Low-Level Military Occupational Blast (MOB) Exposure and Mitigation

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Abstract

Prior to the last decade, research on exposure thresholds for mild traumatic brain injury (mTBI) from blast exposure have relied heavily on animal data, which is often critiqued for being under-conservative due to differences in results between animal species and challenging extrapolation of animal-based results to humans, who have much larger brains than mice, rats, and swine. The combination of ethical issues in testing humans and difficulty in rapidly obtaining data from humans post aggressor-initiated blast exposure has left the scientific community lacking a large repository to determine hazardous levels of exposures. Recent efforts by the Office of the Secretary of Defense (OSD) to form both the NeuroTactical Research Team and the COmbat and training QUeryable exposure/Event Repository (CONQUER) and Walter Reed Army Institute of Research (WRAIR) to obtain both blast gauge data and mTBI symptom data from training operations has resulted in an improved understanding of a reasonable level of blast overpressure and impulse that may result in personnel experiencing mTBI-like symptoms. The current WARIR recommended value for risk of mTBI is at 4 psi exposure and add a placeholder 31 psi*ms impulse exposure threshold. This interim guidance builds upon a historically used threshold of 4 psi, that was based on tympanic membrane rupture and hearing effects. However, several other studies note exposure risk may vary with increased cumulative exposure. The medical community is actively exploring whether cumulative exposure should be considered. This presentation notes ongoing developments in quantification of risk to personnel and means of mitigating exposures that are being proposed by the various Army sub-working groups as well as ongoing efforts from the Special Operations Command (SOCOM).

Introduction

This paper gives an overview of ongoing DOD efforts to improve warfighter brain health by increasing understanding of low-level military occupational blast exposures that may produce mild traumatic brain injury (mTBI) symptoms and further development of available engineering solutions to reduce overpressure and impulse exposures. Planned approaches to monitoring and quantifying risk to warfighters are addressed along with some of the challenges in quantifying exposures and risk. Additionally, the data is summarized to conclude that observations can be made in comparison to explosives safety criteria for intentional detonation sites (IDS).

Army Working Group Overview

Army Blast Effects on Personnel (BOP) Working Group

The Army Blast Effects on Personnel working group was formed to bring the agencies involved in medical, operational, and engineering related functions together to form and execute a plan to quantify blast exposure on personnel from various operations, determine risk at various blast exposure levels, and develop and implement engineering solutions for reducing risk. Sub-working groups were formed for medical and engineering solutions. Solutions with previous research and development data were prioritized over those with less proven performance. The working group formed a list of 80% solutions and accepted proposals on how to bring those solutions to full development for large scale implementation.

Medical Sub-Working Group

The medical sub-working group is focused on determination of appropriate testing methods for mTBI, appropriate data collection means, and establishing exposure thresholds for points of risk of mTBI occurring. This group helped to develop the current baseline testing for high-risk personnel and will aid in determining cognitive changes in follow-on testing. One of the many challenges faced by this sub-working group is avoidance of violating Health Insurance Portability and Accountability Act (HIPAA) in discussions of personnel exposures, while sharing cross-agency data. Another challenge faced is pursuing data collection and testing means that are not seen as an overly burdensome interruption to live-fire training activities. An equally persistent obstacle is addressing if mTBI risk is defined by pressure, pressure and impulse, or cumulative exposure of one or both metrics. The lack of methodologically rigorous adequately detailed studies that include blast exposure measurements and health outcome measurements in vulnerable human domains is a significant challenge in attributing acute and chronic brain health deficits to low-level blast exposure.

This group determined that the previously outlined 4 psi limit for overpressure generating potential mTBI risk should remain as well as a 31 psi*ms impulse limit. The group is actively investigating if cumulative exposure can decrease the peak exposure needed to experience mTBI symptoms. Over ¾ of high-risk military personnel have been tested for cognitive baselining this year. Once this testing is complete, the rest of the Army will be tested, and the high-risk personnel will be re-evaluated directly following their respective training exercises to measure changes in their baseline evaluations.

and quantify the occurrence rate of the symptoms in each operation. This data can then be compared to the established pressure and impulse exposures from wearable gauges used during these operations.

Engineering Solutions Sub-Working Group

The engineering solutions sub-working group is focused on determination of available and new methods for reducing overpressure and impulse exposure to personnel. In general, many of the 80% solutions discussed involve modifications to the weapon system due to limited standoff from the source of overpressure to personnel in artillery and other training operations. Methods being further developed in this category have had prior successful implementation and proven potential for expanded use.

Cognitive Baseline Testing of High-Risk Personnel

Following a policy directive from the Department of Defense (DoD) in August 2024, the U.S. Army initiated a cognitive baseline testing program for high-risk personnel. This program is part of a wider DoD brain health effort designed to detect and mitigate traumatic brain injuries (TBIs), especially those caused by blast overpressure. The testing is used to establish a service member's baseline cognitive function, which can be referenced later in their career to more easily diagnose subtle neurological changes. Initial testing focuses on personnel during initial entry training and those in high-risk, active-duty roles, with a long-term goal of testing all service members.

This baseline cognitive testing sets a path forward for substantially improving DoD understanding of which explosives and live-fire operations present hazardous exposures for personnel. This information will then be used to inform working groups on prioritization of research and development as well as confirm or counter current understanding of pressure and impulse levels that correlate to heightened risk of mTBI.

Facilities Explosives Safety (FES) Mandatory Center of Expertise (MCX) Role

The US Army Corps of Engineers (USACE) FES MCX supports projects involving the design, construction, or modification of facilities that manufacture, store, handle, maintain, develop, demilitarize, test, or dispose of ammunition or explosives, and facilities within the Explosives Safety Quantity Distances (ESQD) of AE facilities that require the involvement of subject matter experts in explosives safety. Both the USACE FES MCX and Range and Training Land Program (RTLP) MCX were pulled into the initial forming of the Army BOP working groups for insight and support. The FES MCX and RTLP MCX have worked on the design and analysis of new and existing live-fire training structures and have experience in mitigation of hazardous exposures to personnel.

The FES MCX has worked on various efforts to improve DoD understanding of the impact of modifications to structural systems on blast overpressure and impulse exposure to personnel. Several of these items and efforts are outlined in the following sections.

This data will expose which operations are generating overpressure and impulse levels that lead to mTBI symptoms being experienced

Literature Review for Overpressure and Impulse Exposures with Risk of mTBI Symptoms

Current DoD explosives safety criteria were examined for any exposure thresholds that may be useful in understanding some of the adverse symptoms occasionally experienced in live-fire training. This data can be seen in Table 1 below. One early finding was that breaching Minimum Safe Distances (MSDs) did not specify that internal breaching could amplify overpressure when the same external MSD is used inside of a structure. This was added into the DOD field activity memo on managing brain health risk from blast overpressure, upon FES MCX request.

Table 1: DoD Codified Pressure Based Thresholds for Personnel Protection

Codified Pressure Based Thresholds for Personnel Protection			
DoD Source	**Limit (psi)**	**Desc.**	**Threshold**
DESR 6055.09	0.065	K328	Intentional Detonation Siting for Repeated Detonations (IDS) for Non-essential Personnel
DESR 6055.09	0.9 or 1.2	K40 or K50	Inhabited Building Distance (IBD) Protection for Unrelated Personnel from Accidental Detonations
DESR 6055.09	2.3	K24	Remote Operator Protection for Accidental Detonation and IDS Essential Personnel
DESR 6055.09	3.5	K18	Essential Personnel Limit for Related Personnel to Adjacent Explosives Operations of Successive Steps (Intraline Distance, ILD)
DoD Field Activity Memo	3.5	K18	Standard Breaching Minimum Safe Distance (MSD)
DoD Memorandum	4	-	Interim guidance on live-fire training exposure threshold for mTBI risk
DESR 6055.09	12	K9	Barricaded Intraline Distance (ILD). Only Used if Barricade is Included Between Buildings and Allowable Buildings for Siting Type
UFC 3-340-02	5	-	Threshold for Eardrum Rupture
UFC 3-340-02	30	-	Threshold for Lung Damage
UFC 3-340-02	120	-	Lethality
UFC 3-340-02	Varies	-	Temporary Hearing Threshold Shift

After examining existing DoD criteria and available data, a literature review was performed regarding overpressure and impulse exposures that led to adverse cognitive and/or gastrointestinal effects. The following issues were found with the data shown in Table 2 below:

- For ethical reasons most existing research on repeated blast exposure was performed in animal studies. It was eventually found that there are significant variations in injury thresholds between animals which may scale with the size of the animal and many other factors. This makes animal-based thresholds nearly irrelevant to exposure threshold discussions for adverse cognitive impacts.
- Combat experienced exposures are often evaluated for mTBI symptoms by a professional a day or two after the exposure. This can lead to a wearing off of the initial symptoms. Additionally, an exact quantification of exposure can be difficult in a combat environment.
- Methods used to determine mTBI symptoms varied between studies, making the likelihood of a difference in results under identical metrics more plausible.
- Lower-bound exposure thresholds for cumulative exposure do not exist due to no studies having occurred on high-cumulative exposure for pressures at or below 1 psi. The only close data points to this are from news articles, collected data on frequencies of intentional detonation site operations, and collected data on maximum artillery firing rates. The collected frequency data relies on the assumption that one-person is seeing these maximum frequencies without reported mTBI symptoms. These data points are only included due to being conservative when compared to an infinity-based assumption at or below 1 psi, in the absence of well-verified data.
- Lastly, some of these data points may have suffered from confirmation bias in initial assumptions. For example, taking the highest peak pressure observed and not considering the cumulative pressure experienced and drawing a conclusion that the peak pressure was the issue and should be a threshold.

Table 2: Literature Review and Data Collected Based Cumulative Thresholds for Personnel Protection

Literature Review Data Points for Cumulative Overpressure Effects on Personnel			
Reference	**Peak Pressure (psi)**	**No. of Exposures per Three Years**	**Effect**
25	5	2	mTBI
5	4	100*	mTBI
24	3	3	Gastrointestinal Issues
24	3 to 10	Various	Reductions in Cognitive Learning Ability
32	1.256	696	mTBI
26	0.35	3600	mTBI
N/A	0.065	3600	Field Collected Data Sample from Max Frequency IDS Operations at K328

The data in Table 2 has been used as a threshold plot for consideration of safe operational frequency when requested to examine this by installations, under the understanding that is not a codified basis, and operations below 4 psi exposure currently meet criteria requirements. See Figure 1 below for reference.

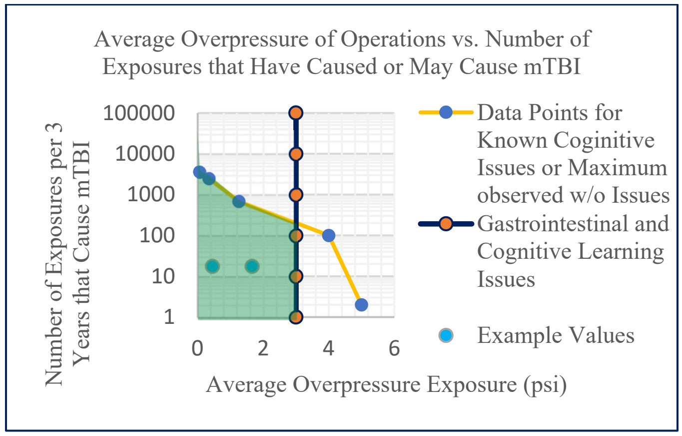


Figure 1. Cumulative Exposure Plot

The literature review data and noted gaps highlight the need for an improved understanding of dose-response relationships which are actively being researched by the Army Medical Working Group and Department of War (DoW) medical research community. These various elements are actively coordinating across the enterprise to direct efforts that will address previous research design short comings to deliver valid characterization of BOP effects across multiple affected domains.

Comparison of BlastX Predicted Overpressure Exposures to Field Collected Data for Breaching and Grenade Training Operations

Due to explosive breaching being done outside of a building nearly matching hemispherical surface burst exposures, but internal breaching adding an increased exposure from confinement, it is useful to have validated models for understanding exposure to both quantify current expected exposures and the impacts of modifications. BlastX Software has been used successfully on multiple projects and shown to match wearable gauge data with a maximum error of roughly 25% in the limited data sets currently collected. See Figure 2 for an example of one model previously used for peak exposure prediction.

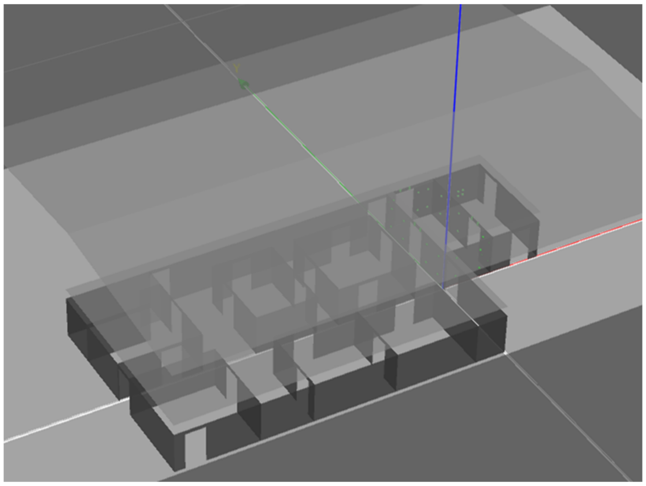


Figure 2. BlastX Model of Breaching Facility

The model shown in Figure 2 was used to generate 112 charge and gauge location combinations, due to 24 doors and 2 to 5 pathways for breachers to go post charge set up to meet MSDs. The output of these gauges was then formed into Table 3.

BlastX Recorded Pressures		
Overpressure Range	**Quantity**	**Percentage**
0 to 1	38	33.9%
1 to 2	72	64.3%
2 to 3	1	0.9%
3 to 4	1	0.9%
Total	112	

Table 3: BlastX Predicted Exposure Data

At the time of this data formation, wearable gauges were not available at the site. However, a few months later they were obtained and used to collected data over a training course period and compare to predicted values. Figure 3 shows the output of wearable gauge data combined from one training course.

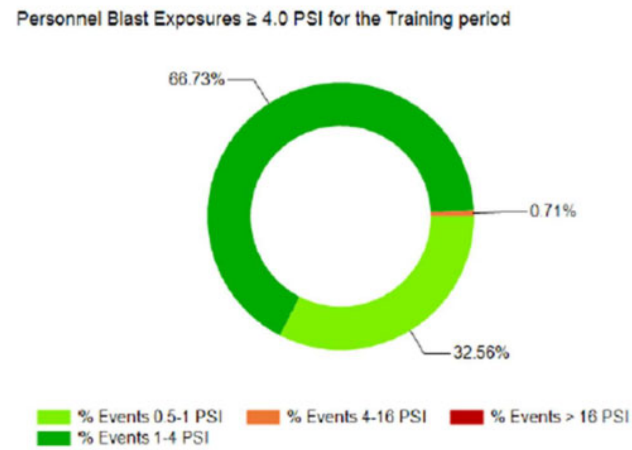


Figure 3. B3 Wearable Gauge Data from Same Facility as Table 3

It can be observed from Figure 3 and Table 3 that BlastX agrees with aggregate data groupings within 1% for each group, and on closer inspection was within 25% of the expected peak value for all data points. These results confirm the reliability of BlastX for breaching facility use and allows for potential modifications to be tested for changes to baseline results.

This was done by conservatively modelling breached doors as solid reflective surfaces and charges as hemispherical surface bursts. Gauges were placed off reflective surfaces to avoid reading as reflected pressures. The air room was modelled as a larger room than the building to allow for venting of gas pressures into open air, which requires modification of the wrapped default setting.

Grenade throwing pits were also examined due to requests through the RTLP MCX to examine potential modifications to throwing pits to reduce exposures without dramatically increasing cost. Wearable gauge data was shared from several sites, which showed that average exposure peaks of 1.4 psi, between three sites, can be seen with some detonations not registering due to wearable gauges having a minimum waveform reading of 0.5 psi. The estimated throw distance for these values was 10 meters. In comparison, the BlastX model shown in Figure 4 below showed a maximum peak of all points of 1.27 psi. For comparison, UFC 3-340-02 Figure 2-15 predicts a peak of 1.2 psi. This data shows a 17% error in predicted peak exposure verses averaged peak among multiple sites. This data confirms that BlastX is a suitable method for overpressure prediction and opens the door to future optimization efforts using the software as a tool for modifications.

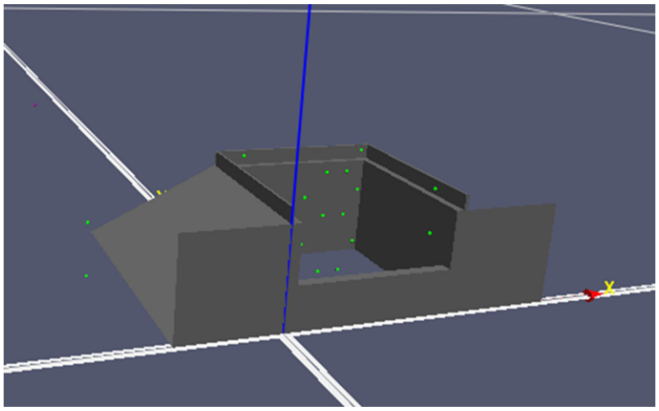


Figure 4. BlastX Model of Grenade Throwing Pit

The DoD’s Blast Overpressure Tool is another capability that could be considered to model blast exposure in the garrison environment. This computational modeling capability provides objective, validated estimates of exposure levels to 15 tier 1 weapon systems in accordance with Section 734 guidance. The tool is nearing transition and is in use by a number of operational and safety aligned end user groups.

Mitigation of Overpressure Exposure Through Material Modifications

Heat-treated ballistic rubber has been found to reduce noise exposure by as much as 70% in a fully confined space for certain manufacturers. It was found that of the more than 60 ballistic rubber manufacturers only a handful have tested application in live-fire explosive environments and only one claims at least a 10% reduction in overpressure in the same conditions. This is partially due to the only existing validation testing being proprietary data. A formal study at breaching locations where said product has been installed has been recommended to the BOP Working Group. Users have stated an improved condition for mTBI symptoms, but also a new hazard from debris being lodged into the ballistic rubber.

After finding that short barrel shotgun breaching could generate overpressure exposures of 4 psi. A study was also performed on if placing a rubber mat material on the door being breached would reduce exposures. Gym mats were used instead of ballistic rubber due to lower cost and easier installation. Figures 5 and 6 show the overpressure reduction of the data recorded in this white paper study.

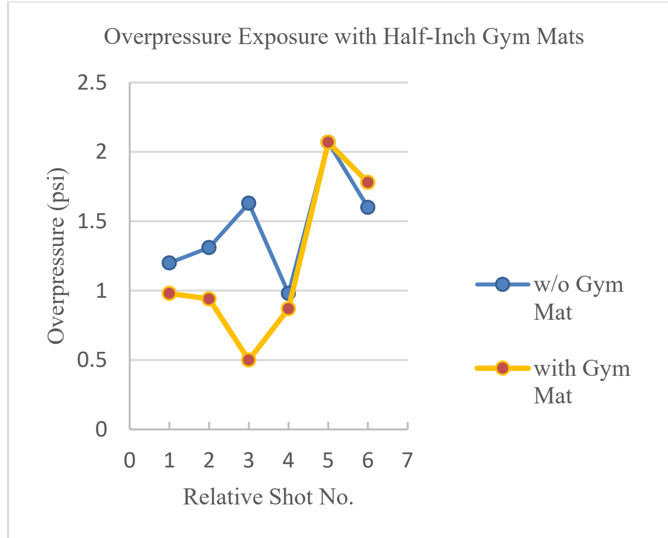


Figure 5. Overpressure Reduction from Gym Mat on Shotgun Breached Door

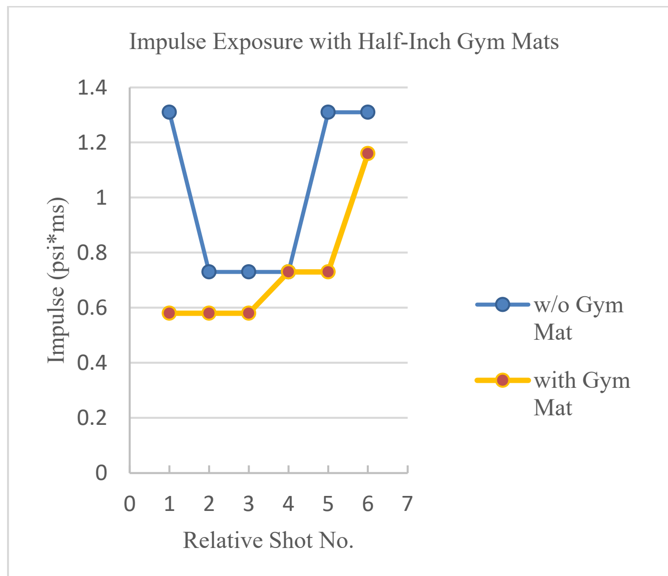
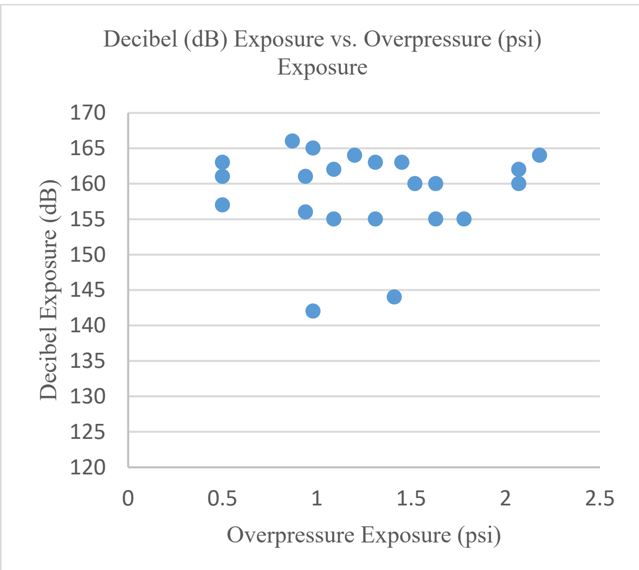


Figure 6. Impulse Reduction from Gym Mat on Shotgun Breached Door

Figure 5 shows an average reduction in overpressure of 19% and Figure 6 shows an average reduction in impulse of 25%. Causes for the first three shots showing a larger reduction in shock and impulse exposure than the fourth-to-sixth were narrowed down to two potential reasons, which require further testing to confirm. The first being that the mats were compressed past an elastic limit and may have absorbed less shock due to that compression. The second being that two different rounds were used, and the fourth-to-sixth had a higher muzzle velocity, which may result in reduced absorption due to increased shock wave velocity. The first potential cause is supported by the largest reduction to impulse being in the first shot. If this is the cause for reduced benefit from material degradation it would likely require disposal of the gym mat with the breached door or double stacking half-inch gyms mats or using ballistic rubber would further improve results. A Mossberg 590 Shockwave was used for this study, which has a longer barrel length than a standard breaching shotgun. This larger standoff is assumed to be the partial cause for the recorded overpressures not reaching the expect 3-4 psi level from other studies.

Testing of Decibel to Overpressure Correlation

In early discussions on mTBI risk to training personnel, much of the data shared by the medical community was only expressed as decibel readings. In terms of Explosives Safety criteria, applying MIL-STD-1494E would simply require that double hearing protection be used over 140 dB and have the noise reduction rating (NRR) to offset the difference between exposure and 140 db. It was found in comparison of several weapon systems that a single overpressure exposure may have a range of four different decibel readings that spans from 142 dB to 166 db. The r^2 correlation was also found to be less than 10% between decibel exposure and overpressure exposure. This limited data set suggests that conversion from decibel to overpressure would likely introduce large margins of error in data sets.



Facility Optimization for Exposure Reduction

A primary area of interest for the FES MCX and underutilized field for blast overpressure exposure reduction is optimization of facility parameters in the design stage to meet training objectives while minimizing overpressure and impulse exposure. When parameters controlling an exposure are quantified and understood, the parameters can then be optimized to meet a given objective. For example, for an internal detonation overpressure and impulse are controlled by charge density, scaled vent ratio, and scaled standoff. If the charge weight is set, then only volume and area of openings can be increased. With validated BlastX models fit against test data, future modifications to layouts can be tested by analysis to determine potential reduction methods. Additionally, combined curve fit equations could be used for quick checks to layouts.

Summary/Conclusions

There are many ongoing efforts in the area of blast overpressure reduction and mTBI risk from live-fire training. The ongoing cognitive baseline testing on personnel is likely to be the most beneficial in the short term due to being the next step on quantifying the numbers and groups of personnel with the highest risk of mTBI and having data to compare against expected exposure levels of risk. This data will then feed the engineering solutions development and medical working group research.

It is recommended that the Explosives Safety community does not attempt any criteria modifications based on BOP findings until collected data is more complete. At this point the 4-psi threshold would not impact DESR 6055.09 criteria.

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Acknowledgments

Thank you to the Army BOP working group for coordination.

Definitions/Abbreviations

mTBI	Mild Traumatic Brain Injury
IDS	Intentional Detonation Site
ESQD	Explosives Safety Quantity Distance
MSD	Minimum Safe Distance