The IMESAFR Science Panel

Kevin McNeill; ATF; Huntsville, AL, USA

Noel Hsu, Ph.D.; Orica; Denver, CO, USA

John Tatom; APT Research, Inc.; Huntsville, AL, USA

William Evans; APT Research, Inc.; Huntsville, AL, USA

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Abstract

ATF recommended and sponsored the formation of the Institute of Makers of Explosives Safety Analysis for Risk (IMESAFR) Science Panel (ISP), which reviews and discusses the technical content of the IMESAFR software, desired future algorithms, and field testing associated with the IMESAFR models. The group was modeled after the Department of Defense Explosives Safety Board (DDESB) Science Panel. The ISP is co-chaired by ATF and IME (but is not an IME committee) and invites participation and technical contributions from the commercial explosives community, associated regulatory bodies, and academia.

Recent accomplishments by the ISP include changes to: the debris algorithms, the barricade logic, the probability of event, and the uncertainty routine. The group will continue to review the maturity of the existing IMESAFR algorithms and discuss any necessary improvements or additions.

The ISP recommends test programs to improve IMESAFR software. The ISP may also recommend numerical modeling or other analytical studies to provide “synthetic data” when testing is not feasible.

Introduction

IMESAFR Software

IMESAFR is an explosives safety quantitive risk assessment (QRA) tool designed to assess and manage risk in the commercial explosives industry. IMESAFR considers the probability of an accidental explosives event and the consequences given such an event. This paper will not cover the details of the tool itself, as that is the subject of a separate paper at this symposium[1].

Bureau of Alcohol, Tobacco, Firearms, and Explosives

The Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF) is the United States (U.S.) federal agency tasked with the regulation of the commercial explosives industry. Those

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[1] Tatom, John T. 2018. "IMESAFR Overview (20720)." In the International Explosives Safety Symposium & Exposition. San Diego, CA: NDIA.

regulations require Federal Explosive Licensees locate explosive storage magazines a set distance from inhabited buildings, public highways, passenger railways, and other magazines based on the quantity of explosive materials stored in each magazine. These set distances, commonly referred to as the American Table of Distances (ATD), were adopted to protect the public in the event of a magazine explosion.

The Association of Manufacturers of Powder and High Explosives, a precursor to the Institute of Makers of Explosives (IME), developed the ATD based on 122 explosives accidents that occurred between 1864-1918 (Lyman 1979). The Federal government adopted the ATD in 1928; ATF accepted the ATD in 1971. While ATD has proven effective over the ensuing century, it has some inherent problems:

- It is conservative (based on mid 19th and early 20th century explosives and storage).
- ATD cannot minimize the risk to the public (assumes explosion hazard is equal in all directions and assumes hazard is zero beyond the distance specified in ATD).
- There is no regulatory incentive for improvements in explosives or explosive storage.

To remedy the inherent problems with ATD, the IME and ATF leveraged work being done by the Department of Defense Explosives Safety Board (DDESB) to develop quantitative risk assessment algorithms that quantify the explosion effects and consequences. IME then developed a software application (IMESAFR) that incorporated the algorithms developed by DDESB. The strength of the QRA methodology is the following:

- It removes conservatism by testing modern explosives, barricades and storage magazines.
- It spatially quantifies the risk to the public and employees allowing the industry and ATF to optimize the risk at a specific distance or azimuth.
- With testing, a QRA methodology gives credit to the industry for improving the safety of their explosives and improving explosive storage.

Since 2014, ATF has accepted QRA applications for explosive storage siting. Unfortunately, the statutory language has not changed from the ATD; therefore, ATF handles each application as a waiver. ATF has accepted a total of 8 waivers since it began accepting QRA applications. An issue that ATF has struggled with regarding QRA is establishing acceptable-risk-criteria. Currently, ATF uses a risk-bank method. This method requires the applicant to calculate the maximum risk the public is exposed to at the site using the ATD range and explosive-weight before adding any new explosive storage. This calculated risk then becomes the acceptable risk criterion for the site under evaluation. The risk-bank method is typically very conservative with acceptable-risk-criteria much less than 1E-6.

Institute of Makers of Explosives

The Institute of Makers of Explosives is the safety and security institute of the commercial explosives industry in the United States. IME is a non-profit, incorporated association, founded in 1913, to provide technically accurate information and recommendations concerning explosive materials and to serve as a source of reliable data about their use.

The primary concern of IME is the safety and security of commercial explosives products, and the protection of employees, users, the public and the environment in the manufacture, transportation, storage, handling, use and disposal of explosive materials used in blasting and other essential operations. Annually, over three million tons of explosives (ammonium nitrate-based products, high explosives, and propellants) are used in the U.S.

IME member companies and their 200 subsidiaries and affiliates produce over 98 percent of the U.S.' commercial high explosives and most of the blasting agents and oxidizers. The member company products are used in every state and distributed worldwide.

The American Table of Distances

The original study to develop safe distances for the location of explosive storage magazines was begun in 1909. Most of the explosive materials were transported by rail, and their storage facilities were located near the railroad lines. Should an explosion occur in the magazine, the potential hazard to passenger carrying trains and residential areas near the railroad necessitated radical changes in magazine location.

A select committee of the Association of Manufacturers of Powder and High Explosives was appointed to study the problem and develop recommendations. Following studies of foreign requirements and their inapplicability, the committee decided to develop an ATD based on empirical data gathered from explosions that had occurred in the field. Information was gathered on several explosions ranging from minimal amounts of explosive materials to some approximating one million pounds. The explosions studied covered a period of almost 50 years and occurred in manufacturing, transportation, and storage, both in the United States and abroad.

The Association of Manufacturers of Powder and High Explosives published the ATF for inhabited buildings and public railways in December 1910 (Institute of Makers of Explosives 1991). The select committee, in conjunction with The IME(founded in 1913) conducted additional studies when it became apparent the distance table should also contain minimum safe distances for the location of explosive storage and manufacturing buildings from public highways.

The highway distances were approved and adopted by the IME in 1914. After the adoption of the ATD, the collection of data on explosions was continued. The table was reviewed in 1919 and 1939, and no significant revisions were made after both reviews.

APT Research Inc.

In 1997, the U.S. Department of Defense began developing its approach to implementing QRA for explosives safety. The Risk-Based Explosives Safety Criteria Team (RBESCT) developed the TP-14 model, implemented in the Safety Assessment for Explosives Risk (SAFER) tool. The RBESCT team comprised representatives of the DDESB and the Services. Seeking a similar solution for the commercial explosives community in North America, IME looked to build upon the work of the RBESCT, which led to the development of IMESAFR for use by the industry.

APT has been the support contractor for the RBESCT since its inception and works on the development of explosive effects and consequence models. When DDESB chose to implement a technology transfer to help IME begin the IMESAFR project, IME hired APT to support the project. This history and relationship is depicted in Figure 1.

Figure 1: The Organizational relationship between DDESB, IME, and APT.

Given APT's historical role in the development of these QRA models, ATF and IME agreed to jointly sponsor APT's participation in the ISP. In additional to technical contributions, APT also serves in a secretariat role for the ISP.

IMESAFR Science Panel

Formation

The formation of the ISP came about from several drivers:

- The ATF was interested in IMESAFR, both as a regulatory and research tool. As a result, the ATF contributed funding to the IMESAFR project.
- The finalization of IMESAFR V2.1 required an objective group to make technical decisions on changes to algorithms as these would have significant effects on the results. In addition, the independent scientific body was needed to determine what extent and how conservatisms could be reduced.
- Greater scientific understanding would be required to address increasingly complex consequence models following the release of IMESAFR V2.1.
- The ISP was modeled after the DDESB Science Panel which made significant contributions to the development of SAFER.
- Decisions are based on technical rather than commercial considerations because the ISP membership includes Government and academic members.

Charter

The objectives of the ISP are the following:

- To validate the explosion effects and consequence algorithms that are embedded within the IMESAFR software and IMESAFR Technical Manual.
- To analyze explosives safety quantity-distances for potential technology and information gaps and make recommendations for changes where applicable.
- To recommend tests to address specific deficiencies that have been identified in the current explosives safety knowledge base.
- To identify other bodies and regulators interested in IMESAFR and evaluate other applications for IMESAFR.

The ISP is co-chaired by one representative from ATF and one representative from the IME. The permanent members of the ISP include representatives from IME member companies, IME's Director of Technical Services, representatives from the ATF, and representatives of APT. Currently, additional members include representatives from Missouri University of Science and Technology, the Canadian Explosives Research Laboratory (CERL), and the Transportation Security Administration (TSA). Unofficial-members include the U.S. Coast Guard (USCG).

Examples of Work

With IMESAFR V2.1 on the horizon, the ISP examined and made recommendations on four issues:

- Public Transportation Routes (PTR) – For rectangular PESs, IMESAFR produces a cruciform pattern for debris. The explosive loading in the PES influences each of the four lobes of the cruciform pattern (depicted in Figure 2) in the PES. Relatively high loading densities can produce long-narrow lobes while relatively low loading densities can produce short-broad lobes. The variation in lobe size due to PES loading can produce counter-intuitive results when placing a PTR in the lethal debris areas of the lobes. With a high loading density, the PTR is exposed to a narrow section of the lethal debris lobe while a low loading density with the same PTR is exposed to a broader lethal debris area. In some scenarios, this produces a counter-intuitive result that the risk to the PTR goes down as the loading density goes up. The ISP reviewed the logic, risk profiles, and debris patterns and concluded that while it is counter-intuitive, the logic and models are sound, and this logic remains unchanged in IMESAFR V2.1.
- Conservation of Mass – Historically, IMESAFR assumed that all the mass in a PES was available to be debris and divided it into 10 kinetic energy bins. However, qualitative assessments of concrete PES blast tests have found that with high (explosive) loading densities these PESs can generate debris so small it becomes a dust cloud. This would indicate that not all the mass is available for debris in these types of PESs. After review, the ISP recommended an additional bin (Bin "G") be added in IMESAFR V2.1 to account for debris that is too small to have lethal kinetic energy. This treatment removed conservatism from the IMESAFR algorithms by no longer adding the Bin "G" mass (too

small to be lethal) to Bins 1-10 which can and did produce additional lethal fragments. It should be noted, the ISP recognizes this change while logical has not been thoroughly tested and requires validation and that this adjustment is only relevant to certain construction types and loading densities.

- Barricade for High-Angle Debris - IMESAFR V2.0 and below divided horizontal debris (PES sides) into two components: low-angle and high-angle debris. The software assumed 50% of the side-wall mass was low-angle ("fly-through") and 50% was high-angle ("lobbed"). A barricade could block low-angle debris but not the high-angle debris. The ISP was asked to consider allowing high-angle debris to be blocked by a barricade. A simple example will demonstrate this, if a PES is built against the side of a mountain, then some of the high-angle debris will be blocked. The ISP concluded that not allowing high-angle debris to be blocked was too conservative. The user can now vary the amount of high-angle debris that can be blocked in IMESAFR V2.1.
- Vertical-Debris-Barricade – ISP was asked to evaluate the addition of a vertical-debris-barricade. For example, if a steel magazine were placed under a mountain. In this case, the mountain would act as a barricade, blocking all high-angle (lobbed) debris from a PES. In IMESAFR V2.1 the user can apply a vertical-debris-barricade. The user must specify the amount of kinetic energy is absorbed by the barricade.

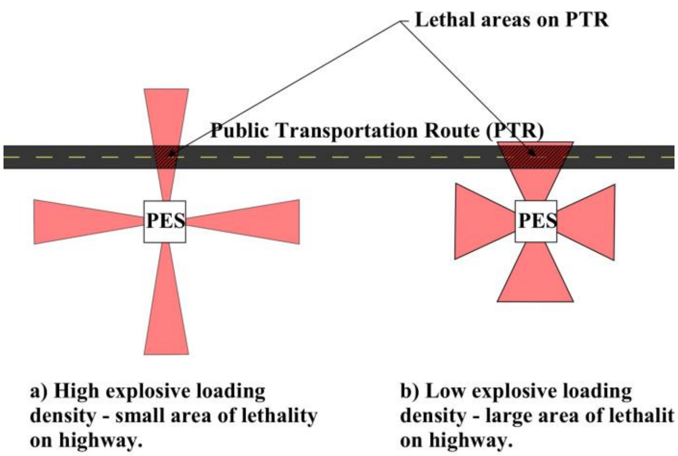

Figure 2: Diagram showing the effect of explosive loading density on a PTR. a) The area on the PTR is smaller for a higher loading density and b) The area on the PTR is larger for a smaller loading density.

ISP Current Work

Recently, the ISP has been focused on a significant initiative, the independent validation of the probabilities of event (P_e) set in IMESAFR. The initiative arose when IME requested ATF approve an acceptable-risk-criterion of 1E-6 (maximum individual annual public risk). ATF responded by requesting an independent validation of the probabilities of event in IMESAFR, before approving a numerical risk criterion. The ISP and IME sought quotes for this task, selected a contractor and are currently in the process of reviewing the final report.

The ISP has started a review of how uncertainty is handled in the IMESAFR algorithms. This review is based on a similar review conducted by the DDESB RBESCT team and their analysis of a 2011 paper by van Bavel (Van Bavel 2011). Currently, the log-normal probability distribution of a given consequence is defined by treating the IMESAFR algorithm's best-estimate of a consequence as the median value of the distribution, and uses a stored upper-bound-multiplier to establish the 3σ value (thus allowing the calculation of the standard deviation). With the log-normal distribution defined, the mean of the distribution can then be calculated. A characteristic of log-normal distributions is that the mean is always to the right of the median. Therefore, using the process described above, the calculated mean is always more conservative than the median. Also, as the standard deviation increases (more uncertainty) the mean will shift even further to the right. This process ensures that uncertainty in the IMESAFR best-estimate is included, see Figure 3. In the van Bavel paper, it was noted that if the SAFER algorithms best-estimate of the consequence is treated as the mean rather than the median then as the standard deviation is applied the median will shift to the left, but the mean will remain constant. This has the effect that regardless of the uncertainty in the SAFER algorithm's best-estimate the mean will remain constant and thus less conservative. Based on the ISPs initial analysis, this process also has the detrimental effect of removing the uncertainty in the SAFER best-estimate. This process is still under review by the ISP, but the initial conclusion was to keep the current IMESAFR process for estimating the mean of the consequence.

Field Testing

There are currently three high priority tests scheduled in support of IMESAFR. The first is an overhead bin test, see Figure 4. In general, the test would consist of an overhead bin filled with approximately 120,000 lb net explosive weight (NEW) of an emulsion or ammonium nitrate and fuel oil (ANFO). This is a widespread storage configuration for the industry, and there is a data gap in the QRA algorithms resulting in conservatism. The test would consist of a DDESB TP-21 style debris recovery, overpressure recordings, and high-speed video for debris velocities (DDESB 2007).

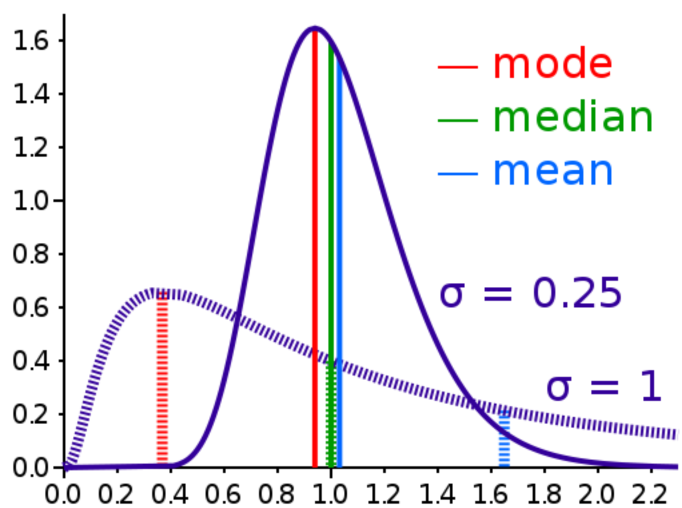

Figure 3: Two different lognormal distributions show the influence of increasing the standard deviation (σ) by a factor of 4 on the mean, median, mode (note axis values are arbitrary). Increasing the standard deviation (uncertainty) drives the mean to the right (Cmglee 2018).

Figure 4: Example of an overhead bin being considered in the overhead bin test (ARMAG Corporation 2018a)

The second test is unique to the oil and gas (O&G) industry. A common practice in the O&G industry is to cement the metal casing in the well bore. This practice supports the casing and separates producing intervals from other zones. However, the cement also separates the pipe from the hydrocarbons. Shape charge technology is used to penetrate both the pipe and the cement to complete the well (Smithson 2012). To utilize this technology, the shape charges are assembled vertically in a gun (pipe) or along a metal strip, see Figure 5, at the company location and transported to the well site. Assembled, the gun and metal strip contain both shape charges and detonation cord and when not in assembly or down-hole they are considered in storage. Due to a lack of more applicable data, IMESAFR models the guns (worst case due to pipe fragmentation) as munitions. Testing is required to determine the actual consequences of an accidental explosion. The tests will consist of single and multiple guns supported horizontally (typical storage configuration) with approximately 100 lb net explosive weight with a TP-21 style debris recovery, overpressure measurements, and high-speed video for debris velocities.

Lastly, the ISP is interested in testing traditional commercial storage magazines, see Figure 6, with net explosive weights in the 100 – 10,000 lb range. These are the most common commercial storage magazine across North America. Currently, IMESAFR has data on a single test (480 lb NEW) in a commercial storage magazine conducted by the U.S. Army Technical Center for Explosives Safety (USATCES). Given these magazines prolific use, the array of sizes, and range of possible explosive loading, the ISP feels additional testing is warranted. The specific details of this test series have not been defined however TP-21 style debris recovery, overpressure measurements, and high-speed video for debris velocities will be collected.

Figure 5: Photograph of a gun (top) with shape charges and a metal strip (bottom) with shape charges.

Figure 6: Typical commercial explosives storage magazine (ARMAG Corporation 2018b).

Future Work

Swisdak et al. developed maturity-matrix of data gaps and convervatisms in the IMESAFR software (Swisdak et al. 2012). The highest priority data gaps from the matrix are the tests outlined earlier in this paper. Future work is required for explosive articles unique to the commercial explosives industry.

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