A New Tool for Managing Risk Associated with Commercial Explosives Operations

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

Co-Author: Lon D. Santis, Institute of Makers of Explosives, 1120 19th St. NW, Suite 310, Washington, DC 20036. Phone: 202-429-9280; FAX 202-266-2420; E-mail: *Ldsantis@ime.org*

ABSTRACT

Recognizing the importance of quantitative risk analysis (QRA) tools, the Institute of Makers of Explosives (IME) has sponsored the development of the Institute of Makers of Explosives' Safety Analysis for Risk (IMESAFR) software tool. IMESAFR is a risk analysis software program designed for use by the commercial explosives industry, which IME represents. IME is a nonprofit safety and security association devoted to the safe and secure manufacture, transportation, storage, and use or disposal of commercial explosives in the U.S. and Canada since 1913. The software methodology's basis is from the U.S. Department of Defense (DoD) Risk Based Explosives Safety Criteria Team's (RBESCT's) Safety Assessment for Explosives Risk (SAFER) software. A diverse group of industry and government experts contributed to modifications of SAFER that adapt it to commercial operations. IMESAFR is intended to supplement the American Table of Distances (ATD) and offer standardized methods of managing risk from a wide variety of commercial explosives operations where the ATD does not apply. The modifications made to SAFER primarily involved the addition of commercial activities and potential explosives sites (PES). A review of commercial explosives accidents and operations over the last 20 years served as the basis for establishing probability-of-event factors. An industry survey of commercial PES types in the U.S. and Canada was conducted to identify and address critical differences in commercial structures as compared to the military structures in SAFER. As indicated, the basis for the development of IMESAFR has been associated with North American commercial explosives operations, but the tool is envisioned for use internationally.

CV

JOHN W. TATOM

Mr. Tatom is the Manager for Explosives Safety Science and Testing at APT Research in Huntsville, Alabama. He serves as the algorithm coordinator for the SAFER project, participates in the Department of Defense Explosives Safety Board (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 U.S. DoD papers concerning explosives safety modeling and testing. He has also written papers on these subjects for other agencies and organizations, as well as technical documents and user's manuals for government and commercial software. John has been involved in numerous other explosives safety software development efforts (DIRE, HEXDAM, VEXDAM, VASDIP). He holds a Bachelor of Electrical Engineering degree from Auburn University.

1.0 BACKGROUND

About ten years ago, the United States (U.S.) Department of Defense (DoD) recognized the need for and usefulness of a risk-based approach for explosives safety siting. The Risk Based Explosive Safety Criteria Team (RBESCT) was chartered to develop the methodology required and then create a model. This led to the creation of the Safety Analysis for Explosives Risk (SAFER) (Refs 1, 2, and 3) software tool, which is a semi-empirical quantitative risk analysis (QRA) model.

The Insitute of Makers of Explosives (IME) followed the progress of SAFER and decided to fund the development of a similar tool, tailored for use by the commercial explosives community in North America. This tool builds on SAFER Version 3.0 and is called Institute of Makers of Explosives' Safety Analysis for Risk (IMESAFR) (Ref 4). Although significant effort has been put into incorporating the requirements of the commercial explosives industry, a continuing improvement plan is envisioned.

1.1 QRA

In a QRA, the ability to accurately model real-world situations is obviously critical. In the end, the model must be able to represent the effects produced by the detonation of the donor and the consequences on the target. The science that goes into such a model must be carefully thought-out and based on as much data as possible.

In an explosive event, the effects that must be considered are the blast wave, the debris, and the thermal environment created by the donor item (material, article, or weapon). The consequences to the target, which is normally a human but could also be other vulnerable assets, include not only the direct results of the event's effects, but also the response of the structure where the target is located. The glass hazard and building collapse are the key facets of this structural response.

Ideally, the algorithms that form a model of an event are based on physics, certainly, but are anchored whenever possible by test and/or accident data. Although a wealth of test data already exists, new test programs are underway that will supply important information for use in models. The data from a test or accident can also be used to check the predictions of the model and point out areas for improvement.

There are generally three types of models: (1) *physics-based*, (2) *empirical*, and (3) *semi-empirical*. Although *physics-based* models can be developed to model explosives safety scenarios, they are, by necessity, quite complex and therefore expensive to develop. *Empirical models*, which report only data points available from tests and accidents, are by their nature limited in scope. *Semi-empirical* models, which use anchor points from available data but "fill in the gaps" with physics-based algorithms, may offer the best compromise between development cost, capabilities, and acceptance of results.

In a semi-empirical QRA model, conservatism is inversely related to the amount of available data. That is, if there are very few (or no) data points available to anchor an algorithm, the model must err on the side of caution. However, when an algorithm can be readily corroborated by test and/or accident data, the model does not need to include conservatism. This is important because the inclusion of conservatism would prevent model results from comparing well with the empirical data anchor points.

It is important to note that both SAFER and IMESAFR attempt to provide “best estimate” rather than “worst case” point estimates of risk[†]. The best estimate can be refined as the model is improved by the introduction of additional test and accident data.

1.2 HISTORICAL METHODS (Q/D, ATD, ETC…)

A recent paper (Ref 5) on the history of the American Table of Distances states the following:

> Accidents associated with the storage of explosives prompted regulating the locations of such storage at least as early as 1719, when an act was passed in Great Britain. During the following years various refinements to the regulations were made, but a major explosion in 1864 in which there was destruction and loss of life as far away as 10 miles, led to the landmark Explosives Act of 1875.
>
> This act certainly had influence on regulators in the United States: when Massachusetts established an explosives distance/weight table in 1904 they referred to the prior British work. Later, Colonel Dunn of the American Railway Association convened a conference of explosives manufacturers to discuss safe storage. From this conference the American Table of Distances was established in December, 1910.
>
> In 1914, the newly-established IME adopted the tables, and added distances relating to highways.

Since the inception of the American Table of Distances (ATD), IME made revisions to the ATD and added the Table of Separation Distances (TSD) for ammonium nitrate (AN) (Ref 6). The ATD and TSD are classic quantity/distance (Q/D) standards that have been modified from time-to-time as new information has come to light.

The ATD along with the DoD equivalent Q/D primarily look at separation distances as a function of explosives weight and are intended for use in rural environments and not where many individuals are exposed to risk. While this approach has worked for many years, it can also under-predict risk due to changing conditions, such as the fact that developers frequently erect inhabited buildings close to existing explosives storage and manufacturing facilities. Multiple elements can influence risk associated with these faculties. These elements are taken into consideration with the use of a QRA model.

1.3 IME

The IME has been the safety and security institute of the commercial explosives industry since 1913. Their mission has been to promote the protection of employees, explosives users, the public, and the environment, and to encourage the adoption of uniform rules and regulations in the manufacture, transportation, storage, handling, use, and disposal of explosive materials used in blasting and other essential industrial operations. In pursuit of these objectives, IME maintains a Safety Library comprised of booklets of recommended practices, training videos, posters, and most recently, software to assess risk (Ref 7). It was intended that IMESAFR would provide an alternative to the ATD and TSD and fill the gaps where standards do not exist.

[†] Both SAFER and IMESAFR have built-in uncertainty models.

1.4 APT

Located in Huntsville, Alabama, APT Research, Inc. (APT) is an employee-owned engineering firm. APT concentrates on safety, and assists numerous U.S. government agencies by providing system support, assessment and analysis efforts, and model development. APT served as the secretariat for the RBESCT, and also developed many of the algorithms for SAFER, as well as the software itself.

In January 2005, the IME commissioned APT to develop IMESAFR. IME's goals were simple: to provide a methodology based on sound science to manage the risk from a wide variety of commercial explosives activities. IME insisted on a transparent software development process and relied on the consensus of government and industry representatives.

1.5 IMESAFR

1.5.1 THE FOUNDATION FOR IMESAFR

In 1997, the DDESB chartered a working group, the RBESCT, to study the feasibility of using a risk-based method for explosives safety. Many European nations had risk-based models at that time and had been using them for years. The RBESCT found that a risk-based approach was feasible and recommended that the DDESB pursue a risk-based method (Ref 8). In 1998, the RBESCT began developing the SAFER model. SAFER uses the following basic formula to estimate the annual probability of fatality to an individual [P(f)]:

$$P(f) = P(e) \text{ x } P(f|e) \text{ x } E(p)$$

where:

$P(e)$ = the annual probability that an explosives event will occur in a given Potential Explosives Site (PES),

$P(f|e)$ = the probability of fatality given an explosives event and the presence of a person, and

$E(p)$ = the exposure of one person to a particular PES on an annual basis (Ref 9).

A second measure is group risk and is expressed as the expected fatalities [$E(f)$] per year. This is defined as the summation of individual risks and provides the average number of fatalities expected per year. It is shown by:

$$E(f) = \sum [P(e) \text{ x } P(f|e) \text{ x } E(p)]$$

where:

$E(p)$ = the exposure of the group to a particular PES on an annual basis.

Since 2000, SAFER Versions 2.0, 2.1, and 3.0 have been delivered to the DoD. Each new SAFER version has included additional data or algorithms to more accurately model possible scenarios. In addition to model development, the RBESCT developed risk acceptance criteria to be used in conjunction with the model (Ref 10).

APT used virtually the same processes and controls in creating IMESAFR as they used in creating SAFER. A diverse team of experts comprising industry and government representatives from DDESB; the Bureau of Alcohol, Tobacco and Firearms (ATF); the Department of Transportation (DOT); the Occupational Safety and Health Administration (OSHA); the Mine

Safety and Health Administration (MSHA); and Natural Resources Canada (NRCan)[†] met seven times in 2005 and 2006 to advise APT on critical design modification issues.

2.0 RELATIONSHIP OF IMESAFR TO SAFER

IMESAFR is a software tool that is based on the 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 storage facility siting.

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

$$P(f) = P(e) \text{ x } P(f|e) \text{ x } E(p)$$

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.

3.0 IMESAFR FEATURES

Features of the models and algorithms used in IMESAFR are described in the following sections.

3.1 MODELS

Each scenario that can be considered by the software must have a model for the elements that will affect the results. These elements are the donor item type, the donor structure (or PES), the target structure (or the Exposed Site (ES)), and any natural or man-made barricades. To the extent possible, these models are based on test data.

3.1.1 DONOR ITEM

The DoD has studied munitions fragmentation extensively, making the development of semi-empirical models for such items straightforward (Ref 11). If the donor item is bulk material, then a model for its fragmentation is not required. Other types of donor items found in the commercial explosives industry (including perforating guns, intermediate bulk containers, and bulk materials metal containers) do not have as much available test data to support development of models. Until such data are available, commercial donor item models will have to be scaled (up or down) from the closest available military model (Ref 12).

3.1.2 POTENTIAL EXPLOSION SITE

Predicting the behavior of various PES types under different loading conditions is the most difficult aspect of an explosives safety QRA model. Many full-scale tests have been performed by the U.S. DoD and their international counterparts, including Distant Runner (Ref 13), ESKIMO (Ref 14), 40/27 Tonne Trials (Ref 15, 16), as well as SciPan (Ref 17). These tests are vital to the understanding of the secondary debris generation, but are also quite expensive to plan and conduct. For this reason, the number of such tests is quite small.

[†] The participation of U.S. or Canadian regulatory agencies in the IME team of experts used to develop IMESAFR does not constitute an endorsement of IMESAFR. The contents of IMESAFR or its related materials do not necessarily reflect the views or policies of any agency of the U.S. or Canadian government.

3.1.3 EXPOSED SITE

The prediction of the ES response to blast loading has tended to be conservative when compared to test results. Therefore, the incorporation of such results into the models to recalibrate the prediction process is essential to producing best estimate output. The SciPan test series and the current testing at Woomera (Ref 18) are contributing important data to various ES models, but much more is needed to adequately anchor all of the ES models.

The protection an ES provides its occupants from debris has not been explored in great detail until recently. The SPIDER test program (Ref 19) and ongoing Swiss brickwork penetration tests (Ref 20) are helping to address this shortcoming.

3.1.4 BARRICADES

The ability to accurately model barricades has been a key concern for both the RBESCT and the IME team of experts. Currently, SAFER allows only ES barricades (the barricade must be closer to the target than to the donor) because of questions about the ability to properly assess the behavior of donor-side barricades. However, IMESAFR allows such PES barricades, while providing some guidance to the user for potential off-line adjustments (Ref 21). Recent testing efforts (including SciPan 3) have provided some useful data, but a more thorough program dedicated to characterizing barricades is needed.

3.2 ALGORITHMS

3.2.1 EFFECTS AND CONSEQUENCES

In order to determine the effects and consequences of an explosive incident, the effective yield of the event must be determined. This is accomplished by adjusting the free-field results to account for the explosive's immediate container (if present), the explosive type, and the attenuation of the blast wave caused by the presence of the donor structure (if applicable).

For modeling purposes, the effects of an explosive incident are the changes in the environment created by the blast outside the donor structure (if one is present). Such effects include overpressure and impulse, debris, and thermal – all of which are considered by IMESAFR. It should be noted that ground shock is not considered (by either SAFER or IMESAFR) because it normally does not contribute to fatality or injury.

The consequences of a blast are the results on the target structure (if one is present). IMESAFR considers two consequences: glass and structural component failure (primarily the roof and walls).

These effects and consequences are then used to determine the target (usually a human) vulnerability. The target vulnerability is considered separately for each applicable effect and consequence.

3.2.2 YIELD

Yield is computed in IMESAFR by using the same algorithms and procedures as the DDESB Blast Effects Computer (Ref 22). They use the equations for a hemispherical Trinitrotoluene (TNT) surface burst as the "basic airblast engine" to generate the various airblast parameters. For situations other than a hemispherical TNT surface burst, including various types of charges in the open or detonations inside a donor structure, effective TNT yields are computed and used. These yields are functions of the scaled distance (distance divided by the cube root of the explosive weight) from the center of the event and the type of donor item and/or structure selected. The calculated effective yields are used in conjunction with the hemispherical TNT surface burst curves to generate the appropriate airblast parameters.

3.2.3 PRESSURE AND IMPULSE

Once an effective yield has been calculated, the airblast algorithms from the Blast Effects Computer are used to generate the pressure and impulse at the location of the ES. The pressures and impulses computed in this manner have been compared to all available test data and have been found to be within a few percent of the actual measured values (Ref 2).

3.2.4 STRUCTURAL RESPONSE

When the target building is "hit" by the blast wave, the structure may provide its occupants some protection. However, as the building breaks up – the worst case being total collapse – the occupants are exposed to the additional hazards produced by the building itself.

3.2.5 GLASS

Extensive research has been conducted, especially by the physical security community, on glazing targets to determine their response to blast loading. Many detailed models, including but not limited to Glass-CF (Ref 23) and WinGARD (Ref 24), draw upon such test data to provide predictions. A "broader brush" program like IMESAFR can use the output of these more detailed models in combination with accident data to generate results suitable for a QRA.

Although the input options are more limited in IMESAFR, the program has been compared with Glass-CF to the satisfaction of the IME. It is important to note that while glass is a serious hazard to personnel in a building with windows, anecdotal evidence suggests that it is rare that fatalities are caused by glass in an explosives event.

Ongoing testing efforts will eventually supply enough data to expand the list of input options in IMESAFR. Safety retrofitting of existing windows is now a relatively common occurrence. Consequently, more work must be done on the glass models to allow such modifications to be taken into account.

3.2.6 BUILDING FAILURE

An extensive amount of testing has been conducted on the blast response of structures. However, actually determining the hazard to the building occupants is another matter. The results of accidental (or terrorist) events can be studied, but it is not always easy to reconstruct the scenario, i.e., the exact location and amount of explosives and the precise position of the people within the building.

Clearly, the first step is to understand the response of the target building to the blast load. Current testing efforts, including SciPan and Woomera, continue to supply data to support this effort. The data points are supplementing earlier testing conducted by the DoD (Ref 25). This empirical data set feeds the development of pressure-impulse (P-I) diagrams, which are then used to predict damage to specific structure (or structural component) based on the blast load (Ref 26).

Given the damage, the hazard to the occupants can be predicted. These types of predictions have been compared between models and to the limited real-world data available, with encouraging results.

One such comparison showed good correlation between Analysis of Death and Injuries Resulting from Explosions (DIRE), a commercially available consequence modeling tool that uses the same P-I diagrams as IMESAFR, and the results of the Oklahoma City (Murrah Building) bombing and the Khobar Towers terrorist attack (Ref 27).

3.2.7 DEBRIS

The debris created by the blast is divided into three categories: primary fragments (the casing and/or immediate packaging of the donor item), secondary debris (the pieces of the donor structure), and crater ejecta (the debris from the crater formed in the ground and/or foundation of a donor structure).

3.2.8 PRIMARY FRAGMENTS

The primary fragment characteristics contained in the models (initial velocity, number of fragments, mass distribution, and maximum range) are consistent with information and procedures contained in DoD literature (Ref 11). As described in the literature, the development of these parameters is based on extensive testing and analysis of donor items.

3.2.9 SECONDARY DEBRIS

Predicting the size, shape, initial velocity and angle, and maximum throw range of debris from the donor building is a particularly challenging task. Even if a given model can accurately predict the debris characteristics of a particular event, it is still quite possible that the same model will be inaccurate for other events. This is the reason it is highly desirable to have multiple data points (usually at different loading densities) for the same building type. The SciPan test series will eventually provide multiple result sets for concrete buildings at different loading densities. The IMESAFR concrete donor building model has been compared to (and is, in fact, largely based on) SciPan results (Ref 12), and will incorporate the results of future tests once they are available.

Ongoing efforts are being conducted by the international explosives safety community to continue to advance the state-of-the-art in secondary debris modeling (Ref 28). These advances will allow the continued improvement of QRA models.

3.2.10 CRATER EJECTA

Characterization of crater ejecta is based on the type of soil around the donor structure; the soil type options are dependent on the PES building type selected. The following soil types are considered: (1) *rock or hard clay*, (2) *loose soil*, (3) *crushed stone or gravel*, and (4) *concrete*. The *loose soil* option is for soil less densely packed than *rock or hard clay* and would be expected to break up into smaller pieces and present less of a hazard. The *crushed stone or gravel* option has a piece size/mass distribution based on standard sieve sizes. (Ref 21)

The crater ejecta equations are based on available models and data. The majority of the information was taken from the literature (Ref 29), other predictive models (Ref 30), and test results (Ref 2).

3.2.11 THERMAL

Thermal effects are only considered for Hazard Division (HD) 1.3 materials (mass fire). It is assumed that thermal effects from a high-explosives event would be insignificant (compared to other effects) if 1.3 items were not present. This assumption is based on the fact that, compared to other blast effects, thermal effects are extremely short ranged; i.e, the hazardous consequences from blast and fragmentation extend to significantly greater distances than do thermal effects.

The thermal models in IMESAFR have not been developed to the level of maturity of the other algorithms in the software. However, the models are based on available data and literature (Ref 31).

3.2.12 VULNERABILITY

Predictions involving the probability of fatality (or injury) for a person exposed to a given hazard are always difficult to corroborate, but a great deal of work has been done in this area. For the human response to direct blast loading (skull fracture, lung rupture, and whole-body displacement), American and European research (Ref 32, 33) led to the development of probit functions (Ref 34, 35) to estimate the conditions required for lethality.

The range (missile launch) safety community has developed and issued standards for determining the vulnerability of people to debris impacts (Ref 36). This standard provides a series of “S-Curves” relating the probability of fatality to the kinetic energy of a fragment. These curves form the basis of the vulnerability routines in IMESAFR.

3.3 DIFFERENCES FROM SAFER

While IMESAFR is based on the SAFER Version 3 program, there are notable differences. These differences require supporting models and associated algorithms. There are also differences in the user community and the implementation guidance for the two programs. It is important to note that there is a lesser degree of maturity for the new models in IMESAFR than the pre-existing models in/from SAFER. Differences between sponsors, user community, features, and implementation are highlighted in sections 3.3.1-3.3.6.

3.3.1 SPONSORS

The RBESCT consists of members from each of the armed Services and DDESB. This team was chartered by the DDESB in 1997 to study the feasibility of using a risk-based approach for explosives facilities siting.

The IMESAFR team of experts consists of representatives from IME member companies and stakeholders from the government and the International Society of Explosives Engineers (ISEE).[†] The IMESAFR team of experts began advising 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. A list of representatives that participated in IMESAFR development meetings follows:

[†] The participation of U.S. or Canadian regulatory agencies and associations in the IME team of experts used to develop IMESAFR does not constitute an endorsement of IMESAFR. The contents of IMESAFR or its related materials do not necessarily reflect the views or policies of any agency of the U.S. or Canadian government.

Dr. Dave Leidel, Chair	Jet Research Center (JRC) Halliburton
Dave Shatzer, Aaron Gerber	Bureau of Alcohol, Tobacco and Firearms (ATF)
John Capers	Austin Powder
Dr. Jerry Ward,	DDESB
Doug Reeves, Joe Nicklous	U.S. Department of Transportation (DOT)
Skip Hurley	Dyno-Nobel
Lon Santis	IME
Larry Schneider	ISEE
Harry Verakis, Tom Lobb	Mine Safety and Health Administration (MSHA)
John Buszard	Natural Resources Canada (NRCanada)
John Lee Turner, Rick Jarvis	Orica
Mark Hagemann	Occupational Safety and Health Administration (OSHA)
Ray Dickes	Schlumberger
APT Research, Inc.	Support Contractor

3.3.2 USERS

Access to and use of IMESAFR is different than SAFER. The following will describe the intended access and users in the United States and internationally.

3.3.2.1 UNITED STATES

SAFER was designed by the RBESCT in conjunction with APT, and is intended for use by U.S. DoD entities and their contractors. Although some users in the U.S. Department of Energy (DOE) have been granted access to the program, SAFER is generally distributed to and used by the U.S. DoD. Distribution of the program is controlled by the DDESB, the four Armed Services, and the Coast Guard. SAFER is not currently available for sale to the general public.

IMESAFR was designed by the joint government-industry team described in Section 3.3.1, again supported by APT. Although the majority of users of IMESAFR are expected to be from the commercial sector, government agencies will have access to the program.

3.3.2.2 INTERNATIONAL

Outside of the U.S., prospective SAFER users must obtain permission from the DDESB to gain access to the software. SAFER does not have an export license.

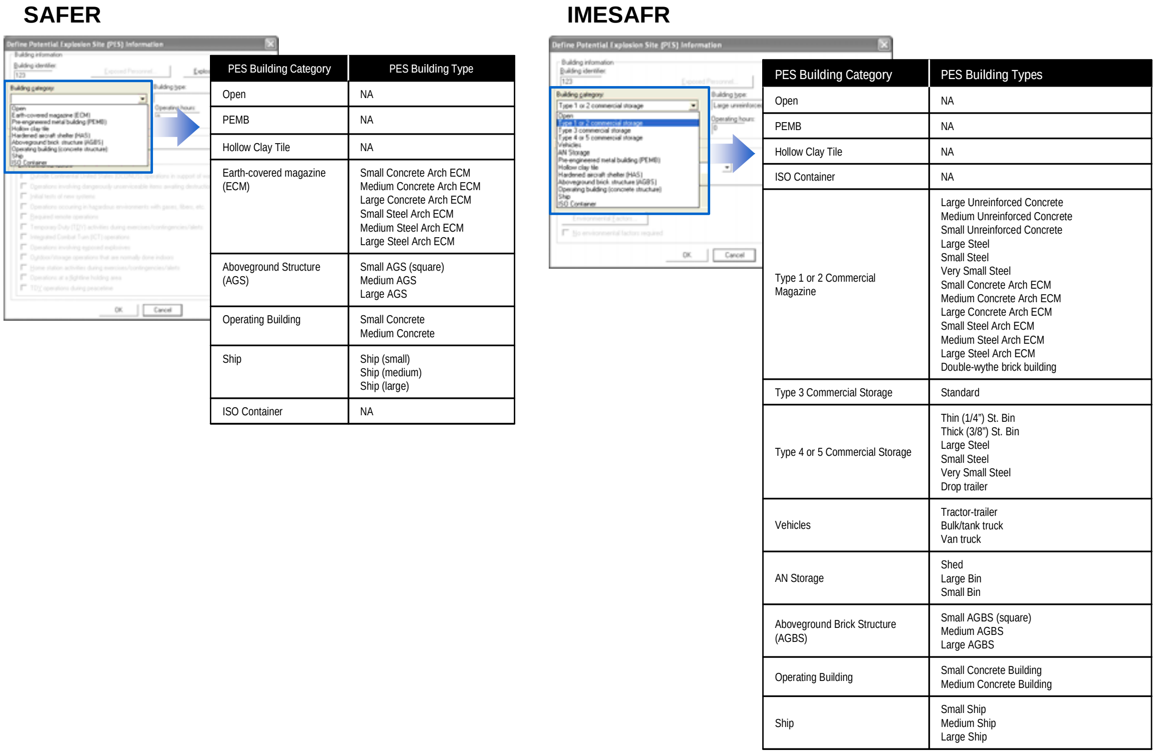
IMESAFR has been classified by the Bureau of Export Administration (BXA) as EAR99, which means it can be exported to nearly all countries without an export license. IMESAFR is not authorized for distribution to “T6” countries (currently Cuba, Iran, Libya, North Korea, Sudan, and Syria). Users from outside the U.S. 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.

3.3.3 GUI/FEATURES

All user interfaces and capabilities in IMESAFR are very similar to those of SAFER, with the exception of some of the user choices. The IMESAFR team of experts chose new user inputs and terms that would better represent the commercial explosives industry. The changes to the graphical user interface (GUI) and additional features are described in the following sections.

3.3.3.1 *PES TYPES*

The SAFER model contains eight PES building categories. Within these building categories, there are building types that are described by building size or building construction. All of these building categories were adopted and are included in the IMESAFR model. In addition to the PES categories in SAFER, new PES building types were developed and are included in the IMESAFR model. Figure 1 shows the building types and categories in SAFER and IMESAFR.



SAFER

PES Building Category	PES Building Type
Open	NA
PEMB	NA
Hollow Clay Tile	NA
Earth-covered magazine (ECM)	Small Concrete Arch ECM Medium Concrete Arch ECM Large Concrete Arch ECM Small Steel Arch ECM Medium Steel Arch ECM Large Steel Arch ECM
Aboveground Structure (AGS)	Small AGS (square) Medium AGS Large AGS
Operating Building	Small Concrete Medium Concrete
Ship	Ship (small) Ship (medium) Ship (large)
ISO Container	NA

IMESAFR

PES Building Category	PES Building Types
Open	NA
PEMB	NA
Hollow Clay Tile	NA
ISO Container	NA
Type 1 or 2 Commercial Magazine	Large Unreinforced Concrete Medium Unreinforced Concrete Small Unreinforced Concrete Large Steel Small Steel Very Small Steel Small Concrete Arch ECM Medium Concrete Arch ECM Large Concrete Arch ECM Small Steel Arch ECM Medium Steel Arch ECM Large Steel Arch ECM Double-wythe brick building
Type 3 Commercial Storage	Standard
Type 4 or 5 Commercial Storage	Thin (1/4") St. Bin Thick (3/8") St. Bin Large Steel Small Steel Very Small Steel Drop trailer
Vehicles	Tractor-trailer Bulk/tank truck Van truck
AN Storage	Shed Large Bin Small Bin
Aboveground Brick Structure (AGBS)	Small AGBS (square) Medium AGBS Large AGBS
Operating Building	Small Concrete Building Medium Concrete Building
Ship	Small Ship Medium Ship Large Ship

Figure 1. Comparison of Building Categories and Building Types

3.3.3.2 *"WEAPON" AND "EXPLOSIVES" TYPES*

The menu items for explosives in SAFER consist of military weapons. In order for the commercial industry to better use the IMESAFR model, the term "weapon type" was modified to "explosives type" and two or three choices are available based on the selection of HD. The choices for the weapon and explosives types are shown in Figure 2.

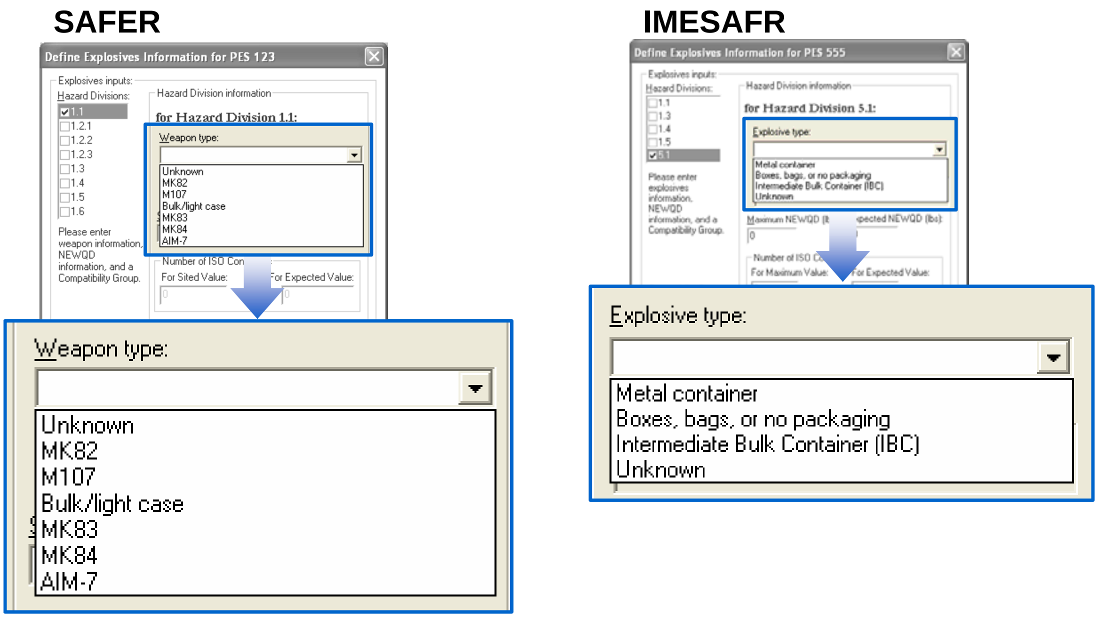


Figure 2. Comparison of Weapon and Explosive Types

3.3.3.3 ACTIVITY TYPES

The activity at the PES is used to calculate the probability of event, *P*(*e*), in SAFER and IMESAFR. SAFER contains 25 different activities. For IMESAFR, the list of activities was reviewed and activities that are not conducted in the commercial industry were removed from the list. IMESAFR also includes four new activities that occur in industry (perforating gun assembly, bulk explosives loading and unloading, AN storage, and commercial long-term storage). Data to calculate the *P*(*e*) values for these new activities were provided by IME, its member companies, and ATF.

The lists of activities included in SAFER and IMESAFR are shown in Figure 3.

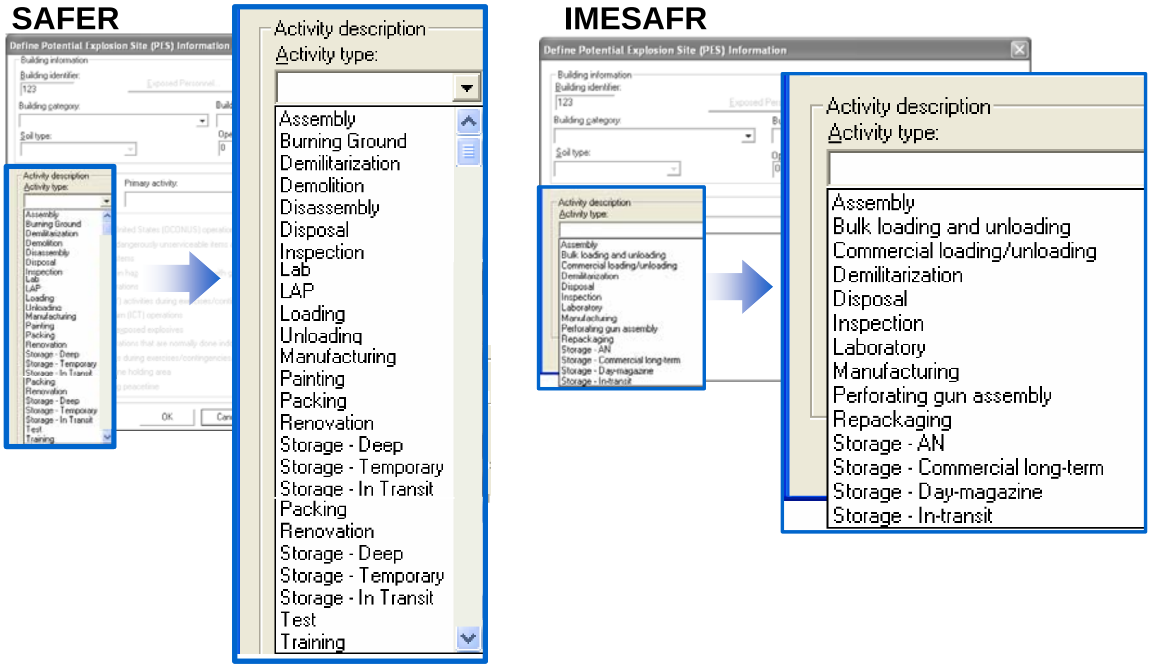


Figure 3. Comparison of Activity Types

3.3.3.4 SOIL TYPES

Soil type is used in SAFER and IMESAFR to determine the amount of crater ejecta that is thrown. For IMESAFR an additional soil type of "crushed stone" is included. The lists of soil types included in SAFER and IMESAFR are shown in Figure 4.

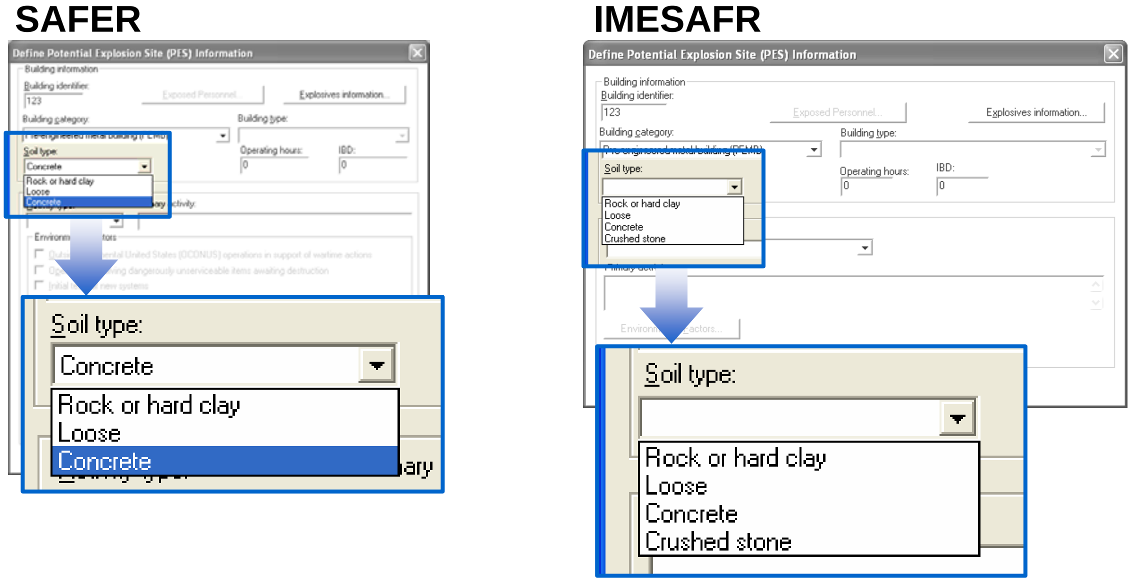


Figure 4. Comparison of Soil Types

3.3.4 NEW CONSEQUENCE MODELS

For the new capabilities in IMESAFR that relate to the consequence, or probability of fatality given an event ($P_{f|e}$), new models were developed. Section 3.3.4.1 describes the new PES models; Section 3.3.4.2 describes the new explosives article models; Section 3.3.4.3 describes the new soil type model; and Section 3.3.4.4 describes the barricade model.

It should be noted that the IMESAFR development team has offered many of the new models in IMESAFR to the RBESCT for possible inclusion in future versions of SAFER. This collaborative approach has potential benefit for both groups.

3.3.4.1 PES MODELS

An important factor in determining the hazards associated with an explosive event is the structure in which the donor material is contained (the PES). The PES may attenuate the blast wave, which reduces risk, but the PES may also become secondary debris that increases the risk.

Many of the PES types from SAFER are applicable to the commercial explosives industry and all of them were retained in the IMESAFR model. Additionally, new structure types were established to model commercial magazines, vehicles, and other structures not adequately represented by the existing PES types in SAFER.

To ensure that the newly created PES types fairly represented the “real world” of the commercial explosives industry, the IME conducted a survey of its member companies, the results of which were reviewed by APT. The survey asked for a description of the PES types that each company currently had in use. The description included details of construction material, technique, dimensions, and usage. Thirteen companies responded to the survey, describing 2,354 PES locations.

In reviewing the survey responses, APT attempted to capture the majority of the donor structures while retaining a manageable list of PES types. A comparison of the PESs in IMESAFR to those reported in the survey would show that IMESAFR covers at least 80 percent of the PESs reported within 20 percent of their size. In other words, the choices of PESs in IMESAFR should allow for reasonable simulation of at least 80 percent of all commercial PESs. The final list of PESs was reviewed by the team of experts and adjusted to establish consistent assumptions and are shown in Table 1. These parameters are used in essentially an identical fashion in IMESAFR to the PES parameter tables provided in DDESB Technical Paper 14 (Ref 36) for SAFER.

Table 1. Summary of PES Models

			Model Dimensions (ft)			Calculated Volume (ft^3)	Component Mass (lbs)			
No.	Type	PES	Length	Width	Height		Roof	Front Wall	Side Walls	Rear Wall
1	1 or 2	Large UC	37.25	75	12	33,525	134,896	48,611	195,750	48,611
2	1 or 2	Med UC	20	40	10	8,000	8,167	21,750	87,000	21,750
3	1 or 2	Small UC	12.5	25	8	2,500	3,190	10,875	43,500	10,875
4	1 or 2	Double-wythe Brick	20	40	10	8,000	8,167	43,500	174,000	43,500
5	1 or 2	Large Steel	33	33	10	10,890	27,715	11,618	23,236	11,618
6	1 or 2	Medium Steel	25	25	8	5,000	15,906	6,893	13,785	6,893
7	1 or 2	Small Steel	12	12	7	1,008	3,665	2,392	4,785	2,392

			Model Dimensions (ft)			Calculated	Component Mass (lbs)			
8	1 or 2	Very Small Steel	8	8	7	448	1,629	1,459	2,918	1,459
9	3	Standard	10	10	10	1,000	970	970	1,939	970
10	4 or 5	Trailer	8	35	8	2,240	14,872	3,517	30,772	3,517
11	4 or 5	Thin (1/4") St. Bin	15	15	14	3,150	11,951	4,454	8,908	4,454
12	4 or 5	Thick (3/8") St. Bin	15	15	14	3,150	11,951	3,216	6,431	3,216
13	Vehicles	Tractor-trailer	8	40	8	2,560	16,997	3,399	33,994	3,399
14	Vehicles	bulk/tank truck	8	26	8	1,664	11,048	3,399	22,096	3,399
15	Vehicles	van track	8	16	5	640	6,799	2,125	8,499	2,125
16	AN Storage	Shed	100	100	40	400,000	482,850	193,140	386,280	193,140
17	AN Storage	Large Bin	12	12	24	3,456	7,649	15,297	30,595	15,297
18	AN Storage	Small Bin	12	12	16	2,304	7,649	10,198	20,397	10,198

These new PES models should represent a close match to the vast majority of actual PES structures in the North American commercial explosives industry. For each component of the PES, the percentage of material (e.g., steel or concrete) and mass distributions are shown in Tables 2 through 5. The data in these tables are used to determine the size of the secondary (PES) debris that is thrown if an event occurs at the PES.

Table 2. Mass Distribution for PES Roof

	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
Large UC	12	88	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Med UC	12	88	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Small UC	12	88	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Double-wythe Brick	12	88	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Large Steel	100	0	0	0	5	5	5	15	20	25	15	10
Medium Steel	100	0	0	0	5	5	5	15	20	25	15	10
Small Steel	100	0	0	0	5	5	5	15	20	25	15	10
Very Small Steel	100	0	0	0	5	5	5	15	20	25	15	10
Standard	100	0	0	0	5	5	5	15	20	25	15	10
Trailer	100	0	0	0	5	5	5	15	20	25	15	10
Thin (1/4") St. Bin	100	0	0	0	5	5	5	15	20	25	15	10
Thick (3/8") St. Bin	100	0	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Tractor-trailer	100	0	0	0	5	5	5	15	20	25	15	10
Bulk/tank truck	100	0	0	0	5	5	5	15	20	25	15	10
Van truck	100	0	0	0	5	5	5	15	20	25	15	10
Shed	12	88	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Large Bin	100	0	0	0	5	5	5	15	20	25	15	10
Small Bin	100	0	0	0	5	5	5	15	20	25	15	10

Table 3. Mass Distribution for PES Front Wall

	Percent Material (%)		Percent Mass (%)									
PES	Steel	Concrete	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
Large UC	0	100	0	5	5	10	40	10	5	5	5	15

	Percent Material (%)		Percent Mass (%)									
Med UC	2	98	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Small UC	2	98	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Double-wythe Brick	0	100	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Large Steel	100	0	0	0	5	5	5	15	20	25	15	10
Medium Steel	100	0	0	0	5	5	5	15	20	25	15	10
Small Steel	100	0	0	0	5	5	5	15	20	25	15	10
Very Small Steel	100	0	0	0	5	5	5	15	20	25	15	10
Standard	100	0	0	0	5	5	5	15	20	25	15	10
Trailer	100	0	0	0	5	5	5	15	20	25	15	10
Thin (1/4") St. Bin	100	0	0	0	5	5	5	15	20	25	15	10
Thick (3/8") St. Bin	16	84	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Tractor-trailer	100	0	0	0	5	5	5	15	20	25	15	10
Bulk/tank truck	100	0	0	0	5	5	5	15	20	25	15	10
Van truck	100	0	0	0	5	5	5	15	20	25	15	10
Shed	0	100	0	5	5	10	40	10	5	5	5	15
Large Bin	100	0	0	0	5	5	5	15	20	25	15	10
Small Bin	100	0	0	0	5	5	5	15	20	25	15	10

Table 4. Mass Distribution for PES Side Walls

	% Material		Percent Mass (%)									
PES	Steel	Concrete	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
Large UC	0	100	0	5	5	10	40	10	5	5	5	15
Med UC	2	98	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Small UC	2	98	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Double-wythe Brick	0	100	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Large Steel	100	0	0	0	5	5	5	15	20	25	15	10
Medium Steel	100	0	0	0	5	5	5	15	20	25	15	10
Small Steel	100	0	0	0	5	5	5	15	20	25	15	10
Very Small Steel	100	0	0	0	5	5	5	15	20	25	15	10
Standard	100	0	0	0	5	5	5	15	20	25	15	10
Trailer	100	0	0	0	5	5	5	15	20	25	15	10
Thin (1/4") St. Bin	100	0	0	0	5	5	5	15	20	25	15	10
Thick (3/8") St. Bin	100	0	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Tractor-trailer	100	0	0	0	5	5	5	15	20	25	15	10
Bulk/tank truck	100	0	0	0	5	5	5	15	20	25	15	10
Van truck	100	0	0	0	5	5	5	15	20	25	15	10
Shed	0	100	0	5	5	10	40	10	5	5	5	15
Large Bin	100	0	0	0	5	5	5	15	20	25	15	10
Small Bin	100	0	0	0	5	5	5	15	20	25	15	10

Table 5. Mass Distribution for PES Rear Wall

	% Material		Percent Mass (%)									
PES	Steel	Concrete	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10

	% Material		Percent Mass (%)									
Large UC	0	100	0	5	5	10	40	10	5	5	5	15
Med UC	2	98	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Small UC	2	98	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Double-wythe Brick	0	100	7.5	12.5	20	12.5	7.5	7.5	7.5	7.5	7.5	10
Large Steel	100	0	0	0	5	5	5	15	20	25	15	10
Medium Steel	100	0	0	0	5	5	5	15	20	25	15	10
Small Steel	100	0	0	0	5	5	5	15	20	25	15	10
Very Small Steel	100	0	0	0	5	5	5	15	20	25	15	10
Standard	100	0	0	0	5	5	5	15	20	25	15	10
Trailer	100	0	0	0	5	5	5	15	20	25	15	10
Thin (1/4") St. Bin	100	0	0	0	5	5	5	15	20	25	15	10
Thick (3/8") St. Bin	5	95	5	5	5	5	7.5	7.5	7.5	7.5	10	40
Tractor-trailer	100	0	0	0	5	5	5	15	20	25	15	10
Bulk/tank truck	100	0	0	0	5	5	5	15	20	25	15	10
Van truck	100	0	0	0	5	5	5	15	20	25	15	10
Shed	0	100	0	5	5	10	40	10	5	5	5	15
Large Bin	100	0	0	0	5	5	5	15	20	25	15	10
Small Bin	100	0	0	0	5	5	5	15	20	25	15	10

The definitions of the bins (as referred to in Tables 2 through 5) are identical in IMESAFR and SAFER, and are shown in Table 6.

Table 6. Mass Bin Characteristics

	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
KE Min (ft-lbs)	100k	30k	10k	3k	1k	300	100	30	10	3
KE Max (ft-lbs)	300k	100k	30k	10k	3k	1k	300	100	30	10
Average Fragment Mass (steel) (lbs)	35.7	14.9	6.34	2.66	1.13	0.473	0.199	0.0852	0.0379	0.0142
Average Fragment Mass (concrete) (lbs)	75.4	31.5	13.4	5.61	2.38	1	0.42	0.18	0.08	0.03

3.3.4.2 *EXPLOSIVE ARTICLE MODELS*

A quantitative risk assessment model, such as SAFER or IMESAFR, must have representative models for each of the input choices that can be selected by the user. In the case of the explosive articles, the effect of the article on the blast (as opposed to an open-air TNT explosion) and the contribution to the debris hazard must be characterized. The following sections describe the new article models developed for IMESAFR.

3.3.4.2.1 *METAL-CASED EXPLOSIVES ARTICLE*

At least 20 million shaped charge perforators are consumed per year globally, making the development of a perforating gun model a necessity for IMESAFR. In IMESAFR, the metal-cased explosives article option represents perforating guns.

Perforating guns can be as small as 1-9/16 in and 2 in outside diameter (through-tubing guns of four shot per linear foot) or as large as 7 in outside diameter and as short as 4 ft in length or as long as 30 ft in length. The small diameter through-tubing guns are used to perforate well casing after the tubing strings are set in the well. Maximum net explosive weight (NEW) for a typical 20-ft gun is 1.7 lb_m.

Casing guns that are used to perforate oil-well casing range from 3-1/8 in outside diameter up to 7 in diameter with much higher explosive loads. A typical gun would be a 4-5/8 in outside diameter by 5 shots per ft resulting in a net explosive weight of 8.6 lb_m of explosive per gun. The worst case is the 7 in diameter by 12-shot-per-ft gun system at close to 25 lb_m of explosive per casing gun.

Estimates indicated that perhaps 95 percent of the perforating jobs completed are casing guns with the higher net explosive weights. Therefore, IMESAFR uses 8.6 lb_m as the average NEW per article. This means that if a user enters 860 lb_m as the total NEW, IMESAFR will assume there are 100 metal-cased explosives articles and determine the number of primary fragments accordingly.

An analysis of the material and design properties of the casing guns revealed that a very small amount of the total charge case mass will form fragments large enough to be considered hazardous. This conclusion is supported by available test and accident data. However, the amount of data is limited, which led to the decision to use a more conservative model for the metal-cased explosives article fragmentation model until more information could be obtained. The closest available model in SAFER was used as the initial fragmentation model by IMESAFR to represent the metal-cased explosives article. Although the model is reasonably conservative for a bare perforating charge, the perforating gun will contain the vast majority of the primary charge case fragments in the event of a gun explosion on the surface. This results in the distribution of fragments into the IMESAFR mass bins for metal-cased explosives articles is shown in Table 7.

Table 7. Metal-cased Explosives Article Fragments

	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
No. of Fragments	0	0	0	0	0	0	4	19	44	79
Ave fragment weight (lb_m)	35.7	14.9	6.34	2.66	1.13	0.473	0.199	0.0852	0.0379	0.0142

3.3.4.2.2 BULK MATERIALS METAL CONTAINER

The metal container model was designed to represent a container used to store a large amount of bulk explosives or AN. Several metal containers, which may sympathetically initiate, may be found within a given PES and can be modeled as such. The capacity of one metal container is 10,000 lb. This capacity was calculated assuming that the container was filled with ANFO, having a density of 840 kg/m^3. The container was modeled using 12-gage steel with a density of 7.85 kg/m^3. These values lead to a total mass calculation of 847 lb of fragments per container. Lacking available test or accident data, the metal container was assumed to break up similar to the closest match available in SAFER. Thus, this model was used as a baseline for scaling up to the mass of the metal container, which results in the distribution of fragments into the IMESAFR mass bins shown in Table 8.

Table 8. Metal Container Fragments

	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
No. of Fragments	0	0	0	0	0	0	80	4111	796	319
Ave fragment weight (lb_m)	35.7	14.9	6.34	2.66	1.13	0.473	0.199	0.0852	0.0379	0.0142

3.3.4.2.3 INTERMEDIATE BULK CONTAINER

The Intermediate Bulk Container (IBC) model was designed to represent a container that will contain explosive material either for temporary storage or transportation. As with the metal container, multiple IBCs may be modeled within a given PES. The capacity of one IBC is 4,000 lb. This capacity was calculated assuming that the container was filled with ANFO, having a density of 840 kg/m^3. The container was modeled using 5/32” steel with a density of 7.85 kg/m^3 (Ref 38). These parameters were used to determine the total mass of the container to be 709 lb. As with the metal container, no test or accident data were readily available, so the IBC was assumed to break up similarly to the closest match in SAFER. This baseline model was used for scaling up to the mass of the IBC, which results in the distribution of fragments into the IMESAFR mass bins shown in Table 9.

Table 9. IBC Fragments

	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
No. of Fragments	0	0	0	0	0	0	67	3447	667	297
Ave fragment weight (lb_m)	35.7	14.9	6.34	2.66	1.13	0.473	0.199	0.0852	0.0379	0.0142

3.3.4.2.4 PARAMETERS/ASSUMPTIONS (AN YIELD)

SAFER does not address HD 5.1., because the U.S. DoD does not consider oxidizers to be an explosives safety concern. However, the commercial storage and transportation community must manage the explosives risks associated with DOT Class 5 AN-based products that possess explosive properties. Billions of pounds of these products are consumed annually in the U.S. alone (Ref 39); therefore, they must be addressed in the IMESAFR program.

Since AN is recognized to offer much less yield per pound than explosives, the issue of TNT equivalency was addressed. The IMESAFR team of experts split the question into two parts:

1. Given that *N* pounds of unsensitized AN is present, how much will be expected to contribute to a high-order event? This term is referred to as the efficiency.
2. Given that *N* pounds of unsensitized AN "explodes", how many pounds of TNT would it take to produce the same amount of energy? This term is referred to as the equivalency.

In other words, given that *N* pounds of AN experience a stimulus that results in an energetic event, what is the TNT equivalency of the reaction?

IMESAFR needs to distinguish between efficiency and equivalency (rather than simply using the product) for uncertainty modeling purposes. Given that the AN is considered low-density (with a higher efficiency but the same equivalency as high-density AN), a review of available test and regulatory data produced the results initially used in IMESAFR, as shown in Table 10.

Table 10. IMESAFR AN Parameters for TNT Equivalency

IMESAFR	Efficiency		Equivalency	Yield	
	Maximum	Expected		Maximum	Expected
AN	100%	50%	50%	50%	25%[†]

[†] this value may be replaced with an equation dependent on NEW when enough supporting data are available

As in SAFER, the IMESAFR maximum yield is used with the maximum NEW to generate the maximum (or sited) risk and consequence values, while the expected yield and NEW are used to generate the expected risk and consequence results.

3.3.4.3 SOIL TYPES

In addition to the soil types available in SAFER, the IMESAFR model required the development of a crushed stone or gravel soil type because of its prevalence in commercial operations. Several contractors and suppliers were surveyed in order to determine the sizes most appropriate for the model, which turned out to be a combination of #57 and #67 sieves. Using the standard sieve definitions and the density of limestone, these sizes were then converted to the mass distribution shown in Table 11.

Table 11. Limestone Gravel Mass Distribution

	Bin 1-4	Bin 5	Bin 6	Bin 7	Bin 8	Bin 9	Bin 10
Mass Distribution (%)	0	0.6	13.8	19.1	27.2	22.2	17.3

3.3.4.4 BARRICADES

Version 3.0 introduced ES barricades into the SAFER model. IMESAFR also allows for ES barricades and in addition considers PES barricades. This is a natural requirement for the program because of the prevalence of donor-side barricades in the commercial explosives world. Additionally, IMESAFR allows users to model "natural barricades" such as topographical features or timber as specified in ATF regulations.[†] A "natural barricade" consisting of timber must block the view of the PES from the ES when the trees are bare of leaves.

3.3.4.4.1 LOCATION

Whereas SAFER requires the barricade to be closer to the ES than to the PES, IMESAFR permits the introduction of a barricade at any distance between the PES and ES. Users of IMESAFR enter the distance of the barricade from the PES, as opposed to SAFER users who enter the barricade distance to the ES. The only coding difference between the two programs is the absence of a check on the relative distances (between the PES, ES, and barricade). In every other regard, the debris screening works the same in IMESAFR as in SAFER.

3.3.4.4.2 GUIDANCE

The allowance for placing barricades very near the PES requires users of IMESAFR to make judgments regarding barricade survivability and ability to stop horizontal fragments. This recognizes the fact that a barricade can become part of the debris field if it is too close to the PES or may allow horizontal debris to bounce off and over it. There are no regulatory requirements for barricade standoff or shape so these possibilities had to be addressed.

[†] 27 CFR 555.11 and 555.218.

As shown in the logic flowchart shown in Figure 5, users must make up to three critical decisions when using barricades with IMESAFR;

1) Will the barricade survive an explosion at the PES?

2) If the barricade will not survive the explosion, will the barricade fragments increase the debris field?

3) Will the barricade stop all horizontal fragments?

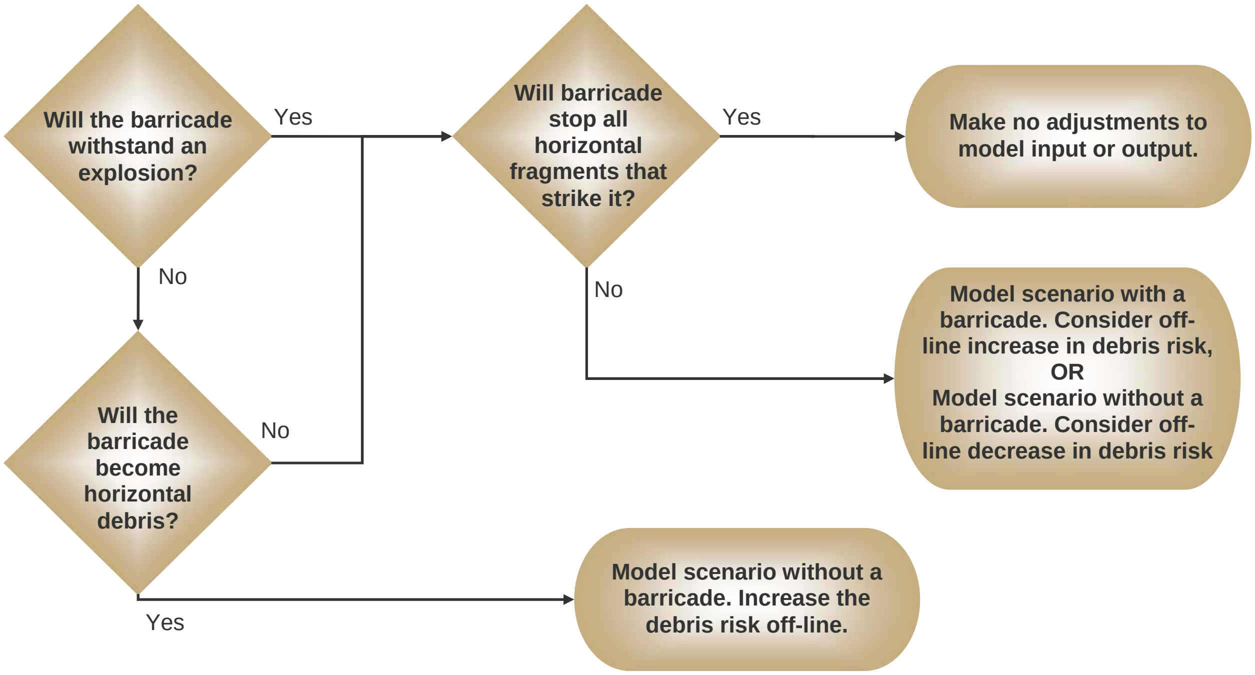


Figure 5. Barricade User Guidance Flowchart

Depending on the answers to these questions, users may need to make off-line adjustments to the model outputs or modify the model inputs. For example, a user may be able to verify that the barricade will stay intact after an explosion at the PES, but cannot verify that the barricade will stop all horizontal fragments. In this case, the user could run the model without a barricade and examine the risk from horizontal fragments. If the user feels that the barricade will stop some, but not all of the horizontal fragments, the user may reduce the horizontal debris risk accordingly and recalculate the overall risk.

Users at sites where natural barricades are present are provided instructions in the IMESAFR User's Manual on how to input the distance of the barricade from the PES and its height. Figure 6 gives an example of how the user would enter the distance from the PES and the height of a natural barricade.[†] Additional information and examples are given in the IMESAFR User's Manual. The team of experts recognized that all natural barricades such as a thin stand of timber may not stop fragments as well as a mound of earth. On the other hand, these types of barricades typically are not thin and would reduce overpressure at the ES. Since in most cases timber would be effective at screening debris and the reduction of overpressure is not accounted for in SAFER

[†] Neither SAFER nor IMESAFR take into account elevation differences between the PES and the ES.

or IMESAFR, the team of experts determined that the use of timber as a natural barricade would be acceptable.

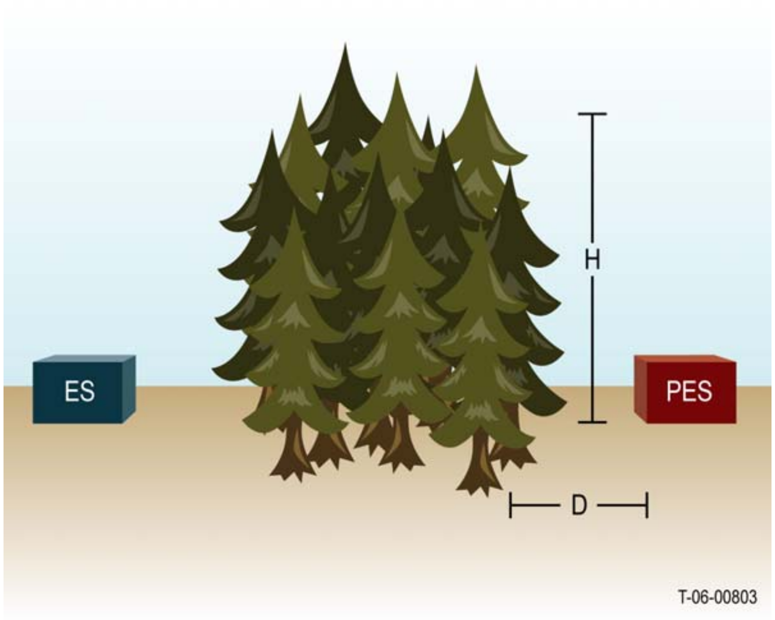


Figure 6. Natural Barricade Scenario

Except when the ES is very near the PES, the horizontal debris risk will usually be an order of magnitude or two below the overall risk and make an insignificant contribution. Nonetheless, the outputs from scenarios with barricades where there is a significant amount of horizontal debris risk, or scenarios where the barricade would be blown away should be thoroughly analyzed by a person knowledgeable of risk management and blast effects.

3.3.5 DEVELOPMENT OF PROBABILITY-OF-EVENT FOR COMMERCIAL ACTIVITIES

Because commercial and military explosives operations engage in distinctly different explosives activities, the commercial industry needed to include several new activities in IMESAFR. The new options were based on typical activities that occur in the commercial explosives industry and the need and probability of success for risk-based management of those activities. New activities for which $P(e)$ values were developed are shown in the list that follows.

AN Storage – Storage of over 1,000 lbs of ammonium nitrate prills or other detonable DOT Division 5.1 AN-based material.

Bulk loading and unloading - Loading or unloading of bulk explosives and oxidizers from one bulk container to another or into boreholes for blasting.

Commercial long-term storage - Storage of explosive materials under ATF or NRCan jurisdiction in magazines other than Type 3 magazines or day boxes.

Perforating gun assembly - Assembly or disassembly of explosive articles, usually prior to transportation and use in oil operations at the well site, using other finished explosive articles such as shaped charges, cutters, detonating cord, and detonators.

Various sources of data were used as the foundation for the IMESAFR *P*(*e*) estimates for these commercial explosive activities. A survey was sent to IME member companies requesting they provide the number of explosives events that occurred from 1985-2004. A description of the explosive event, material involved, activity at the PES, and the location of the event was also requested. The survey also requested the number of PESs for each activity. In addition to the IME members survey, the IME database of explosives accidents and ATF data were used to determine the *P*(*e*) for commercial long-term storage.

An *explosives event* was defined as an initiation and subsequent release of energy from an explosive. If an accidental explosive event was anticipated, and had been planned for by incorporation of facility protective design features, the event may be considered a "routine process event" and those events did not count as an event for *P*(*e*) calculations. Examples of routine process events are:

- unintended explosions of small amounts of explosive material during the manufacturing process, where the explosion was prevented from propagating to other surrounding explosive materials by facility design features or engineering controls, or
- explosives testing events in which a planned detonation occurred prematurely, but the explosion was prevented from propagating to other surrounding explosive materials by facility design features or engineering controls.

The *P*(*e*) for activities in which events had occurred and a statistically significant amount of data was available was determined by dividing the number of explosives events by the number of PES-years. This approach was used for the activities of manufacturing, commercial long-term storage, and perforating gun assembly. For the AN storage activity, no events had occurred so the team of experts' judgment was used to assume that the *P*(*e*) was at least one-half order of magnitude less than commercial long-term storage. The team of experts recommended adopting the *P*(*e*) values from SAFER for the activities of assembly, demilitarization, disposal, inspection, lab, in-transit storage, day magazine storage (temporary storage in SAFER), and loading/unloading.

The need to accurately model the bulk loading and unloading activity required the development of an activity with a bi-modal *P*(*e*) and consequence. During this activity, a pump is used to fill or unload a tank with an emulsion or watergel explosive. Two distinct outcomes can result from an event with this bulk loading/unloading activity: an explosive event may be contained in the pump and not propagate to surrounding quantities of the product (resulting in a "small event") or the event can propagate to the tank (resulting in a "large event"). A technique was needed to incorporate the two defined outcomes into the analysis logic without combining them into a single distribution. To do this, two values were determined for the *P*(*e*).

There were four bulk loading/unloading accidents that resulted in the "small event" and there were no accidents that resulted in a "large event." A single-sided binomial confidence interval (Ref 40) was used to determine the *P*(*e*) for both the small and large event. Using the single-sided binomial confidence interval to a 50-percent confidence level, the *P*(*e*) for the small and large event were estimated to be 3.08E-4 and 4.57E-5 events per year, respectively. The consequence of these two outcomes will assume the "small event" will involve 10 lbs of emulsion in the pump and the "large event" will be modeled assuming the net explosive weight (NEWQD) entered by the user.

Environmental factors were developed to account for appropriate circumstances that increased or decreased the probability of an event. The magnitude of the adjustment was based on the value in SAFER for that environmental factor or expert judgment by the team of experts. A list of the potential environmental factors and the multiplier made to the $P(e)$ is shown in Table 12. It should be noted that IMESAFR has some factors that reduce the $P(e)$, whereas SAFER does not. If more than one environmental factor is selected, only the largest factor is applied.

Table 12. Environmental Factors in IMESAFR.

	Environmental Factors	$P(e)$ Multiplier
1	Operations in substandard conditions or adverse environments.	10
2	Operations involving dangerously unserviceable items awaiting destruction.	10
3	Initial tests of new systems.	10
4	Operation occurring in hazardous environments with gases, fibers, acids, etc.	10
5	Required remote operations.	10
6	Heightened security levels (DHS level 5 - red).	10
7	Outdoor operations normally done indoors.	3
8	Operations at the well-site (on land or offshore).	3
9	Three-shift operations.	3
10	Heightened security levels (DHS level 4 – orange).	3
11	Two-shift operations.	2
12	Operations involving only water-based explosives.	0.3
13	Operations involving only blasting agents.	0.1
14	Bulk loading/unloading or blasting agent manufacturing operations without a pump (with conveyor belt, auger, bucket conveyors, pneumatic, etc.).	0.1

One other item required expert judgment: definition and magnitude of the upper bound (3-sigma values) used for the $P(e)$ values (Ref 41). The upper bound values are used to calculate the uncertainty in the risk results.

3.3.6 IMPLEMENTATION

Unlike U.S. DoD users of SAFER, where one regulatory body (DDESB) governs its application, commercial explosives industry operations in the U.S. must comply with the rules of dozens of federal agencies, hundreds of state agencies, and thousands of local jurisdictions. Additionally, the commercial industry has civil liability needs to manage risk regardless of regulatory requirements. This makes implementation of IMESAFR difficult to predict but initially, implementation is expected to be limited. Similar to the DoD application, the ATD will suffice in the vast majority of commercial scenarios. The complexity of the IMESAFR model will initially limit its use to scenarios with significant capital investments.

Without a doubt, though, IMESAFR will be used by IME members and perhaps others to make siting decisions based upon quantitative risk management. Safer operations are more productive operations, but only to a point. For example, a plant manager faced with the need to expand production may now compare the cost-benefit between constructing a new barricade or installing blast resistant windows, or both.

4.0 PLANS

Future plans for IMESAFR are described in the following sections.

4.1 SOFTWARE

Since IMESAFR is a commercial product, future improvements will be in part based on the feedback from the user community. However, some improvements are already envisioned by the IMESAFR team of experts. Currently, two main focus areas for future work are barricades and AN yield.

4.2 TRAINING

IME requires that all persons who purchase and plan to use the IMESAFR model to obtain training. This training is provided by APT Research, Inc. through the purchase of a training voucher. The training course gives a complete overview of the model architecture and methodologies and also provides a thorough walkthrough of how to setup and use the program. Students achieve understanding through the use of classroom examples that represent real world situations. Furthermore, students gain knowledge of the history behind QRA and IMESAFR.

4.3 USER COMMUNITY

The IMSAFR model was designed for use by safety professionals to assess explosives risk. The individual user should have some knowledge of the application of ATD principles, explosives Hazard Class/Divisions, explosives quantity, and information concerning the facilities and personnel surrounding the PES and the ES.

4.4 APPLICATIONS

For regulatory compliance, IMESAFR has two general primary applications. The first application is to regulatory requirements that essentially require operators to limit risk to reasonable levels. There are no regulatory Q/D criteria for many commercial activities such as AN storage. Generally, the only commercial activity that is explicitly regulated by Q/D is permanent storage. IMESAFR will provide a consistent methodology to determine what the risks are and how they are affected by various parameters. These risks can then be compared to acceptable levels of risk such as those developed by DDESB or other standards.

The second general regulatory application will be to justify exemption from regulations such as Q/D standards. Whereas the U.S. DoD can use SAFER whenever an activity has an operational need and cannot meet Q/D, commercial operations will have differing bars to hurdle. For example, some agencies, will only grant an exception from strict compliance with a regulation if the applicant can show that an equal or greater level of safety will be achieved by following the alternative. In these cases, IMESAFR could be used to quantitatively prove that point.

Table 13 presents a summary of regulated situations that may benefit from a more detailed analysis of explosives risk.

Table 13. Summary of Typical Regulated Situations

Regulatory Arena	Requirement	IMESAFR Application
Long-Term Storage	Cannot store more than a certain quantity in one place.	Show that storage over that amount is reasonably safe.
	Q/D Limitations	Justify requests to vary from Q/D limitations.
	Activity must comply with differing civilian and military standards.	Provides compromise solution.
Occupational Safety	Do not expose workers to too much risk.	Determine what level of risk workers are exposed to.

Transportation	Limit public risk from in-transit storage.	Use “in-transit storage” activity to determine level of public risk.
	Limit public risk from loading/unloading.	Use loading/unloading activities to determine level of public risk.
Off-site Consequences	Permit for disposal of waste.	Use “disposal” activity to justify permit request.
	Limit risk to public.	Determine level of public risk.
Security	Take action when the threat is elevated.	Increase in P(e) helps determine what action is needed to maintain the same level of risk.

Aside from potential regulatory compliance applications, IME members will use IMESAFR to more wisely allocate their limited resources to minimize their risk. Many times, federal regulations do not address an activity and IME members could use IMESAFR to provide consistent risk management of these activities. Often, IME members must operate in close quarters with other contractors in parts of the world where there are no rules or limited guidelines governing explosive safety, for example overseas field camp locations in the oil/gas production industry. All activities involving explosives present some risk which now can be quantified in a consistent manner and managed effectively.

5.0 SUMMARY

IMESAFR is a valuable tool for the commercial explosives industry to manage risk and has recently been made available by the IME. This new tool is based on the work of the RBESCT in developing SAFER 3.0. Modifications to SAFER were made based on the consensus of a diverse panel of commercial explosives industry experts and regulators and should approximate most commercial activities. The tool may be helpful in a variety of regulated and unregulated situations. Based on the experience gained while applying this tool and as new situations arise in the manufacture, transportation, storage, and use of commercial explosives, the IME will determine the type of future enhancements that will be made to the model.

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