Extremely Insensitive Explosive DDT Results during SLSGT

by

Nicholas Albrecht

And

Jeremiah Amato

Warhead Development Branch

Fuze and Warhead Division

OCTOBER 2019

NAVAL AIR WARFARE CENTER WEAPONS DIVISION

China Lake, CA 93555-6100

1.0 INTRODUCTION

The Air Force sponsored a feasibility study to investigate the ability of existing fuzewells (specifically auxiliary booster and component geometry) to initiate two candidate explosives fills that improve both insensitive munitions (IM) response and lethality. This report documents only a small subset of the full series of tests conducted to determine if legacy and production representative fuzewells will initiate the mainfill explosives (Reference 1). Super Large Scale Gap Tests (SLSGT) were performed on each candidate explosive at ambient temperature in which unique test results were observed.

1.1 BACKGROUND

The current standard explosive mainfill for Air Force penetrator warheads is an RDX based plastic-bonded explosive that has been fielded in many applications. As the requirements of legacy warheads are being extended, more survivable and more lethal explosives are required. The Air Force led a multi-year investigation into a better penetration-survivable explosive, which produced two candidate mainfill formulations to replace the legacy fill. The two candidate explosives are plastic bonded formulations with theorized improved sympathetic detonation characteristics. This new formulation can be categorized with similar sensitivity levels to the legacy mainfill, however is considered an extremely high-blast explosive

Prior to committing to Final (Type) Qualification and a full suite of Insensitive Munitions testing, the AFLCMC desired to perform a risk reduction test sequence in which multiple characteristics of the two candidate mainfill explosives were assessed.

Along with surrogate explosive interface testing, a secondary objective of the test series was further characterize the shock sensitivity of this new formulation. This objective was accomplished via Large Scale Gap Tests (LSGT), Expanded Large Scale Gap Tests (ELSGT), and Super Large Scale Gap Tests (SLSGT). During the SLSGT series, unique results in which contradictory results were obtained depending on evaluation criteria, were observed, and summarized within the following sections.

1.2 APPROACH

A series of SLSGT's were performed in accordance with STANAG 4488 Edition 2 (Reference 2) on the explosive to obtain the shock sensitivity of the explosives in large diameters subjected to long duration stimuli. The shock sensitivity values were compared against historical testing (Reference 3).

2.0 TEST ITEM DESCRIPTION

Ten SLSGT gap tubes were fabricated in accordance with STANAG 4488 Edition 2. The steel tubes are 8-inches in diameter and 16-inches long with 0.50-inches thick walls. In addition to the size and tolerance requirements, piezoelectric pinholes were incorporated. Eight piezoelectric pins holes formed a helical pattern at a constant interval spacing (2 inches) along the length of the tube.

The SLSGT donor explosives utilized were in accordance with STANAG 4488 Edition 2 (Reference 2) which were provided by the AFRL's High Explosive Research Department

(HERD). The charges consisted of Composition B and Composition A-3. Some of the Composition B donors were shipped within a thin-walled cardboard sleeve, which we could not remove without damaging the explosive. Because of the low density of the cardboard, and the minimal effect it would have on the donor stimulus, the sleeves were retained for testing. Donor charges with and without the sleeve can be seen in Figure 2 and Figure 5 within the proceeding sections.

Due to the large quantity of items being filled for the full test series and the limited kettle size, the explosive casting operations were broken up into two mixes. To reduce variability between mixes, the same lots for all ingredients were used. Additionally, the test items were split evenly between the two mixes; five tubes from each mix. The explosive Quality Assurance (QA) report for all mixes provided expected results for the QA tests conducted.

All finish assembly, prep, and explosive machining was completed by the Energetics Processing Branch of NAWCWD China Lake. All the gap tubes required machining in order to ensure the input surface of the tubes were smooth, flat, and within 0.002-inches from the top metal surface. The pins were inserted until they were seated fully in contact with the explosive surface and glued in place.

Prior to testing, all items were radiographically inspected by the Ordnance Test and Evaluation Division of NAWCWD China Lake. Any anomalies in the explosive load were recorded within the inspection reports. The tubes all had various small void pockets and minor low-density regions. However, they all met Navy Munitions Document (NMD) requirements.

3.0 TESTING

Ten SLSGT shots were performed in accordance Reference 1 and 2. Testing was conducted by the Ordnance Test and Evaluation Division, Warhead and Explosives Evaluation Branch of NAWCWD China Lake.

The series used the Neyer Most-Likely analysis software to provide the shot progression and derive the mean sensitivity data.

The test items were tested at “Standard Ambient” temperature (+77°F ±18°F). The test items were held to an out-of-conditioning time limit of 25 minutes prior to firing.

3.1 TEST SETUP

The 8-inch SLSGT tubes were placed on 0.25-inch wooden standoffs on top of a 16-inch x 16-inch x 1.50-inch thick witness plate. In order to raise the test setup off the ground, the witness plate was placed on two wooden 2x4 studs.

Eight piezoelectric pins were incorporated to provide TOA data of the shock or detonation front to assist in “GO/NO-GO” evaluation. A diagram of the test setup can be seen in Figure 1. A typical SLSGT pre-test photograph is shown in Figure 2.

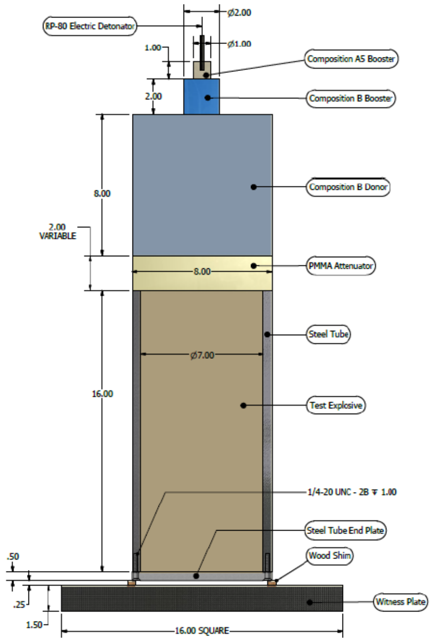


Figure 1: SLSGT Schematic

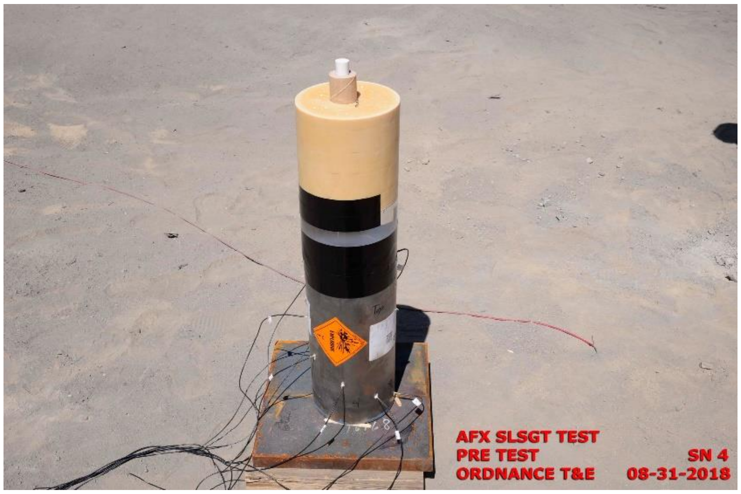


Figure 2: Typical SLSGT Setup

3.2 CRITERIA OF FIRE

"GO/NO-GO" criteria were determined by evaluation of the witness plate in conjunction with the piezoelectric pin TOA data. The test was scored a "GO" if the post-test hole in the witness plate was larger than the diameter of the explosive column (7.00-inches) and the calculated detonation velocity was a minimum of 80% the published detonation velocity as calculated from the TOA data. Post-test damage corresponding to a "GO" can be seen in Figure 3.

Figure 3: Characteristic SLSGT Witness Plate Damage for a "GO"

3.3 TEST EXECUTION

Table 1 summarizes the test results for the ten SLSGT shots within the series. The test series gap thickness progression and results can be seen in Figure 4.

During the 10-shot series progression, it was observed that four of the tubes resulted in conflicting determinations based on which "GO/NO GO" criteria was applied. For shots A-3, A-7, A-8, and A-19 the initial look at the piezoelectric pins showed a shock wave traveling through the material at roughly the explosive's bulk sound speed (indicating a "NO-GO"). However, the witness plate had an adequately sized hole and peripheral spall fracture that would indicate a "GO" reaction. After reviewing the pin data more thoroughly, it appears that on these four shots (A-3, A-7, A-8, A-19) the pins recorded multiple waves of varying amplitude after approximately 65µsec of the passing of the initial wave through the last pin. Each of the questionable shots displayed a sequence of later-time spikes in the data record that correlate to the explosive's detonation speed. This would indicate that the explosive may have detonated at a later time after the passing of the initial shock wave.

The High Speed Digital Video (HSDV) verified that the initial shock wave through the explosive did not result in a prompt detonation. Witnessed via the HSDV, the timing of expulsions of dust, glue, and explosive material being ejected out of the pin holes and the gap between bottom surface of the tube and witness plate correlate with the timing recorded with the pins. However, the HSDV captures a brief viewing of a detonation reaction (bright light associated with an explosive reaction) out the bottom of the tube at a much later time. This light corresponds to the timing seen on the data record matching to the later-time pulses. Unfortunately, the viewing of the later-time detonation light and cylinder expansion is obscured by the detonation products of the donor explosive. This provided only the bottom portion of the tube and witness plate visible at this later-time. This removes the ability to observe if the explosive was detonating from the top or bottom of the tube, as the expansion of the tube is not observed. It was unknown if the cause of the conflicting results were due to the explosive formulation and mix's properties, or due to a test setup problem that could be skewing the results.

Multiple attempts were made to alter the test setup in order to capture a longer view of the SLSGT tube. A wooden table with a circular cutout was placed around the tube and used for subsequent shots such that the table would deflect the donor's fireball long enough to continue capturing HSDV on the tube. This was done in an effort to visually see where and how the SLSGT tube began expanding to provide a possible detonation point and/or direction. Unfortunately, the size of the table was limited due to the height of the HSDV camera mount and obscuring the view by a large tabletop. Additionally, a mirror was placed on the ground in front of the test item, angled rearward to view the top of the SLSGT's input surface. This was done in order to prolong the view of the tube by seeing underneath the fireball as it radially expanded.

Both these methods provided slight increases in HSDV data capture with Shot A-19's HSDV providing significant qualitative input to the reaction sequence. A view of the altered test setup is shown in Figure 5.

While the reason for a delayed reaction is still not known, these conflicting test shots were deemed a GO in the analysis. Additional data is presented in Section 4.

Table 1: Super Large Scale Gap Test Results

Shot Number	S/N	PMMA Gap (in)	Witness Plate Hole Dia (Max) (in)	Slug Dia (in)	Average Velocity (Relative %)	GO / NO GO
A-1	5	4.755	9.5	8	97	GO
A-2	1	5.645	9.75	7	98	GO
A-3	4	6.508	10	7	33	GO*
A-4	2	7.996	-	-	31	NO GO
A-5	3	7.252	-	-	36	NO GO
A-6	6	6.802	-	-	32	NO GO
A-7	7	6.618	10	7.25	33	GO*
A-8	8	6.698	9.75	7	33	GO*
A-19	9	6.750	N/A – 4 pieces	8	35	GO*
A-20	10	6.801	-	-	34	NO GO

NOTE: GO* defined by witness plate only, not detonation velocity

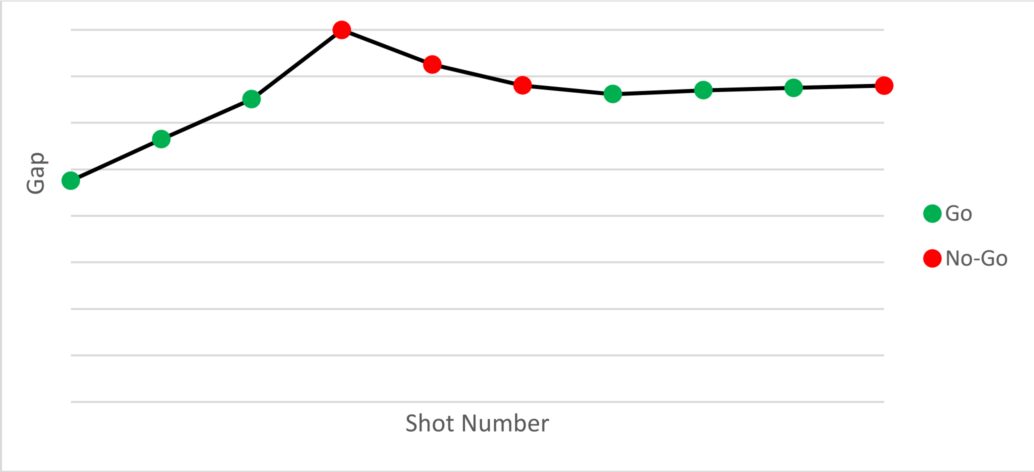


Figure 4: Shot versus Card Gap Plot

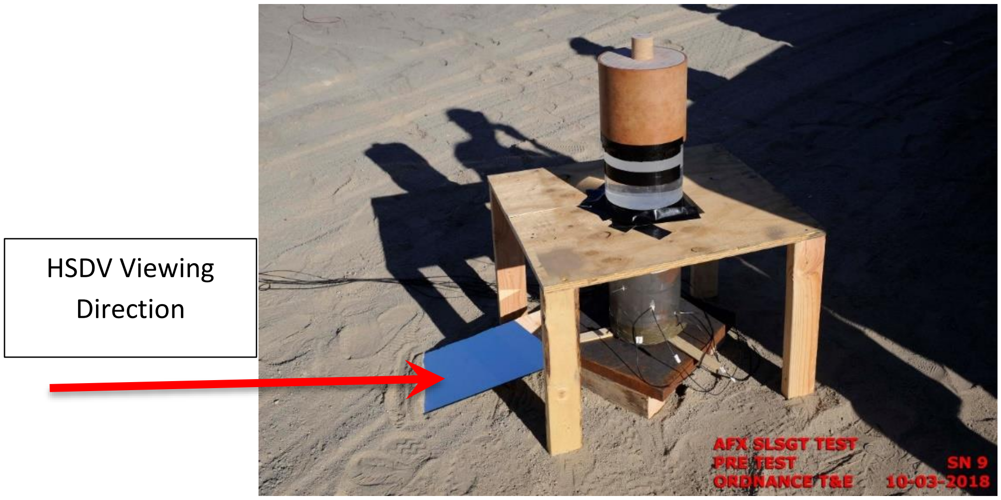


Figure 5: Altered SLSGT Test Setup

The explosive provided a mean sensitivity of 28.8-kbar (6.776-inches with a standard deviation of .064-inches). This value is significantly more sensitive than historical reporting (40.36-kbar) and is a drastic deviation from the trend of this series' other gap test results. Both the LSGT and ELSGT results obtained during the full test series proved to be relatively similar to previously reported results. This is due to the unique results obtained during this test series and the inclusion of the contradicting resultant tubes being scored a "GO.' If scoring the tubes in which contradictory results were obtained a "NO-GO," then the "GO/NO-GO" threshold is between 41.9-kbar (5.645-inches) and 31.5-kbar (6.508-inches). Because the testing progressed scoring them as a "GO," the large step in gap thicknesses was not resolved further, and the mean sensitivity would most likely lie somewhere in between the two values.

4.0 Post Test Analysis and Discussion

Figure 6 displays the incremental velocity calculated from the TOA recorded by the piezoelectric pins. The TOA data points plotted within the figure represent the first trigger that the pin saw that was above 5-volts with the required rise-time. With the noise seen within the data record on many of the pins, premature triggers appear in some of the later-time traces. These events are seen as the un-characteristic spikes in these velocity curves below.

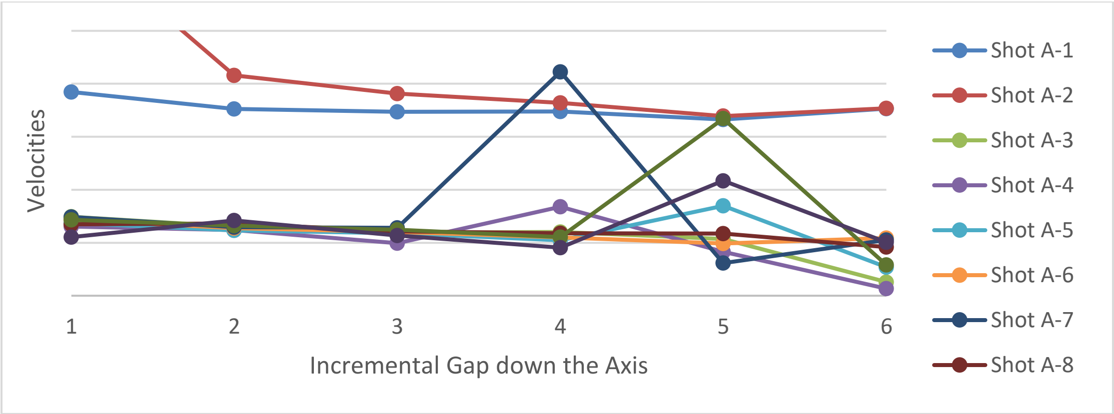


Figure 6: Incremental Detonation Velocity Plot

As indicated in Section 3, shots A-3, A-7, A-8 and A-19 provided conflicting "GO/NO-GO" results depending on the criteria evaluated. After further analysis, a late-time Deflagration-to-Detonation (DDT) event is believed to have occurred. The data record for shot A-3 is presented in Figure 7. It can be seen that at approximately 288 μsec (after the detonator firing pulse triggering a zero time), there is another event that excites pin 6 followed by pins 7 and 8. The calculated speed of the shock causing the second set of voltage spikes is 98% the published steady state velocity.

In addition to the large amplitude triggers observed, the pins recorded considerable noise in the 1 to 4-volt range. Plotting the noise seen on each pin's data trace and calculating the difference in each pin's noise onset time, an interval of roughly 5 mm/μsec is observed. It should be noted that determining a consistent TOA for the onset of noise is not a precise measurement. However, it is believed that a shock traveling through the steel tube is causing the noise in the pin's data. The sound speed of steel is published as 5.8 mm/μsec.

The second, late-time event is theorized to be a detonation wave that emerges from a DDT event within the length of the tube. Shot A-7, A-8, and A-19 data records appear similar in having a late-time second set of pin triggers.

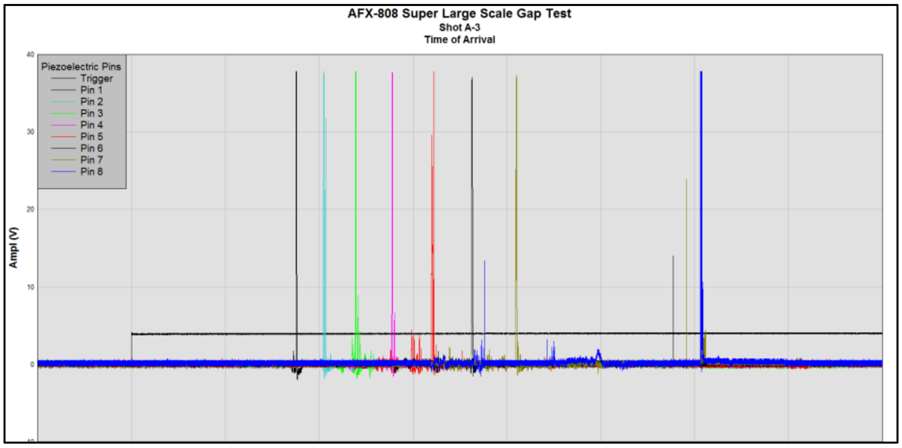


Figure 7: Shot A-3 SLSGT Time of Arrival Data Plot

A typical “prompt,” ‘GO’ reaction, as captured on the HSDV at approximately 125μsec after the firing line trigger, is presented in Figure 8. Of importance is the location of the fireball; bright light filling the top of the image, relative to the tube’s first-light out of the bottom of the SLSGT tube. The bright white light out the bottom of the tube is indicative of the initial breakout of a detonation reaction. Additionally, it can be assessed that the cylinder expansion views within the HSDV display a typical response from a detonation at the top of the tube. Time is required in order for the explosive detonation products to accelerate the steel tube uniformly. This still image was taken multiple frames after the tube began to expand in order to view the expansion more dramatically. This image demonstrates that the explosive was most likely detonating at the top at a much earlier time than the first-light reaching the bottom of the tube.

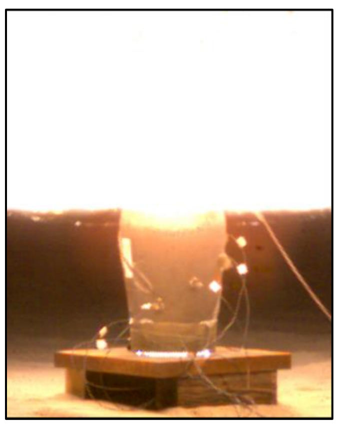


Figure 8: Typical SLSGT 'GO' Reaction

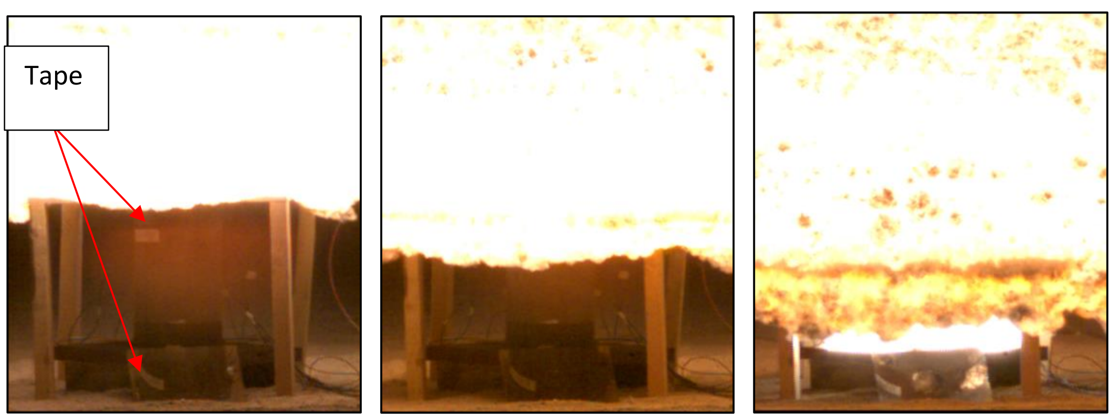
A composite of three still images taken from the HSDV for shot A-7 are presented in Figure 9. Frame B is approximately the same time compared to Figure 8. It can be seen that there is no reaction within the explosive at this time. The tube remains stationary and unreacted until a much later time as seen by Frame C at approximately 303μsec. In reviewing the pin data, the last pin (Pin 8) is initially triggered at 229μsec with the passing of the first shock. The tube remains unchanged until Pin 8 is triggered again at 298μsec. The second, later-time pin 8 trigger reasonably matches the timing of detonation light out the bottom of the tube.

Unfortunately, the fireball obstructs the ability to observe tube expansion at this late time and the location and/or direction of detonation cannot be surmised from this shot's HSDV alone. However, it can be seen that the bottom portion of the tube's explosive is detonating.

Frame A – 86µsec   Frame B – 124µsec   Frame C – 303µsec

Figure 9: SLSGT Witnessed Late Time Reaction

Figure 10 displays a composite of HSDV still images from shot A-19. This shot utilized the modified test setup in which a wooden table and mirror were used to view underneath the fireball for a longer duration. Shot A-19 exhibited a late time reaction. As seen in Figure 10 Frame C, significant detonation products are being expelled out the bottom of the tube at this time. By witnessing the frame-by-frame movement, or lack-thereof, of the mirrored image of a strip of tape positioned towards the top of the tube, cylinder expansion of the tube can be observed. Figure 10 Frame C is the first frame where the mirrored image of the tape moves, indicating the tube is beginning to expand radially. First light out the bottom of the tube is seen before the tube expansion. This provides evidence that the initiation location (or transition to detonation location) is not biased towards the top of the tube. The HSDV and pin data suggest a potential Deflagration-to-Detonation-Transition event occurring within the tube somewhere around pin 6 or 7.



Frame A ~ 135µsec   Frame B ~ 205µsec   Frame C ~ 343µsec

Figure 10: SLSGT Witnessed Late Time Reaction for Shot A-19

The root cause of this DDT event is unknown and could not be determined by the limited testing performed in this series. It is well understood that variations in obtaining the mean sensitivity through gap testing can be effected by a plethora of influencing factors. For example, these may include (but are not limited to):

- Small changes in explosive ingredient ratios and proportions within the specification limits
- Changes in ingredient particle size distributions
- Small changes in test hardware assembly, i.e. greased cards, alignment fixtures, etc.
- PMMA surface roughness and density variations
- Booster density and mix variations

However, the large variation in the SLSGT testing due to the witnessed DDT event is largely outside the range of typically accepted test-to-test variation for a large gap test, far away from the explosive's failure diameter.

A few possible causes to this unique event have been postulated. They include;

- Movement of the explosive billet during the donor shock and subsequent compression stages in conjunction with the formulation's oxidizer particle-size-distribution that is initiating the explosive due to friction caused by the relative movement between the explosive molecules, metal fuel particles, oxidizer particles, and binder materials.
- A reflected shock off the bottom of the SLSGT tube from the witness plate that is traveling back upwards towards the top of the tube. This additional shock, when combined with the initial shock stimulus from the donor and its accompanying reflections through the PMMA, plus the shock traveling through the steel tube and its transmitted pre-stimulus into the explosive, could provide a unique stimulus for a long enough duration that it exceeds the explosive's threshold Energy Fluence required to transition to detonation.

The testing resulted in a mean sensitivity of 28.8-kbar (6.776-inches with a standard deviation of .064-inches). This value is significantly more sensitive than historical reporting and is a much larger increase in sensitivity over historical results than what is observed in this series' other tests. Previously reported SLSGT results were 40.36-kbar. This is due to the unique results obtained during this test series and the inclusion of the contradicting resultant tubes being scored a 'GO.'

If the tubes in which contradictory results were obtained were scored a 'NO-GO' the mean sensitivity may have lied between 41.9-kbar (5.645-inches) and 31.5-kbar (6.508-inches). Because the testing progressed scoring the contradictory tubes as a 'GO' the large step in gap thicknesses cannot be resolved further, and the mean sensitivity would most likely lie somewhere in between these two values.

REFERENCES

1. Air Force Life Cycle Management Center, Hard Target Munitions Branch. *[Redacted] versus [Redacted] Ignition Reliability Test Plan,* by Stephen Kelley. Eglin Air Force Base, Florida. October 2017. (publication UNCLASSIFIED).

2. NATO Standardization Agency. *STANAG 4488 (Edition 2) – Explosives, shock Sensitivity Tests.* NATO Standardization Agency Brussels, Belgium. 27, April, 2009. (STANAG 4488 Edition 2, Publication UNCLASSIFIED).

3. Air Force Research Laboratory Munitions Directorate. *The Development of [Redacted].* by B.T. Woodworth et al. Eglin Air Force Base, Florida. February, 2014. (AFRL-RW-EG-TR-2014-027, publication UNCLASSIFIED).