid. A methodology will need to be made on how to deal with mixed AE.