IMESAFR Version 2.0: A Next Generation Tool for Managing Risk Associated with Commercial Explosives Operations – 2014 Update

by

John Tatom (A-P-T Research, Inc),
Michael Swisdak (A-P-T Research, Inc),
Lon Santis (Explosives Risk Managers, LLC) and
Tyler Ross – Update Author (A-P-T Research, Inc)

The original version of this paper was presented by the authors at Parari 2011, the 10th Australian Explosives Ordnance Symposium, which was held in Brisbane, Australia, from 8 to 11 November 2011. It was printed as SAFEX Topical Paper No 07/2011 with the kind permission of the Symposium Organisers. This 2014 update was prepared to incorporate updates to the software.

SAFEX Topical Papers Series

Paper No 07/2011

Published: December, 2011

About the Authors

John Tatom is the Manager for Explosives Safety at APT Research in Huntsville, AL. He serves as the algorithm coordinator for the SAFER project, participates in the DDESB Science Panel, and has developed original technical routines for use by SAFER. He has played a similar role in the development of IMESAFR. He is the author of numerous papers concerning explosives safety modeling and testing. He holds a Bachelor of Electrical Engineering degree from Auburn University.

Michael Swisdak is a Senior Scientist in the Explosives Safety Group at APT Research Inc, headquartered in Huntsville, AL. He is retired from the Department of Defense after 45 years of service. His specialties include airblast, explosion-produced debris, and the effects of debris on explosives safety quantity-distance. He is the author or co-author of over 150 technical publications in these fields and holds a Master of Science degree in Physics from the University of Florida.

Lon Santis graduated from the University of Pittsburgh with a BS and MS in Mining Engineering in 1985 and 1986 respectively. He has worked as a sales representative for the Ensign-Bickford Company, spent 12 years at the Pittsburgh Research Laboratory of the US Bureau of Mines and 15 years as the Manager of Technical Services at the Institute of Makers of Explosives (IME) in Washington, DC. In 2013 he started Explosives Risk Managers LLC, a consulting firm providing a wide array of services to the explosives industry and others. He is a chair of the NFPA Technical Committee on Explosives and the ANSI A10.7 subgroup on explosives safety in construction and participates in many other industry groups.

Dr. Tyler Ross is an Explosives Safety Structural Engineer at APT Research in Ogden, UT. He provides algorithm development and validation support to the IMESAFR program. In this role he has developed new mass and debris models for version 2.0 of the software. He has developed methodologies to perform hybrid analyses with QRA software allowing new facility types and unique scenarios to be analyzed. He currently leads the structural engineering support at APT. He is a licensed civil engineer and holds a PhD in Structural Engineering from the University of Utah.

Contact details:

John W. Tatom, APT Research, Inc, 4950 Research Drive, Huntsville, AL 35805. Phone: +1-256-327-3392; FAX: +1-256-837-7786, E-mail: JTatom@APT-Research.com

Michael M. Swisdak, APT Research, Inc, 4950 Research Drive, Huntsville, AL 35805. Phone: +1-301-908-8272; FAX: +1-256-837-7786, E-mail: MSwisdak@APT-Research.com

Lon D. Santis, Explosives Risk Managers LLC, 11104 Innsbrook Way, Ijamsville, MD 21754, +1-202-288-2029; E-mail: Santis@ermanagers.com

Tyler J. Ross (update author), APT Research, Inc, 4950 Research Drive, Huntsville, AL 35805. Phone: +1-801-458-5468; FAX: +1-256-837-7786, E-mail: TRoss@APT-Research.com

1.0 SUMMARY

SAFEX does not promote any product commercially. This Paper is published as a Topical Paper because of its contribution to the domain of quantitative risk assessment. The tool it describes, IMESAFR, is very relevant to the commercial explosives industry using algorithms for debris and blast which many consider as state of the art for this type of application. IMESAFR (IME Safety Analysis for Risk) was developed and released by the Institute of Makers of Explosives (IME) and A-P-T Research, Inc. (APT). Previous versions of this software program have been described in published papers and have been compared to available real-world test and accident data. IMESAFR was first released in 2007. The most recent edition of the software, IMESAFR Version 2.0, was released in February 2013.

Version 2.0 incorporates many new features and advanced tools. Some of the new features in Version 2.0 include:

- Graphical Interface System (GIS) to help map and visualize facility layouts and input in order to display the software results visually.
- Both Imperial (English) and SI (Metric) versions.
- Reduced algorithm conservatism in many aspects of the Potential Explosion Site (PES) and Exposed Site (ES) models.
- The ability to use GIS information to check compliance with quantity-distance (QD) standards.
- The ability to separate or "turn off" the contribution from the uncertainty model that is designed to conservatively increase the estimated risk hazard due to uncertainty in the input and natural variations in circumstances.

These changes and new features, along with many others, are discussed and demonstrated.

2.0 INTRODUCTION

Around the world, wherever explosives are manufactured and stored, safety is of paramount importance. In order to reduce the risks associated with explosives, these risks must first be understood. Advances in explosives safety, in both defense and industry, need to be shared internationally.

The IMESAFR (Institute of Makers of Explosives Safety Analysis for Risk) software tool, which was based on the SAFER (Safety Assessment for Explosive Risk) program [Reference 13], has been commercially available since 2007. Although it was originally designed for use by the commercial explosives industry in the United States, it is in use around the world. The IMESAFR 1.0 Development Team included representatives from IME member companies and stakeholders from the government and the International Society of Explosives Engineers (ISEE). The IMESAFR Development Team began consulting with APT on development issues in 2005. This team used the SAFER model as a baseline methodology and developed new models to apply to the commercial explosives industry.

Generally, the effects and consequences algorithms in IMESAFR have been recognized as state-of-the-art and are supported by test data. However, the initial releases of IMESAFR (Version 1.0, Version 1.1 and Version 1.2) have had several limitations that have restricted the usage of the program outside of the United States. The software user-interface requires a fair amount of manual data entry, and visualization of the calculated risks was never the focus of the design. Also, potential users have often asked for a metric-unit option. Finally, the probability of event (P_e) could not be altered (or entered) by the user, which limits the event frequency to only those built into the program.

In 2006, at the 32nd

Department of Defense Explosives Safety Board (DDESB) Seminar, APT and IME began publishing the details of IMESAFR [Reference 1], including its relationship to SAFER [Reference 2]. The description was updated in 2007 by a paper presented at Parari [Reference 3] that included additional details of the IMESAFR models. In 2008, at the ISEE Conference [Reference 4], IME presented a paper that worked through three hypothetical Quantitative Risk Analysis (QRA) scenarios. Later in that same year, APT and IME presented a paper at the 33rd DDESB Seminar [Reference 5], which included real-world examples of regulatory approvals using IMESAFR.

In 2010, APT and the US Army Corps of Engineers performed a comparison between the IMESAFR predicted debris distribution for a truck and test data collected on the ISO-1 and ISO-2 test programs [Reference 6]. This comparison effort found encouraging agreement between IMESAFR and the test results, and was continued and updated later that year [Reference 7].

In 2010, IME and APT performed comparisons between IMESAFR, DIRE (Death and Injury Resulting from Explosions), and the original data used by Assheton to set intra-plant distances [Reference 8]. Dire is a consequence tool that assumes that the event has occurred. This study demonstrated conservative results for IMESAFR for close-in exposures when people were in the open; the study was updated later in the same year to include people in buildings [Reference 9]. Finally, in 2011, APT and IME compared IMESAFR predictions to a recent Australian accident [Reference 10, 11], with the software again demonstrating conservative results for people very close to explosive events.

Based on these studies, IME and APT proceeded with the development of the next generation of the IMESAFR tool. IMESAFR Version 2.0 was developed between 2011 and 2013. It was released in February 2013.

Due to the algorithm updates and host of new features in IMESAFR, an extensive series of sensitivity studies was conducted between 2012 and 2014. These studies serve to ensure that new features perform as expected, algorithm updates produce logical answers throughout a range of input parameters, and verify that final risk answers are credible and include an established level of conservatism. These studies are described in Reference 16. A brief description is provided here.

The first series of sensitivity studies was completed in October 2012 as a “sanity check” of the QRA technical model. This study verified that the many individual components of the technical model, including updates and new features, interacted properly. Output was compared to explosives test data and accident histories, as well as output from previous releases of the software.

The principle sensitivity study effort occurred throughout 2013. This effort was designed to thoroughly test the interaction between facility types at varying ranges of explosives quantities and distances. More than 800,000 individual scenarios were analyzed and the results were organized into more than 14,000 graphs, providing an immense catalogue of data that can be used to find patterns in algorithm behavior and evaluate performance of new or updated software features. Results were organized by hazard mechanism (e.g., debris, overpressure, etc.) or facility type.

Analysis of the sensitivity study data has continued through 2014 in support of the IMESAFR 2.0 Development Team.

The sensitivity study process has provided the IMESAFR 2.0 Development Team with the opportunity to verify the behavior of the software and recommend improvements or corrections as needed. The improved models have been systematically tested to ensure that individual algorithm component behavior, as well as overall interaction between components, performs as intended. The sensitivity study testing created a large library of data that can be queried to further analyze the behavior of specific aspects of the models.

By testing the analysis algorithms across a wide range of input variables, confidence is built in QRA tools. The sensitivity studies led to the improvement of the tool as models were refined to work in better coordination with each other.

3.0 RELATIONSHIP TO SAFER

IMESAFR is a software tool that is based on the US Department of Defense (DoD) SAFER model, but is intended for use in the commercial explosives industry. IMESAFR supports the commercial industry in the same way that SAFER acts to enhance the DoD's ability to perform explosives facility siting.

The basic QRA concept of the "risk equation" is the same in both SAFER and IMESAFR:

$$P_f = P_e \times P_{f|e} \times E_p$$

In both programs, the probability of fatality (P_f) is the product of the probability of event (P_e), the probability of fatality given an event ($P_{f|e}$), and the exposure (E_p). However, IMESAFR incorporates several features specific to the commercial explosives industry, which are not available in SAFER. Similarly, IMESAFR does not contain some of the features in SAFER that are military-specific [Reference 1]. Except for these differences, the algorithms in SAFER and IMESAFR Version 1.2 were virtually the same.

It should be noted that the US DoD is moving towards a "one stop shop" for explosives safety siting, and will therefore consolidate the explosives safety programs that it supports. The ESS program [Reference 12] will be designed to access standardized installation databases of facility information; thus SAFER will be implemented as a module within ESS in order to take advantage of the interface designed to be used with the DoD database.

4.0 DEVELOPMENT OF IMESAFR V2.0

QRA software tools are moving to a geographic information system (GIS) interface, allowing import of site plans or aerial images. Since SAFER will be tied to GIS data in a proprietary format available only to the US military and its allied forces, IMESAFR and SAFER have reached a fork in the development road. IMESAFR V2.0 has been developed with an independent GIS interface that can accept many available formats of GIS information.

Additionally, IMESAFR V2.0 has introduced many user-defined parameters. Users of IMESAFR have repeatedly requested the ability to input their own values for many of the pre-defined parameters in the software. IMESAFR V2.0 now allows users to define parameters such as the P_e and the properties of explosive articles.

The IMESAFR V2.0 Development Team once again includes IME, APT, representatives from IME member companies and stakeholders from the government. APT began advising the IMESAFR V2.0 Development Team on explosives safety technical issues and software development issues for version 2.0 of the software in 2010. This team has once again used the SAFER model as a baseline methodology and has developed new models to apply to the commercial explosives industry.

4.1 New Interface

As mentioned previously, IMESAFR 2.0 includes a new graphical user interface (GUI) that allows for easier input data entry and better results visualization. This new GUI is GIS-based, but is completely independent of the ESS program. Rather than working from a standardized database like ESS, IMESAFR 2.0 has been designed to import any common type of data file or image in order to make setting up the scenario easier.

IMESAFR 2.0 can read from a data file (registered image, jpeg, bitmap, etc.) and create a depiction of the scenario with a relative coordinate system, as well as a “tree structure” to represent the relationship between PES and ES entries. A basic sample screen from IMESAFR 2.0 is shown in Figure 1. This example shows two explosives facilities and an ES structure. The relationship between the facilities is shown in the panel on the left. A basic measurement grid is shown and can be utilized with or without background imagery.

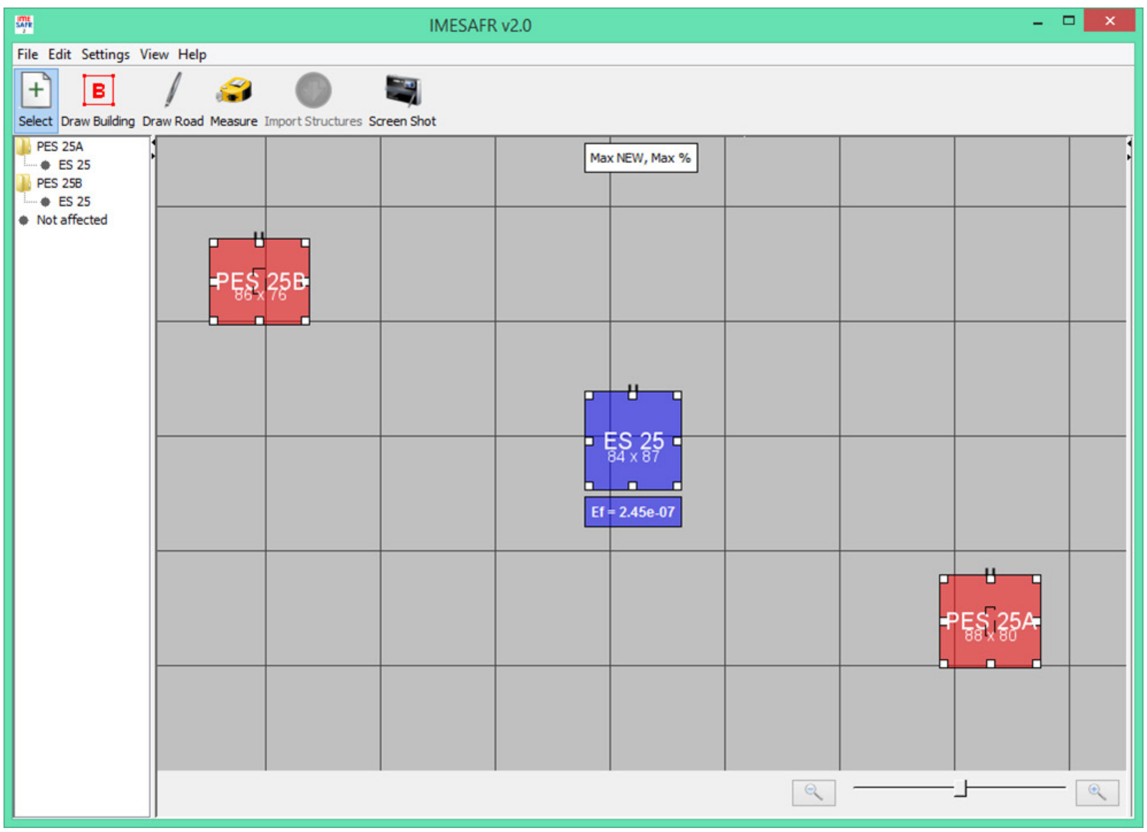

Figure 1. IMESAFR 2.0 GIS Interface

IMESAFR 2.0 also has the capability to automatically determine building outlines, which the user can amend or supplement with manual entries. This feature can be used to quickly create a complex scenario based on an image file.

Whether the facilities are manually drawn or automatically recognized, the user provides a facility name and adjusts the properties of the structures. Properties include information concerning the explosives, activities, and people involved in the scenario. These steps can be used to create complex scenarios with many structures.

After the user finalizes the scenario details, IMESAFR calculates and displays the risks. A hypothetical set of results for a complex scenario is shown in Figure 2. This figure illustrates a scenario that has been developed based on an imported background image. Several key output features are represented in this figure. These will be discussed individually.

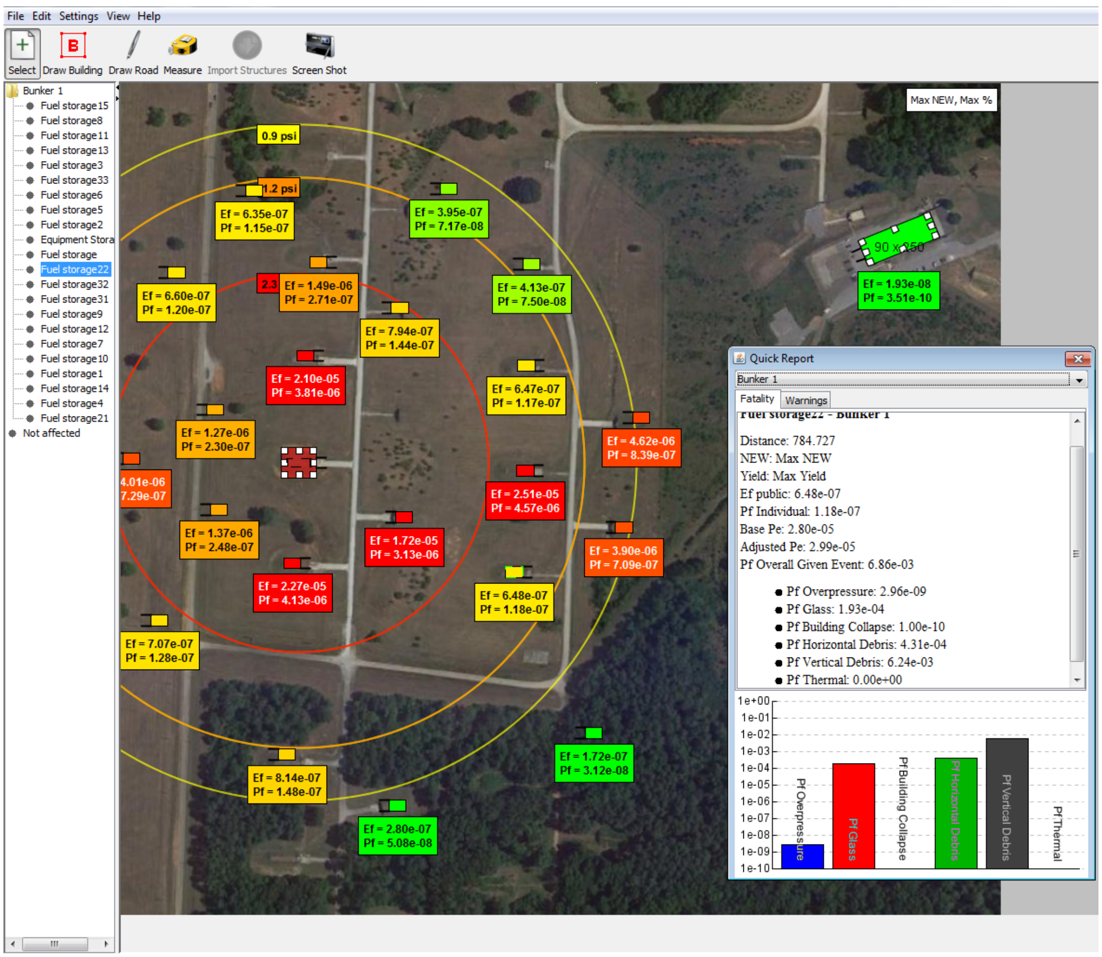

Figure 2. Sample Complex Scenario with Multiple Types of Output Displays

First, the PES structure for this scenario is shown in the center of the concentric circles. Each of the surrounding exposed sites display results from individual risk calculations based on the hazards generated at the selected PES structure. Each ES is color-coded based on the relative amount of risk at each site. It can be seen that facilities that are near the PES have a greater overall risk. The calculated risk values are dependent on the details of each ES and the level of protection that they afford the occupants.

Second, the concentric circles around the selected PES represent overpressure levels. Debris hazards are represented in a different manner and will be discussed separately. The software will also display the Risk-Based Evaluation Distance (RBED), which illustrates the distance from a specific PES beyond which the hazards are low enough that exposed structures generally need not be considered.

Third, the software can illustrate details of each component of the risk calculation for a specific PES-ES pair in a pop-up window referred to as the Quick Report. This optional window provides calculation details for exposure, probability of event and the magnitude of hazards from individual hazard mechanisms (e.g., horizontal debris, overpressure, glass, etc.). This powerful display tool allows the user to gain important insight into which hazards are the greatest for a given scenario. This information is critical when analyzing potential risk mitigation strategies such as barricades or construction materials used at facilities.

In addition to the risk results shown in Figure 3, IMESAFR 2.0 can also display effects, such as the debris density (shown in Figure 3). In this scenario, the view has been extended to display additional area around the PES. The debris contours illustrate that the debris hazard from this PES facility is focused in orthogonal directions coming from the PES walls. IMESAFR 2.0 incorporates advanced debris density models that are based on analysis of explosives testing programs and historical accident data. These debris models will be described in more detail in a subsequent section.

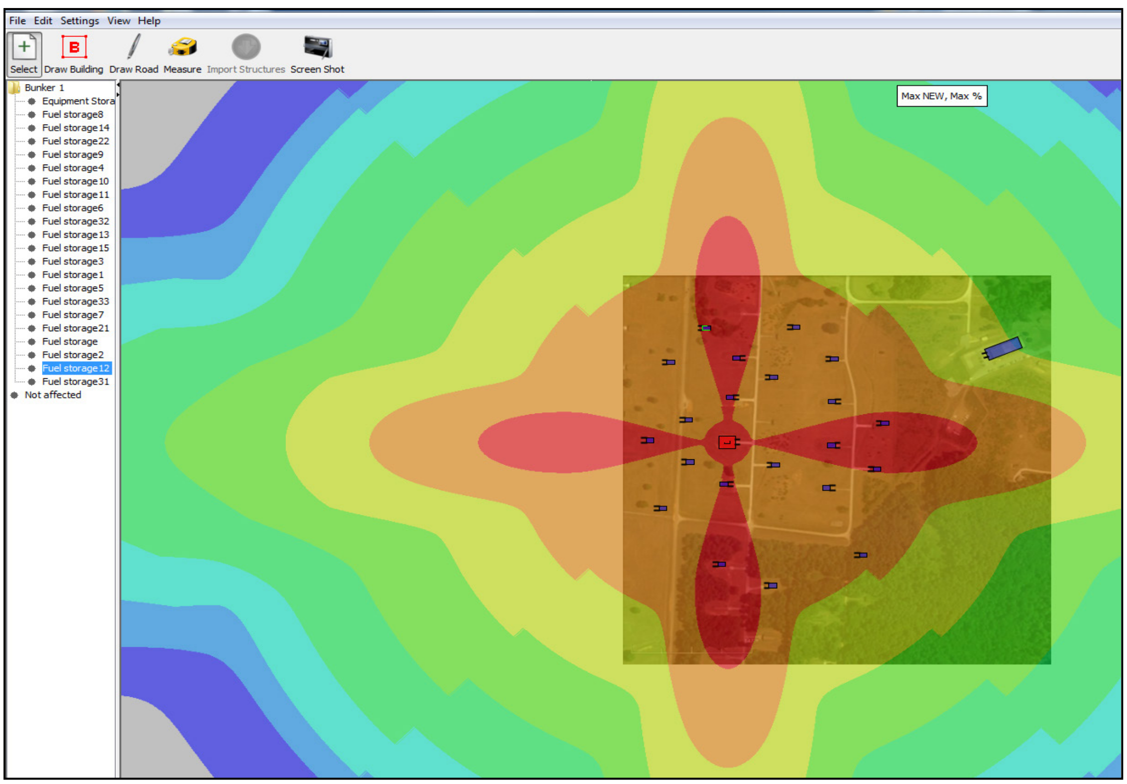

Figure 3. Debris Density Display

With this type of information, the user may decide to rotate the PES such that the consequences change. This type of risk management is a key aspect of a visualization tool, and is an important capability of IMESAFR 2.0 (i.e., it is not just "pretty pictures"). For example, in many scenarios, debris is the dominant risk factor and can be accounted for more accurately by taking into account orientation as well as distance. In the hypothetical case shown in Figure 3, the difference in risk between the green, yellow and red zones are orders of magnitude. Furthermore, exposed buildings at the same radial distance (but different azimuths) may have markedly different risks, which can be seen immediately in the debris density display.

Metric

Although the sponsors of both IMESAFR and SAFER are from the US, it has not gone unnoticed that other users would like the ability to work in metric units. IMESAFR 2.0 now incorporates this capability, and it is not be limited to simple conversion of inputs and outputs. A complete, parallel "metric engine" has been developed so users can extract information at the algorithm level from the program's System Log in metric units.

User-Defined P_e

In addition to the built-in activity types and their associated probability of event, IMESAFR 2.0 users are able to create customized P_e values that are more applicable to their scenario. This will allow the user to control that element of the risk equation; however, the software will flag the results as being affected by the user's choice (which is an input that the program cannot verify).

Conservatism Adjustments

In an effort to reduce potential undue conservatism in some situations and improve user control, IMESAFR 2.0 has implemented several changes to key algorithms and in some scenarios allows the user to "turn off" certain aspects of algorithms that are based on philosophical modeling decisions. These user-controlled options are referred to as conservatism "switches".

The following two lists give a brief description of each of the algorithm adjustments and conservative switches, with the IMESAFR/SAFER architecture step number given as a reference for those familiar with that nomenclature. The descriptions and terminology assume knowledge of the algorithms. Details for each of these adjustments or switches are provided in Reference 15.

It is important to note for the conservatism switches that in general the default mode is to calculate risks with all of these conservatisms "turned on" unless the user chooses to turn them off. Some scenarios, such as attempting to recreate a specific event, will be more accurately modeled with at least some of these conservative settings disabled. As with user-defined P_e values, if any changes to the default settings are made, the software will flag the results as being affected by the user's input decisions.

Algorithm Adjustments (Not user-selectable)

- Step 12 and 13 - primary fragment blocking: the default sequencing assumes that primary fragments escaping the remnants of the PES will have an unimpeded velocity; the more realistic treatment for robust structures would be to set the velocity to that of the applicable secondary debris. When applicable, IMESAFR 2.0 automatically adjusts the initial velocity of primary fragments based on the type of construction material of the PES. Escaping primary fragments are slowed to secondary fragment speed if the PES is a robust material such as concrete or masonry.

- Step 14 - nominal and dynamic mass distributions: the nominal mass distributions have been updated and the dynamic mass distribution routine is allowed to be more aggressive than the IMESAFR 1.2 model. A new, more realistic algorithm has been developed that allows the mass distribution to vary as the charge weight goes below the nominal weight, and to allow the dynamic mass distribution to shift more mass into smaller bins as the charge weight goes above the nominal weight. IMESAFR 2.0 contains various new nominal mass distributions and dynamic adjustment models for multiple material types. These updated values and new models are based on recent explosives test programs as described in Reference 15.
- Step 15 - debris probability functions: the high angle debris density distribution is treated as a Bi-Variant Normal (BVN) function in IMESAFR 1.2; IMESAFR 2.0 utilizes a toroid function which is more representative of test data. This new model creates less conservative debris densities in the immediate vicinity of the explosion, but higher debris densities downrange (see discussion for Figure 10 and References 10 and 11). This new model is applicable for specific PES components and debris types.
- Step 16 - low angle debris terminal velocity restriction: by rule, the calculated final velocity of the low-angle fly-through debris was not allowed to be lower than terminal velocity; this is physically impossible (unless the debris imbeds in the ground at the first point of impact), so the velocity decay is now allowed to occur naturally.
- Simplified Close-In Fatality Methodology (SCIFM) - change X_1 and shape of curve in transition region: the extent of the plateau region (determined by the X_1 parameter) and the shape of the transition region curve were set conservatively; more realistic X_1 values for each ES and a less conservative transition curve have been incorporated. This update is based on new analyses described in Reference 15.

Conservatism Switches (User-selectable)

- Step 17 - building response before debris arrival: in IMESAFR 1.2, the default sequencing assumption was that the ES has responded to the blast wave before the debris has arrived, thus (potentially) reducing the ES debris protection capability; a more probable sequence is that the ES debris protection has not been compromised by the blast wave before the debris arrives. This feature has been incorporated in IMESAFR 2.0 as a switch with four options that the user can select to determine which types of debris arrive before and after the potential effects of overpressure have been considered.
- Uncertainty – decouple basic risk equation from uncertainty: by default, the uncertainty affects the base estimate of risk; IMESAFR 2.0 now shows uncertainty as a separate term, if so requested by the user.

Advanced Debris Density Predictions

For centrally-located charges in rectangular buildings, it has been observed that debris density is strongly affected by azimuth (i.e., the wall debris tends to go directly out “along the normals” and not “in the corners”). This effect, referred to as a cruciform or cloverleaf pattern, is an important factor in risk assessment when debris is a serious concern. A notional cloverleaf pattern is depicted in Figure 4, where the blue wall debris is ejected normal to each wall.

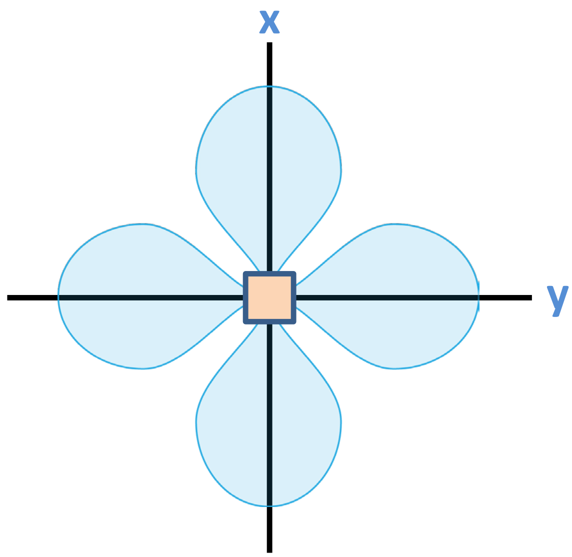

Figure 4. *Wall Debris "Cloverleaf" Pattern (Plan View)*

It should be noted that the roof debris is usually modeled as having no azimuthal dependency (i.e., the roof goes up and out in all directions). This is shown in Figure 5, where the tan roof debris lands uniformly at all angles.

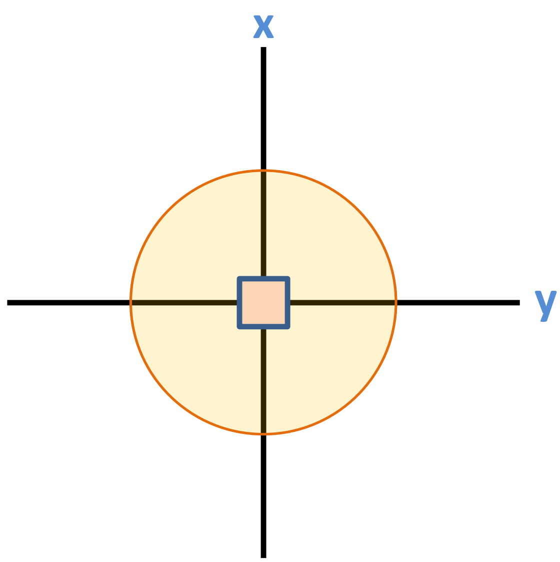

Figure 5. *Roof Debris Uniform Pattern (Plan View)*

The wall debris generally travels farther from the donor than the roof debris, so a combined roof/wall debris density pattern typically looks like Figure 6.

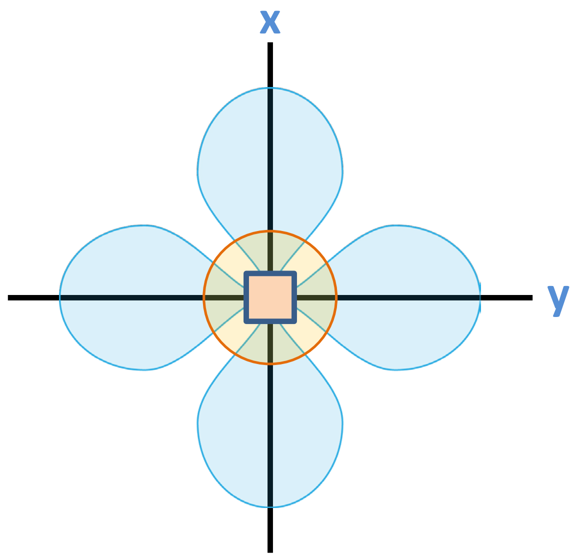

Figure 6. Combined Debris Pattern (Plan View)

If the charge is not centrally located, or if for any reason the user chooses not to represent the expected azimuthal variation for the wall debris, IMESAFR 2.0 can use an average distance function, similar to what is done in the previously released versions of IMESAFR. This option is shown (overlaying the expected cloverleaf pattern) in Figure 7.

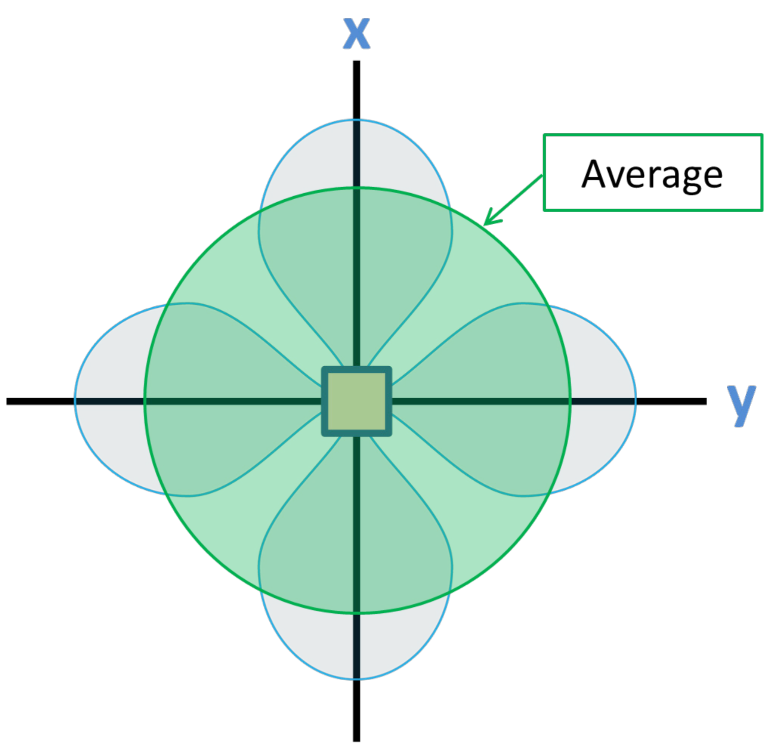

Figure 7. Alternate Wall Debris Modeling Functions (Plan View)

The debris density models, referred to as Probability Density Functions (PDFs), developed for IMESAFR 2.0 have two principal components as shown in Figure 8. The density as a function of distance from the PES is referred to as the downrange component. The density as a function of azimuthal angle is referred to as the cross-range component. The more simple PDFs have only downrange component and do not vary by azimuth. The BVN “anthill” distribution (shown in Figure 8) has no azimuthal variation and has been used to represent vertical and horizontal debris in the past.

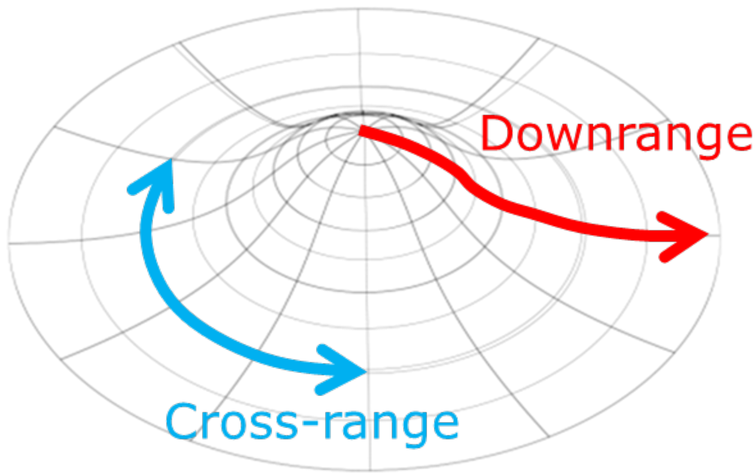

Figure 8.   BVN or "Anthill" Debris Distribution

The BVN PDF has been demonstrated to be conservative at close range [References 10 and 11]. This PDF not only has the problem of over-predicting high-angle debris density near the donor, it may in fact under-predict debris density at some ranges.

A new toroidal PDF has been developed to better match available test data and improve the accuracy of the model. The new downrange PDF component of this PDF is referred to as the Initial Sloping Upward Range Function (ISURF) model. The complex shape of the ISURF model is controlled by parameters that can be modified to represent variations in fragment size, debris material type, and component type (e.g., wall vs. roof). This distribution shows the debris density peaking at some distance (not at the origin), as shown in Figure 9.

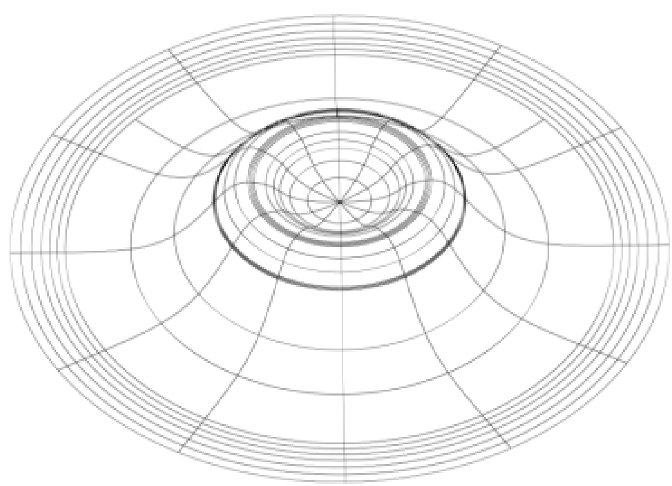

Figure 9.   Toroid Debris PDF Model with the ISURF Downrange Distribution

A comparison of the BVN and toroid distribution options (Figure 10) shows that there is a region where the current treatment of high-angle debris may be non-conservative (i.e., the toroid curve is above the BVN curve), but the toroid greatly reduces the high-angle debris density predictions close-in.

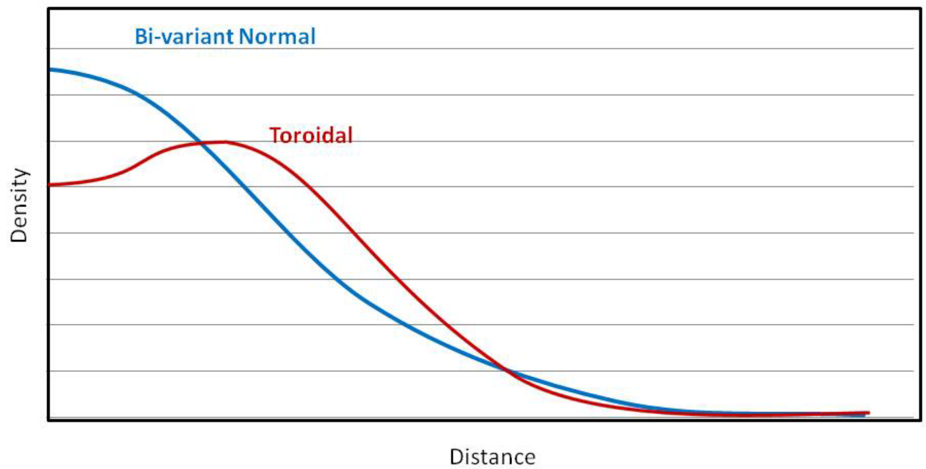

Figure 10. Cross-Sectional Comparison of BVN and Toroid Debris Distributions

Each of the PDFs described to this point have had no azimuthal variation (i.e., they produce the same results in all directions). These models are suited for directionally-uniform hazards such as roof debris or for scenarios in which the debris is dispersed in random directions.

A cross-range distribution can be introduced to produce the effect of azimuthal variation or "cloverleaf" pattern shown in Figure 4. This is accomplished by introducing a Gaussian Azimuthal Decay (GAD) cross-range model. The ISURF model is used as the downrange component in all directions with the peak relative amplitudes occurring in the four orthogonal directions. A Gaussian "normal" distribution (i.e., a "bell curve") centered over each normal direction is used as the cross-range component.

In summary, the final debris pattern consists of the new ISURF model as the downrange component and the GAD model as the azimuthal variation. This produces an "ISURFGAD" overall debris density model, as shown in Figure 11. The amplitude along the centerline varies with range as predicted by the ISURF model. The standard deviation of the GAD model is a constant angle at all ranges, though this standard deviation depends on the material type.

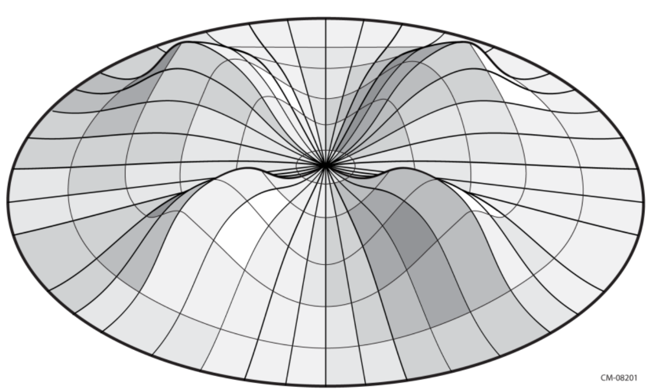

Figure 11. ISURFGAD Probability Density Function

This new type of PDF is flexible and has been tuned to match test and simulation data by altering the parameters of the downrange ISURF component or the standard deviation of the cross-range normal distribution. This powerful new model provides improved accuracy for many real-world scenarios.

The models for low-angle fly-through debris continue to utilize the Modified Pseudo Trajectory Normal (MPTN) method described in Reference 14.

Quantity-Distance Compliance

IMESAFR 2.0 users can now take QD considerations into account. QD tables have been built into the program and can be visualized in the GIS interface (as shown in Figure 12).

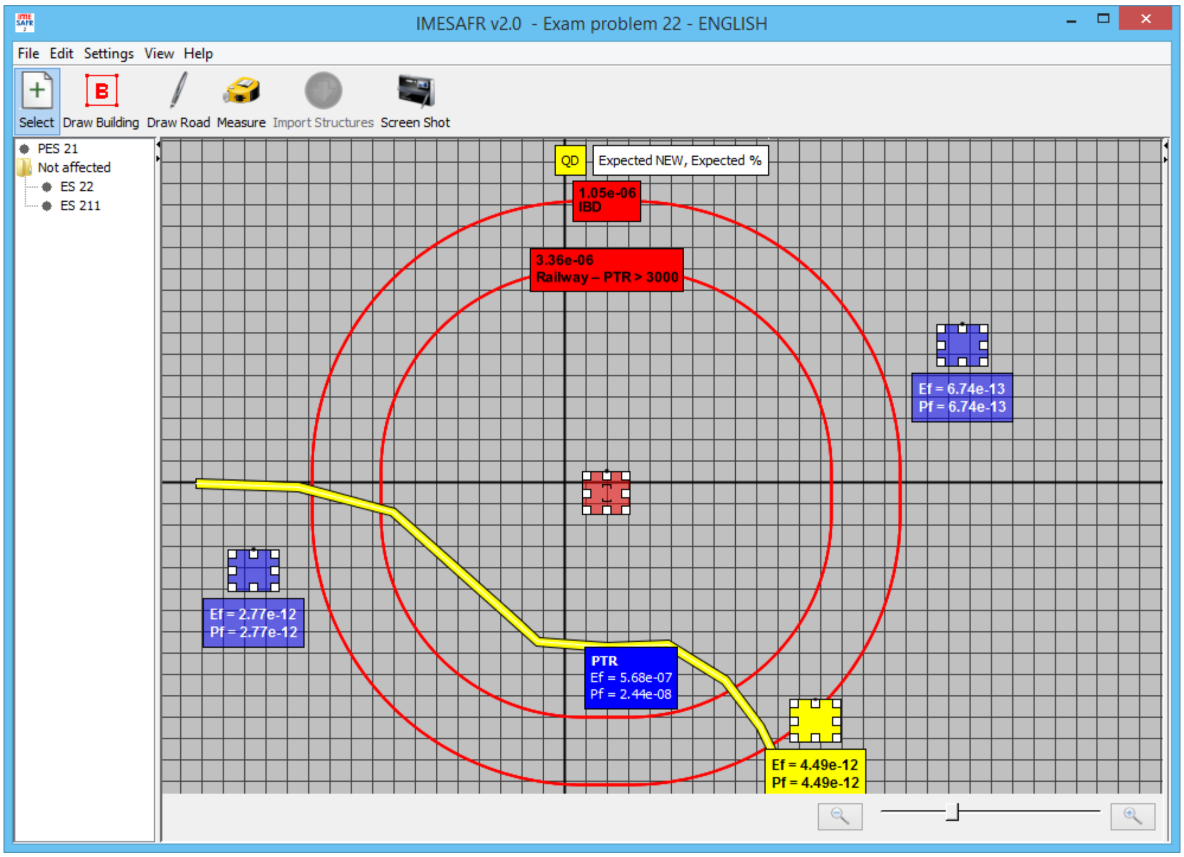

Figure 12. Example of the QD Display

IMESAFR 2.0 currently contains QD criteria from the American Table of Distances (ATD) and a subset of NATO QD tables. The software also allows users to create and store other QD tables.

IMESAFR uses edge-to-edge measurements for QD purposes, and measures from the closest point on the building (thus meaning the QD arcs will normally not be perfect circles). The software highlights any exposed facility that does not meet the selected QD criteria (designated as the yellow facility in Figure 12). The software also accounts for aggregation of explosives quantities in two or magazines that do not meet magazines separation requirements.

5.0 OTHER SUPPORT WORK

In addition to changes to the software itself, several supplementary efforts have been conducted to advance the state-of-the-art.

P_e Updates

IMESAFR 2.0 incorporates several updates to the Probability of Event options.

The "Bulk loading and unloading" activity type has been split into two subcategories. These include "pump" and "reservoir" options, each with a unique probability of event.

The probability of event values for storage activity types have been updated. The values for different types of storage originated from a mixture of government and commercial sources. This introduced unintended logical inconsistencies when transitioning between compatibility group (CG) options and frequency of handling. The values for "Day magazine storage" and "In-transit storage" were altered to maintain logical consistency for all combinations of CG and storage activity type.

Also, the value for "AN storage" has been updated. The values are a somewhat modified version of those given in the SAFEX Good Practice Guide (GPG) [Reference 18]. The values in the SAFEX GPG were generated using historical data. The values in the GPG are most appropriate for AN manufacturing plants, multiple operation sites and very large AN stores, as these types of sites were the main basis of the historical data. On explosives sites (including 5.1 ANE sites), the risks are different and, in general, the AN inventories are much smaller. The default values in IMESAFR were modified to reflect those realities. It is, however, suggested that the SAFEX GPG values be used for any site where that is more appropriate.

IME has developed recommended values to be used for AN-related explosives types when using the User-Defined Explosive Article (UDEA) tool in IMESAFR. These values are shown in Table 1.

Table 1 - IME Recommendations for UDEA values

Type	Maximum Yield		Expected Yield	
	% Contribution	TNT Equivalency	% Contribution	TNT Equivalency
Packaged 1.5	100% of NEWQD	0.85	70% of NEWQD	0.70
AN Prill	100% of NEWQD	0.42	50% of NEWQD	0.42
1.5* or 5.1 AN Emulsion	100% of NEWQD	0.75	75% of NEWQD	0.68
>92% AN Solution	100% of NEWQD	0.40	25% of NEWQD	0.40

Criteria Development

The IME has developed draft criteria for tolerable risk for use in conjunction with IMESAFR. IME has identified four populations for which tolerable criteria may be set: PES operators, related workers, unrelated workers, and the public. For these populations, IME has proposed quantitative tolerable criteria for broadly acceptable and de minimus risk levels. Activities with risk falling between the values would be encouraged to engage in ALARP (as low as reasonably practicable) principles. These values are shown in Table 2 and Figure 13.

Table 2 - IME Draft Tolerable Risk Criteria

Population	Individual Risk (fatalities/yr)		Societal Risk (fatalities/yr)	
	Max. Broadly Tolerable	De Minimis	Max. Broadly Tolerable	De Minimis
Public	Risks below 1e-6	Risks below 3e-8	Risks below 1e--5	Risks below 3e--7
Unrelated Workers	Risks below 3e-6	Risks below 1e--7	Risks below 3e--5	Risks below 1e--6
Related Workers	Risks below 1e--5	Risks below 3e--7	Risks below 1e--4	Risks below 3e--6
PES Operators	Risks below 3e--5	Risks below 1e-6	Risks below 3e--4	Risks below 1e--5

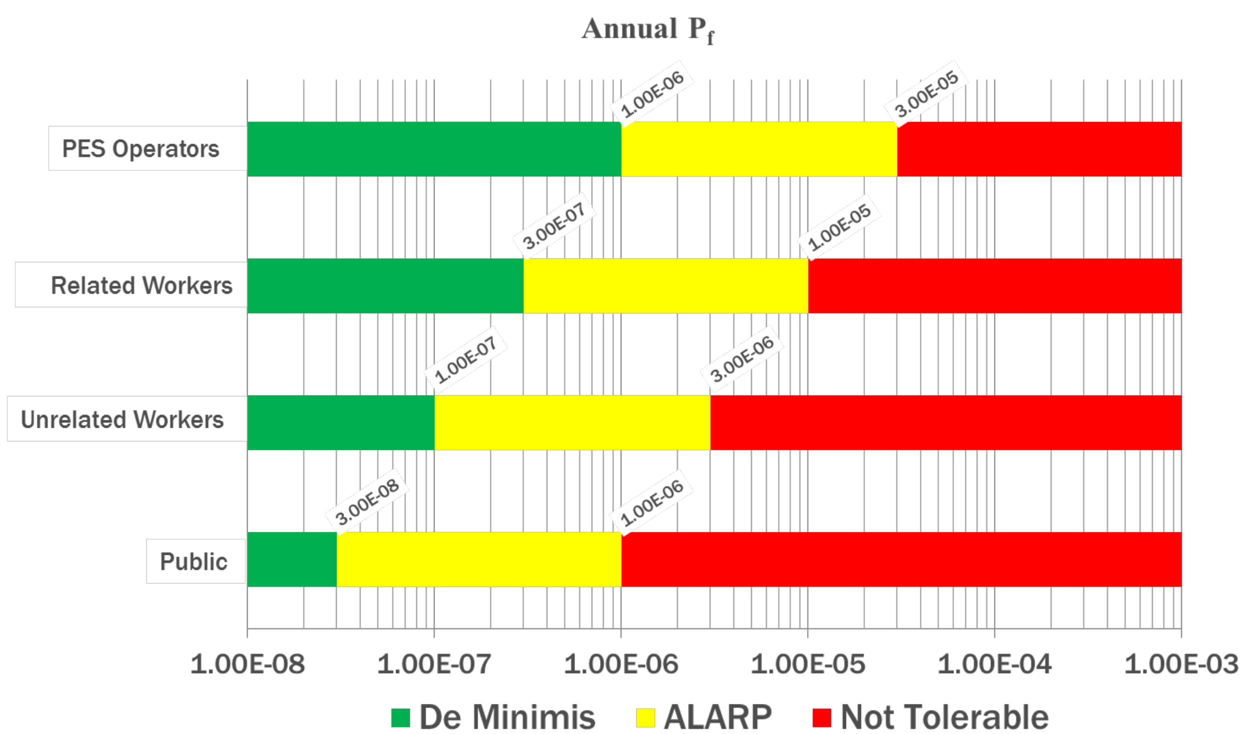

Figure 13. IME Draft Tolerable Risk Criteria

Catastrophic event aversion criteria have also been developed. These are shown in Table 3 and Figure 14.

Table 3 - IME Draft Tolerable Risk Criteria – Catastrophic Aversion

Catastrophic Aversion Criteria (fatalities per event)		
Population	**Max. Broadly Tolerable**	**De Minimis**
Public	30	1
Unrelated Workers	35	1
Related Workers	45	5
PES Operators	60	8

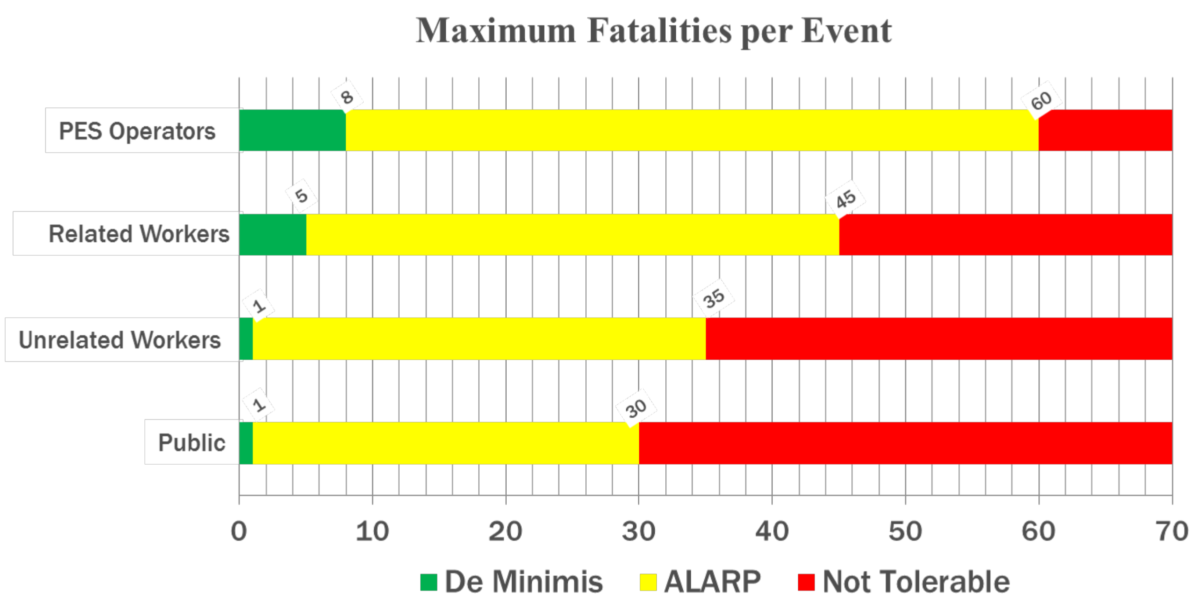

Figure 14. IME Draft Tolerable Risk Criteria – Catastrophic Aversion

Maturity Matrix and Test Program Recommendation

While the consequence algorithms in IMESAFR are considered state-of-the-art, and originally mirrored the algorithms used in SAFER, there is always room for improvement. Therefore, the science and the underlying data behind the software have been assessed for their maturity. This process has identified areas of remaining excess conservatism within the tool that could be improved if data were available. Test data are needed in these areas to continue to remove or reduce such conservatism.

Several explosive articles would appear to benefit from a more realistic characterization of their airblast and fragmentation characteristics. The sympathetic detonation characteristics of the IMESAFR explosive articles should also be verified. Likewise, several PES types unique to the commercial explosives industry and IMESAFR were also identified. A commercial explosives industry equivalent of the DDESB long-term testing program should be established and testing initiated to investigate these industry-unique structures.

IME and APT presented the results of this effort, including test program recommendations, at the 2012 International Society of Explosives Engineers (ISEE) Conference on Explosives & Blasting Techniques [Reference 17]. The results are presented in the form of a matrix that reports the current maturity of individual feature (e.g., mass distribution or kinetic energy) for each of the applicable explosive article, PES or ES types. To address the identified issues, full-scale testing programs to provide the needed data are proposed and described. These proposed testing efforts include work in two main areas: (1) improved characterization of explosive articles that are unique to the IMESAFR software (i.e., not in SAFER) and (2) more refined modeling of the Potential Explosion Site (PES) types that are unique to IMESAFR, particularly small metal structures. The goals of each of these test programs is discussed in detail, as well as the requirements involved with conducting the actual tests.

IME has proposed a series of tests for the coming years. The first test would be an elevated Ammonium Nitrate (AN) and/or Ammonium Nitrate Emulsion (ANE) bin. This test has been budgeted for 2016. The second test series is for perforating guns and has been budgeted for 2017. The final planned test is for US Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF) type magazines. This test or test series is planned for 2018.

Furthermore, users of IMESAFR are encouraged to suggest aspects of the program that appear to be unduly conservative and work with IME and APT to design a test program to generate the necessary data.

TP-14 Equivalent

In the past, the technical reference for IMESAFR has been TP-14 [Reference 13]. With minor interpretive insight, TP-14 has adequately served this purpose since the algorithms were so similar and differences have been reported in the open literature.

However, to document the new features and advanced algorithms as well as to provide additional transparency, IME and APT have developed an equivalent to TP-14 for IMESAFR 2.0. This document eliminates the need for any interpretation and consolidates all technical background for the IMESAFR 2.0 algorithms. The document is titled "IMESAFR Technical Manual," and will be formally published by IME in early 2015.

6.0 RELEASE INFORMATION

IMESAFR 2.0 was officially released in February of 2013 and is commercially available for use internationally. As with previous versions of the software, IME normally requires that users be trained in order to obtain a licensed copy of the software.

IMESAFR has a NLR designation (not requiring license) under US Export Administration Regulations (EAR) if shipped to countries other than those the Department of Commerce has listed as restricted (currently Cuba, Iran, Sudan, and Syria). Users from outside the US have the same access to IMESAFR as they do to other items in IME's Safety Library, or they can obtain the software from APT.

7.0 SUMMARY

IMESAFR has been commercially available since 2007 and has continued to evolve and improve since then. Because SAFER will use the ESS interface, IMESAFR 2.0 and future editions will use a different interface. IMESAFR 2.0 has been developed and was released in February 2013.

IMESAFR 2.0 includes many new features and incorporates a completely redesigned GIS-based GUI and debris density model. This new interface and new advanced debris algorithms allow the user much more control over the realistic treatment of real-world scenarios, and the results can be visualized in new and powerful ways. Users can also set-up cases and review results in metric units.

IME and APT have conducted additional work to support the release of Version 2.0 (as described in Section 5), and are pleased to be able to include QD compliance features in the new software.

References

1. Santis, Lon, Hardwick, Meredith, Leidel, David and Tatom, John, "IMESAFR—A Tool for Managing Risk from Commercial Explosives Operations, Minutes of the 32nd DDESB Explosives Safety Seminar, August 2006.
2. Tatom, John, Hardwick, Meredith, and Santis, Lon, "A Comparison of SAFER and IMESAFR Methods, Features, and Models", Minutes of the 32nd DDESB Explosives Safety Seminar, August 2006.
3. Tatom, John, and Santis, Lon, "A New Tool for Managing Risk with Commercial Explosive Operations," Minutes of PARARI 2007, November 2007.
4. Santis, Lon, "Managing Commercial Explosives Operations Using Quantitative Risk Assessment," Proceedings of the 34th Annual Conference on Explosives and Blasting Techniques, February 2008.
5. Tatom, John, Santis, Lon and Leidel, David, "The Status of Risk Assessment in the Commercial Explosives Community," Minutes of the 33rd DDESB Explosives Safety Seminar, August 2008.
6. Bryant, Amos, and Davis, Jesse, "Comparison of IMESAFR Debris Density Results to ISO-1 and ISO-2 Test Data," Proceedings of the 36th Annual Conference on Explosives and Blasting Techniques, February 2010.
7. Bryant, Amos, and Davis, Jesse, "Comparison of IMESAFR Debris Density Results to ISO-1 and ISO-2 Test Data," Minutes of 34^{th} DDESB Seminar, July 2010.
8. Santis, Lon, "A Modern Look at the Origins of Intra-plant Distance Tables," Proceedings of the 36th Annual Conference on Explosives and Blasting Technique, February 2010.
9. Santis, Lon, Tatom, John, and Swisdak, Michael, "Comparison of Data Used to Establish Intra-plant Distance Tables to Predictive Models," Minutes of 34^{th} DDESB Seminar, July 2010.
10. Tatom, John, Swisdak, Michael, and Santis, Lon, "A Comparison of the Quin Site Explosive Event Results to IMESAFR Consequence Predictions," SAFEX Congress, May 2011.
11. Swisdak, Michael, Tatom, John, and Santis, Lon, "A Comparison of the Quin Site Explosive Event Results to IMESAFR Consequence Predictions," Minutes of PARARI 2011, November 2011.
12. Wager, Phil, "Status of Automated Site Planning in the DOD," Minutes of 34^{th} DDESB Seminar, July 2010.
13. Hardwick, Meredith, Hall, John, Tatom, John, and Baker, Robert, "Approved Methods and Algorithms for DoD Risk-Based Explosive Siting," DDESB Technical Paper 14, July 2009.
14. Swisdak, Michael, Tatom, John, and Hoing, Craig, "Procedures for the Collection, Analysis, and Interpretation of Explosion Produced Debris—Revision 1," Department of Defense Explosives Safety Board Technical Paper 21 Revision 1, October 2007.
15. "IMESAFR Technical Manual," APT Research, Expected publication date – Spring 2015.
16. Ross, Tyler, Tatom, John, and Santis, Lon, "IMESAFR Sensitivity Studies," Proceedings of the 40th Annual Conference on Explosives and Blasting Techniques, February 2014.
17. Swisdak, Michael, Tatom, John, Santis, Lon, and Leidel, David, "A Proposed Test Program To Improve Explosive Risk Management," Proceedings of the 38th Annual Conference on Explosives and Blasting Techniques, February 2012.
18. "Good Practice Guide: Storage of Solid Technical Grade Ammonium Nitrate," SAFEX Good Explosives Practice Series, GPG 02 rev01, SAFEX International, March 2011.