

Tying Explosive Hazard Classification and Insensitive Munitions Testing to Explosive Quantitative Risk Assessment Modeling

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Abstract

The goal of both explosive hazard classification (HC) and insensitive munitions (IM) testing is to characterize the hazards of the explosive material or article. This testing provides information about whether the explosive material or article is detonable, creates hazardous fragments, mass fire, or has a potential to propagate to other articles to create a sympathetic reaction. Data such as overpressure, impulse, debris generated, and thermal flux are also determined from these tests. All this valuable information can be used in explosives quantitative risk assessment (QRA) models, such as Technical Paper (TP) 14, to better quantify risk associated with that specific explosive material or article. Currently, TP-14 characterizes the risk from the explosives by HC and not the specific explosive materials or articles. Using the HC and IM test results can provide a more accurate account of the risks associated with the explosive material or article. This paper reviews the HC and IM tests and determine what data can be used to model that explosive material or article using TP-14 methodology. Scaling from a HC and IM test to large net explosive weight (NEW) storage configurations is discussed.

Introduction

TP-14 provides the Department of Defense Explosive Safety Board (DDESB) approved methodologies for calculating risk associated with explosives operations and storage. TP-14 includes models that estimate explosive effects and consequences. The models are anchored by various tests and years of research by explosive experts. A limitation of the models used in the current published revision of TP-14, which is Rev 4, are the use of generic hazard classifications and weapon types to define all scenarios. There may be times when TP-14 models for Ammunition and Explosives (AE) are overly conservative. All AE will conduct explosive HC and IM testing. This paper argues that data from both HC and IM tests can be used to more accurately model AE using TP-14 models. The following sections provide an introduction to HC and IM tests, the data obtained from those tests, a brief summary of the TP-14 architecture, an explanation of how HC and IM tests can be used in TP-14 models, and benefits and limitation of using HC and IM test data to model AE.

It is important to note that this paper uses the methodology in TP-14 Rev 4. TP-14 Rev 5 is currently in development. It is expected that Rev 5 will remove the specific weapon types used in Rev 4 and use generic weapon types. The premises of this paper will still apply when TP-14 Rev 5 is published.

The Purpose of Explosive HC and IM Testing and the Data Obtained from these Tests

The purpose of explosive HC and IM testing is to characterize the hazards of an AE. HC testing will indicate if the explosive article is detonable, creates fragments, is susceptible to sympathetically detonating, and if it has any thermal hazards. The testing flow chart shown in Figure 1 is the classification protocol a new AE will go through to get properly classified. There are three 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? Technical Bulletin (TB) 700-2 (Ref 1) is the governing requirements document for HC for the Department of Defense (DoD).

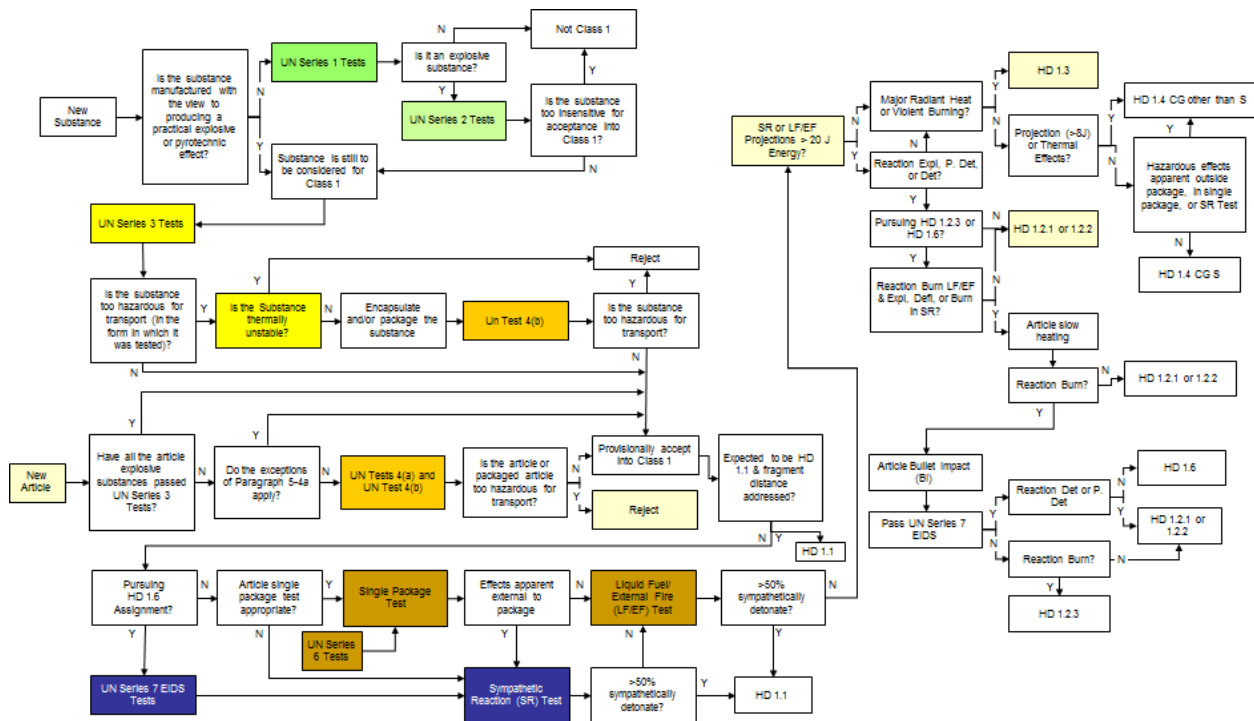


Figure 1. Explosive Hazard Classification Procedure

For the purposes of modeling AE in TP-14, UN Test Series (TS) 6 tests provide the best data. The following tests are involved in UN TS 6.

- UN TS 6(a): Single Package (SP) Test – Demonstrates if hazardous effects are apparent outside package when a single AE within the package is detonated. This test is conducted unconfined and 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 fuel.

To properly classify the AE, the following data are obtained from the tests: debris recovery, blast measurements, thermal readings, and high-speed video. All of these data can be used to model

the AE using TP-14 methodology. All three tests and data obtained from the tests provide information on the number of fragments that can be generated, the velocity of the fragments, the maximum distance fragments can go, what overpressure is created, and thermal hazards.

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. IM tests simulate threats as shown in Figure 2.

<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
					

Figure 2. IM Threats

Figure 3 shows the IM tests used to simulate the threats.







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

Figure 3. IM Tests

IM tests are evaluated by the response of the AE. The following reaction types are used to grade IM responses (Ref 2).

- **Type I (Detonation Reaction).** The most violent type of explosive event. A supersonic decomposition reaction propagates through the energetic material to produce an intense shock in the surrounding medium, air or water for example, and very rapid plastic deformation of metallic cases, followed by extensive fragmentation. All energetic material will be consumed. The effects will include large ground craters for AE on or close to the ground, holing/plastic flow damage/fragmentation of adjacent metal plates, and blast overpressure damage to nearby structures.
- **Type II (Partial Detonation Reaction).** The second most violent type of explosive event. Some, but not all of the energetic material, reacts as in a detonation. An intense shock is formed, some of the case is broken into small fragments, a ground crater can be produced, adjacent metal plates can be damaged as in a detonation, and there will be blast overpressure damage to nearby structures. A partial detonation can also produce large case

fragments as in a violent overpressure rupture (brittle fracture). The amount of damage, relative to a full detonation, depends on the portion of material that detonates.

- **Type III (Explosion Reaction).** The third most violent type of explosive event. Ignition and rapid burning of the confined energetic material builds up high local pressures leading to violent pressure rupturing of the confining structure. Metal cases are fragmented (brittle fracture) into large pieces that are often thrown large distances. Unreacted and/or burning energetic material is also thrown about. Fire and smoke hazards will exist. Air shocks are produced that can cause damage to nearby structures. The blast and high velocity fragments can cause minor ground craters and damage (breakup, tearing gouging) to adjacent metal plates. Blast pressures are lower than for a detonation.
- **Type IV (Deflagration Reaction).** The fourth most violent type of explosive event. Ignition and rapid burning of the confined energetic material leads to nonviolent pressure release as a result of a low strength case or venting through case closures (loading port/fuze wells, etc.). The case might rupture but does not fragment; closure covers might be expelled, and unburned or burning energetic material might be thrown about and spread the fire. Propulsion might launch an unsecured test item, causing an additional hazard. No blast or significant fragmentation damage to the surroundings; only heat and smoke damage from the burning energetic material.
- **Type V (Burning Reaction).** The least violent type of explosive event. The energetic material ignites and burns, non-propulsively. The case may open, melt, or weaken sufficiently to rupture non-violently, allowing mild release of combustible gases. Debris stays mainly within the area of the fire. This debris is not expected to cause fatal wounds to personnel or be a hazardous fragment beyond 15 m (49 ft).
- **Type VI (No Reaction).** Type VI reaction is no reaction of the energetic material without a continued external stimulus; the recovery of all or most of the energetic material with no indication of sustained combustion; and no fragmentation of the casing or package greater than from a comparable inert test item.

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. Also, like HC tests, IM test data can be used to model the AE using TP-14. The difference is that for IM tests additional threats (FI, BI, SCO, SCJ) are considered.

TP-14 and its Explosive Models

TP-14 Rev 4 provides the DDESB approved methodologies for calculating risk associated with explosives operations and storage. Safety Assessment for Explosive Risk (SAFER) is the software application that implements TP-14. TP-14 defines the models and logic associated with determining explosive effects and consequences for an explosive event. Figure 4 shows the 26-step architecture TP-14 follows to model explosive consequences and effects and estimate the risk to personnel. The following groups are associated with the architecture (Ref 3):

- 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

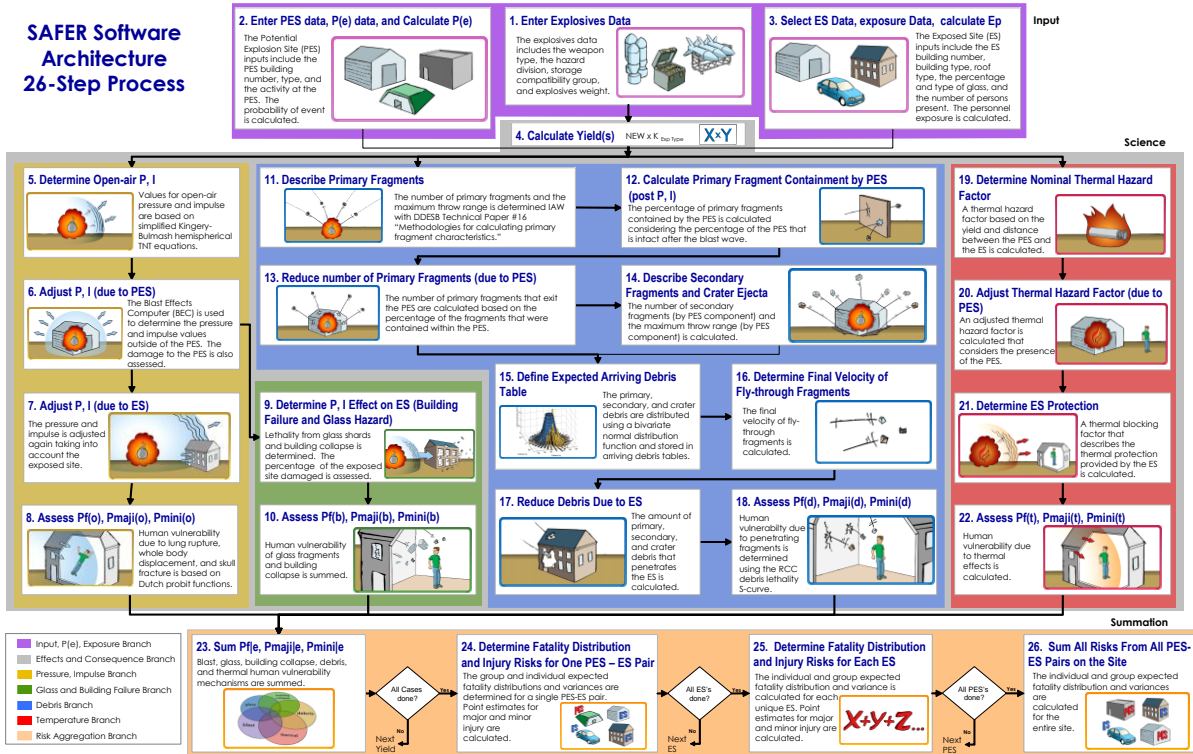


Figure 4. TP-14 Architecture 26-Step Process

Figure 5 shows a simplified view of the pressure/impulse, building failure/glass, debris and thermal branch.

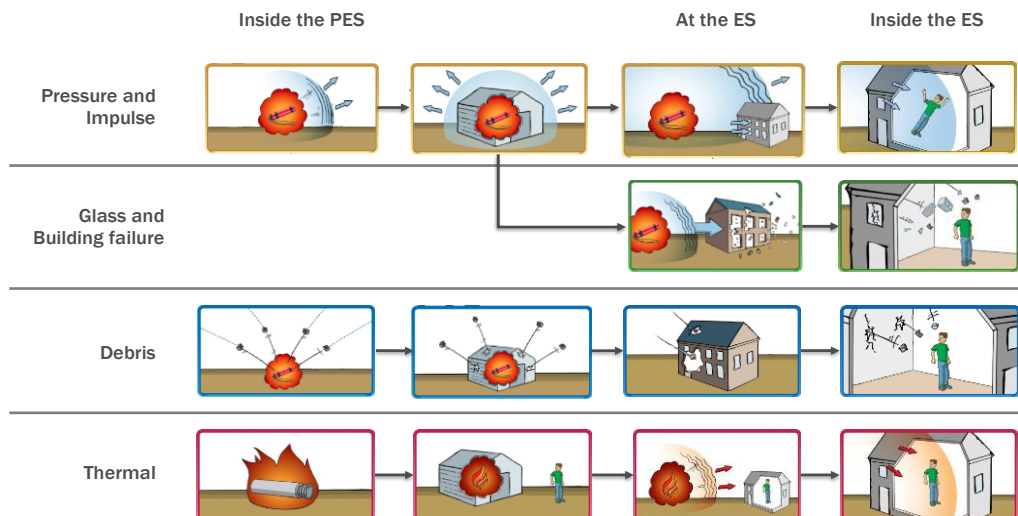


Figure 5. Explosive consequence and effects branches

As can be seen in both Figure 4 and 5, TP-14 first models the explosive effects (pressure, impulse, primary debris, crater ejecta and thermal) from a defined explosive. Currently TP-14 only considers generic HC 1.1, 1.2.1, 1.2.2, 1.2.3, 1.3, 1.5, and 1.6 explosives and the net explosive weight (NEW) to estimate the effects from that explosive. Next, the logic determines the effects from the potential explosive site (PES). Does the PES reduce the pressure and impulse, create secondary debris or reduce the thermal hazards? The logic then, determines if there is any glass breakage at the exposed site (ES), potential of building collapse, and what debris penetrates the ES walls and roof. Finally, the debris that penetrated the ES walls and roof, overpressure, glass breakage, building collapse, and thermal hazards are used to calculate the probability of fatality given an event (P_{fe}) for that ES.

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 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. Generic HC is used to calculate both maximum and expected yield. TNT conversion factors are also used to calculate the equivalent NEW.
- **Step 5:** Determine open-air pressure and impulse. Uses the yield in Step 4 and Kingery-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 Kinetic Energy (KE)/mass bins. There are 10 bins, each at a half order of magnitude in width. TP-14 then defines the average mass that, at terminal velocity, produces the KE midpoint for each bin, which allows the creation of 10 corresponding 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. The same predefined weapon types used in Step 11a are used to determine the maximum throw range.
- **Step 14c and d:** Describe crater ejecta. Ejecta is debris originating from the ground or foundation of the PES. 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 the TP-14 Architecture

As explained in the sections above, TP-14 Rev 4 uses generic hazard divisions and weapon types shown in Table 1 to cover all scenarios. At times these predefined hazard divisions and weapon types will provide a good estimate of the effects and consequences from an explosion. Other times they may be considered overly conservative. Modeling the specific AE in TP-14 will provide a more accurate estimation of the risk compared to using one of the default hazard divisions and weapon types.

Table 1. TP-14 Rev 4 Weapon Types and Descriptions

HD	Weapon Type	Weapon Description
1.1	MK82	Robust or thick-skinned bomb
	M107	Robust or thick-skinned 155-m projectile
	Bulk/light-case	Thin skinned
	MK83	Robust or thick-skinned bomb
	AIM-7	Fragmenting or thin-skinned missile warhead
1.2.1	M1 105 mm projectile	Robust or thick-skinned 105-mm projectile
1.2.2	40 mm projectile	Robust or thick-skinned 40-mm projectile
1.2.3	MK82 bomb – only 1 round detonates	Robust or thick-skinned bomb
1.3	Bulk propellant	Bulk propellant
1.4	N/A	N/A
1.5	Bulk/light case	Thin skinned
1.6	MK82 bomb – only 1 round detonates, consider only blast effects	Robust or thick-skinned bomb

To be able to model the specific AE in TP-14, a knowledge of how the data obtained from the HC and IM test are transferred to the TP-14 model. Table 2 shows what data is needed, what HC and IM test can be used to obtain that data, and what TP-14 steps use that information.

Table 2. Correlation between HC and IM test data and TP-14 Model

Data Needed	HC and IM tests	TP-14 Steps
Pressure	SP, ST, FCO, BI, FI, SD, SCO, SCJ	4,5
Impulse	SP, ST, FCO, BI, FI, SD, SCO, SCJ	4,5
Primary fragments	SP, ST, FCO, BI, FI, SD, SCO, SCJ	11
Initial velocity	SP, ST, FCO, BI, FI, SD, SCO, SCJ	11
Maximum throw range	SP, ST, FCO, BI, FI, SD, SCO, SCJ	11
Crater Ejecta	SP, ST, FCO, BI, FI, SD, SCO, SCJ	14c and 14d
Thermal hazards	FCO	19

As shown in Table 2, any of the HC and IM tests can obtain pressure, impulse, and debris information. It is expected that each test can provide different results, because of the different testing stimulus and if they are under confinement or not. For example, an AE explosive response can be completely different after a SP test compared to a SCO test. It is up to the user to decide what data to use for each TP-14 step. The user may choose to 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 and not dependent on what stimulus causes the AE to explode. Another option is to 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.

As stated previously, SAFER is the software application that implements TP-14. SAFER does not have the capability to enter user-defined weapon types. Future versions of TP-14 will not use SAFER for implementation. A new software application named Risk Based Explosives Siting (RBESS) will implement the next version of TP-14. It is expected that RBESS will have the ability to enter a user-defined weapon type. The method of how it will allow the user to enter a user-defined weapon type has not been determined.

Institute of Makers of Explosives Safety Assessment for Risk (IMESAFR) is a similar explosive safety QRA tool for the commercial explosive industry. IMESAFR has the ability to enter a User Defined Explosive Article (UDEA). To do this, IMESAFR uses a UDEA wizard to help the user enter the necessary information to define the explosive article. RBESS may incorporate something similar. The UDEA wizard in IMESAFR walks the user in multiple steps to enter the necessary information. First, the wizard prompts the user to enter the TNT equivalence value of the UDEA and either map the pressure and impulse equations to an existing explosive

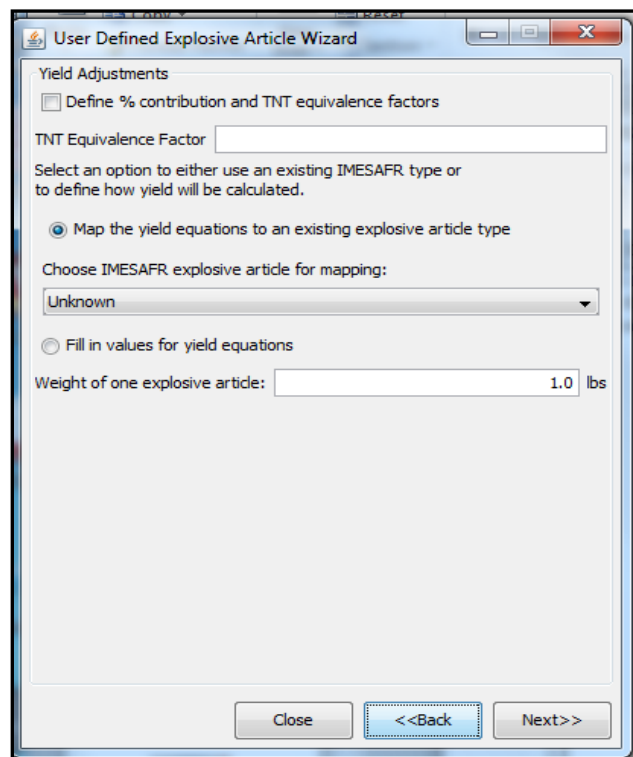
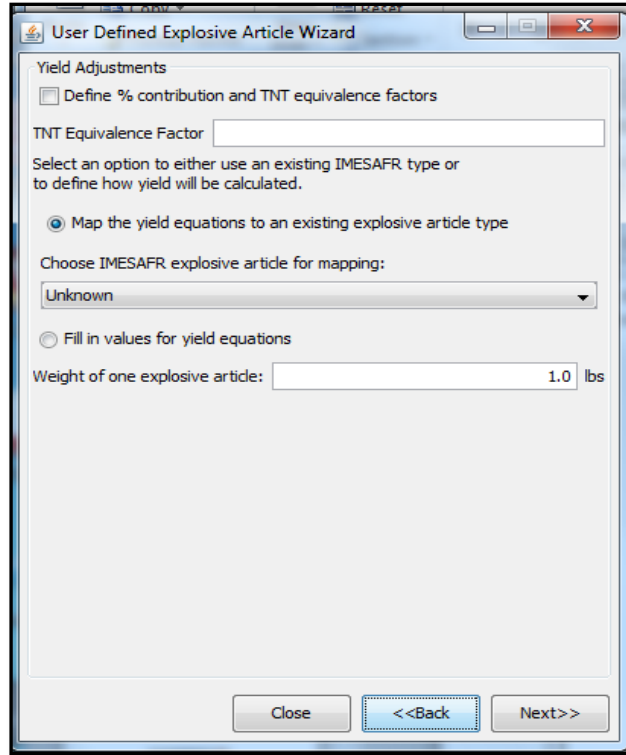


Figure 6. IMESAFR UDEA Wizard - Defining Yield



article or fill in the values as shown in

Figure 6.

Users can also define the scaled ranges and choose the appropriate calculation for effective yield, as well as the coefficients for that equation. This is shown in Figure 7.

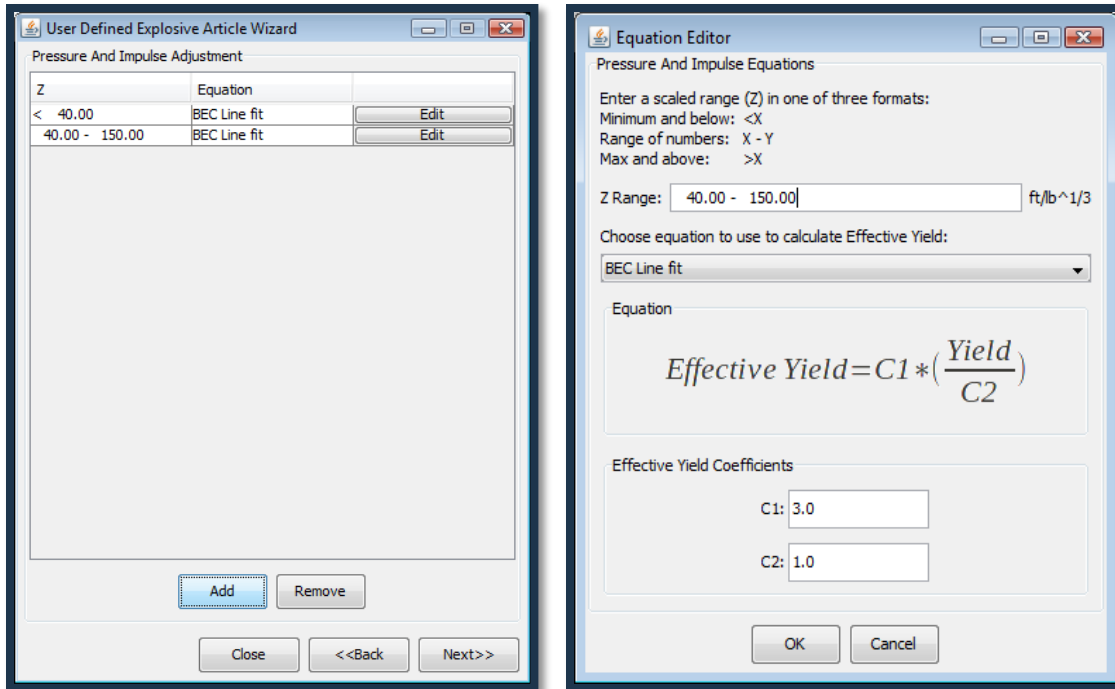


Figure 7. IMESA FR UDEA Wizard – Pressure and Impulse Scaled Range

The last step is for the user to define the primary fragment mass bin. The user has the ability to map an existing explosive article or create a new mass bin. This also includes setting the initial velocity and maximum

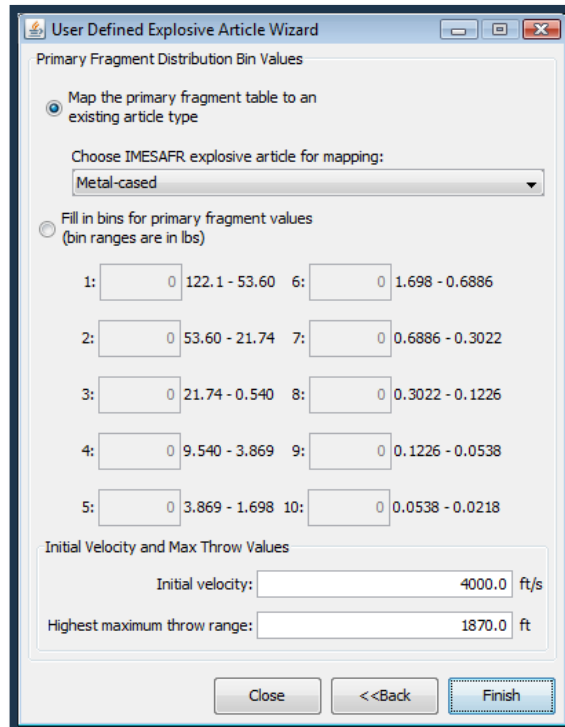
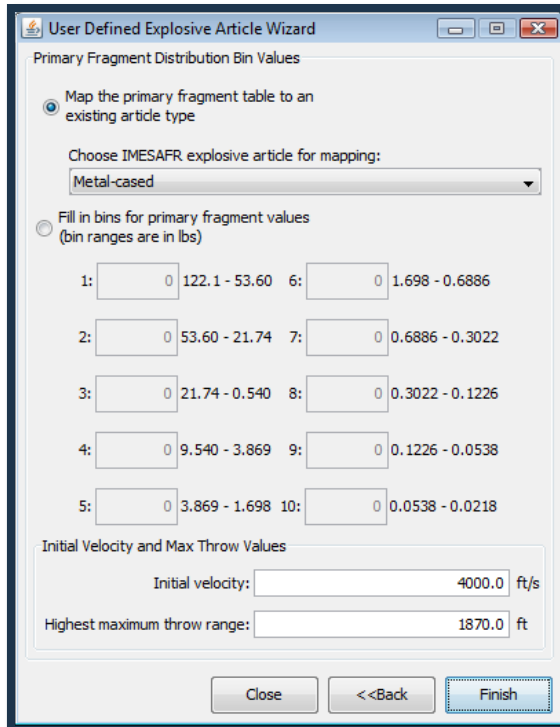


Figure 8. IMESA FR UDEA Wizard – Defining Primary Fragments



throw range. This step is shown in

Figure 8.

Benefits and Limitations of using HC and IM Tests to More Accurately Model AE using TP-14 Models

Having the ability to accurately model the specific AE used in a scenario can have multiple benefits. First, the explosive effects and consequence outputs will reflect the AE, not a generic weapon type. This can be important if the AE does not behave the same as the generic hazard class and weapon types that are defined in TP-14 Rev 4. The AE may have included mitigation to reduce the effects from the threats that are tested in the HC and IM tests. The AE can also have directional effects associated with its design. IM tests can also show that the AE has a very low probability of having an accidental explosion that the probability of event P(e) used for that AE can be very low. Another benefit that may be incorporated in future revisions of TP-14 is the ability to estimate the effects and consequences by hazard threat. Since HC and IM tests are testing multiple types of threats, the model can estimate the consequence 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. This provides another level of accuracy if needed.

There are some limitations to using HC and IM tests to define AE. Usually, when risk-based siting is conducted, the quantities of explosives used for the analysis are much greater than what was used in both the HC and IM tests. Valuable information on how a larger quantity of the AE will react is found from the HC and IM tests, but an understanding on how to scale up those effects will need to be understood and modeled within TP-14. The other limitation is when the

scenario has mixed AE. A methodology will need to be made on how to deal with mixed AE and still use the AE's HC and IM results.

Summary

TP-14 Rev 4 uses generic hazard divisions and predefined weapon types to cover all types of scenarios. If a more accurate risk assessment is needed, the default options in TP-14 may not be enough. This paper makes the argument that valuable data is obtained during the HC and IM tests that can more accurately model an AE. This data can be used in the existing TP-14 architecture and can possibly be entered relatively easily using a wizard that walks the user step by step to enter the necessary information. Modeling the specific AE used in the scenario can lead to better understanding of the risk.

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