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FY2014 LX-21 Blasting Cap Testing

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Introduction

For a new material to qualify as an Extremely Insensitive Substance (EIS), the material must pass the UN Test 7, EIS Cap Test [1]. This test attempts to measure the shock sensitivity of the material to a *standard detonator* at its nominal shipping density. The standard detonator specified for this test is based upon the historical number eight, #8, blasting cap. The standard detonator must contain a base charge (output charge) greater than or equal to 450mg and have a detonation velocity of at least 7.0 km/s. The Du Pont E-1A blasting cap, which is no longer made by Du Pont, was originally used to qualify TATB-based insensitive materials in the DOE. This detonator met the requirements of the EIS Cap Test. Several other commercial vendors currently sell products that are listed as equivalent to a number eight blasting cap, but have, in several cases, exceeded the original output energy of the historical number eight. By the loose specification that the number eight contain at least 450mg of output explosive, any product containing at least this quantity can be labeled as a number eight. Indeed, for most applications, higher output energy merely means a better, more reliable product. For standards testing, variation the output energy greatly affects the test results.

Pantex has maintained a quantity of the original, number eight blasting caps the DOE used to qualify TATB materials (The DOE uses an IHE qualification, which is similar to the HD 1.6 classification, and requires a similar EIS Cap Test.) In FY-13, we acquired blasting caps from the original Pantex supply and from two commercial vendors for characterization and comparison. Our goals were to first characterize each of the three *standard detonators* with the intention of using a detonator that was as equivalent to the Du Pont number eight blasting cap as possible. Second, to work with a commercial vendor to produce a number eight equivalent that would either be based on a safer initiation technology such as an exploding bridge wire (EBW) or exploding foil initiator (EFI) – most commercial units hot-wire based, which present considerable safety concerns.

Set-up

The test configuration is shown in Figure 1. In this configuration, four velocity measurements are made using Photonic Doppler Velocimetry (PDV). Three of PDV probes measure the expansion of the aluminum cup (wall) velocity in the lateral direction. From the expansion of the wall velocity, the output energy can be measured. Two different configurations were used for the fourth probe. One configuration measured the particle velocity in a PMMA window from which the output pressure the detonator could be inferred, and the other configuration monitored the velocity of the aluminum can as it expanded in the direction of the detonation.

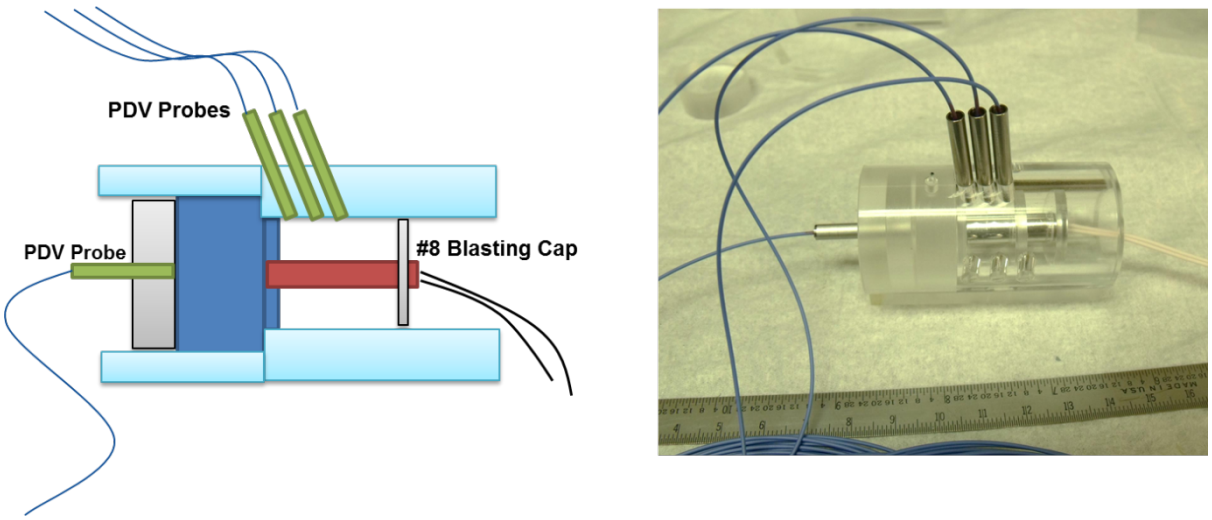

Figure 1: Standard Test Detonator Set-up

Comparisons of the Du Pont number eight blasting cap to Mantelec's number eight and to the RISI RP-81 are shown in Figures 2 through 5. The rear probe of the RP-81 was placed behind the energetic material in Figure 5 this point should be ignored. In all cases, the Du Pont blasting cap has lower output energy and lower output pressure than either the Mantelec or the RP-81.

We set-up a simple 2D hydrocode model to aid us in redesigning the RP-81 so that it would have an output similar to the original Du Pont number eight blasting cap. To address the question why not simply use Du Pont's number eight blasting cap now, Du Pont no longer makes a number eight blasting cap. To have a test consistent with the original qualification of TATB materials, our desire is to reproduce its output in an exploding bridgewire (EBW) detonator that can be specified with a maximum output energy.

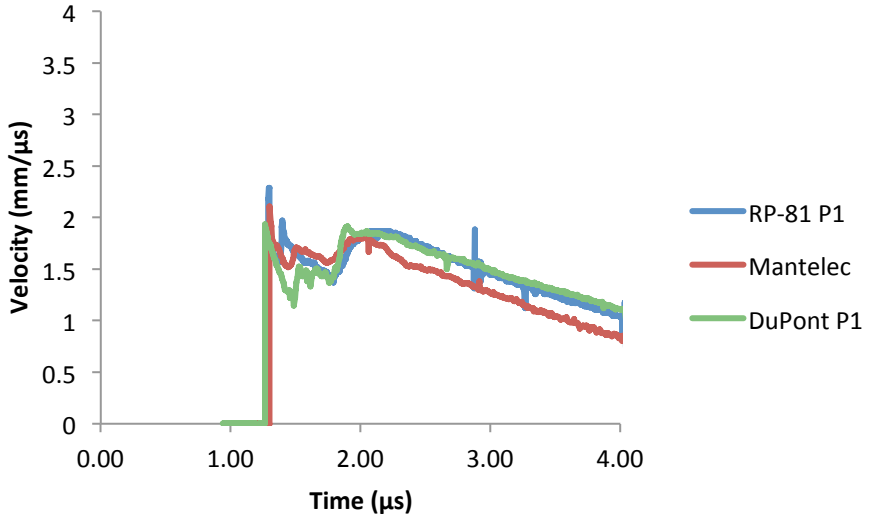

Figure 2: Probe 1 into PMMA window.

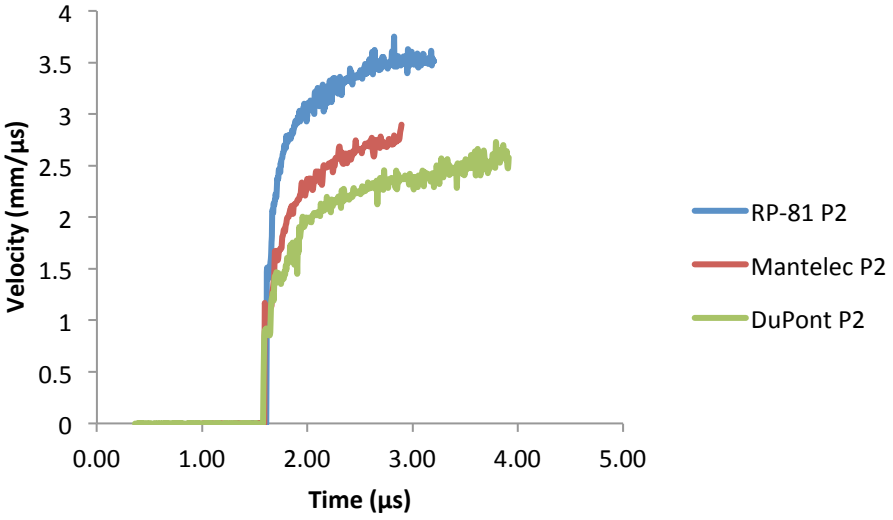

Figure 3: Probe 2 Wall Velocities

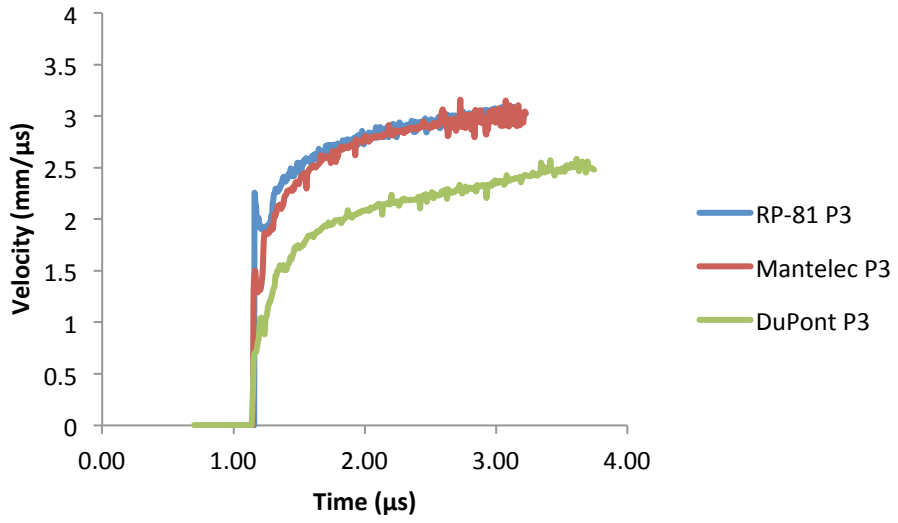

Figure 4: Probe 3 Wall Velocities

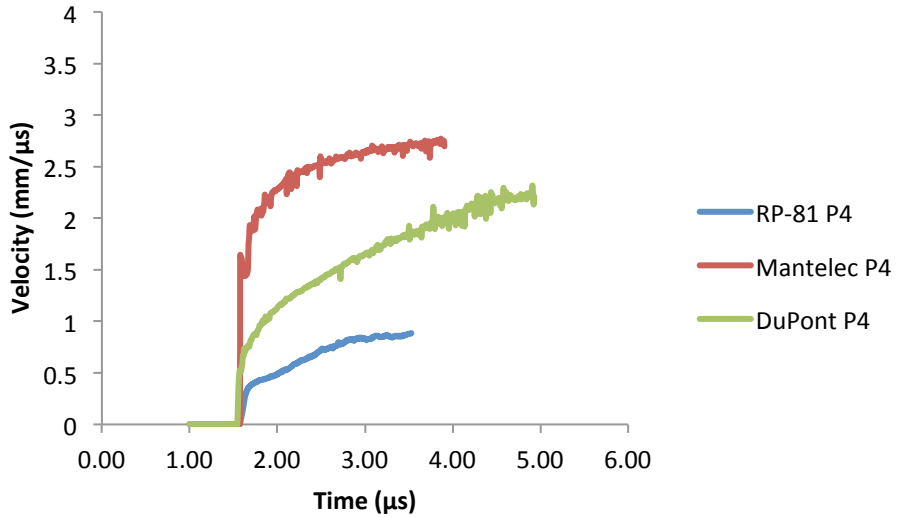

Figure 5: Probe 4 Wall Velocities. For the RP-81, this probe is behind the initial pressing.

Based on the Du Pont data, we constructed a 2D hydrocode model to help redesign the RISI RP-81. (See Figure 6.) With this model, we varied the density of the PETN output pellets. The densities were varied from 1.2 to 1.6 g/cc. For a best match with the experimental data from the Du Pont number eight blasting cap, we selected a pellet density of 1.4 g/cc.

The Mantelec #8 has a output charge of 550 mg PETN with an initiating charge of 250 mg Lead Azide. The Du Pont, E-1A has an output charge of 6.9 grains or 447 mg of PETN.

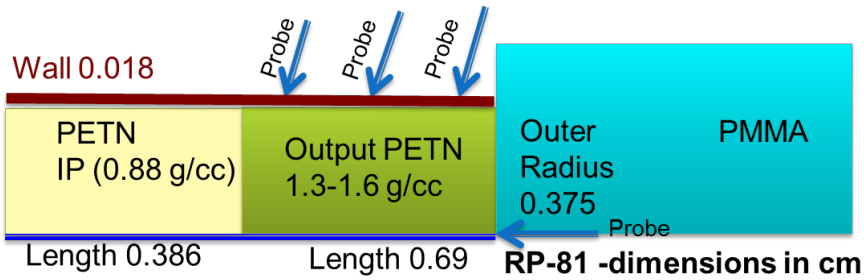

Figure 6: Simplistic view of hydrocode model

We contracted RISI to construct new EBW detonators that had pressing densities between 1.3 and 1.5 g /cc to mimic the Du Pont blasting cap. These were tested against Du Pont to validate the code and for future testing of LX-21 as a potential EIS material.

Using both the LLNL hydrocode, ARES, and the *JWL Tweaker 3*[2] the estimated detonation velocity of various densities of PETN output pellets are given in Table 1.

Table 1

PETN Density (g/cm^3)	Detonation Velocity (mm/μs)
1.30	6.995
1.40	7.086
1.50	7.164
1.60	7.232

Based on the current version of the TB 770-2, the standard test detonator is required to have an HE load of no less than 450 mg and a detonation velocity of at least 7.0 km/s. From the above table the 1.3 g/cm^3 detonator configuration is below this specification and the 1.4 g/cm^3 configuration is just above the specification – both configurations meet the 450 mg output explosive mass requirement (as built 454mg PETN output pellets).

LX-21 Cap Tests

We scaled the blasting cap test due to lack of available material on hand. The scaling factor was approximately one fourth based on material mass. It is our belief that a material that would detonate in the scaled configuration would be equivalent to or more sensitive than a material that would detonate in the full scale configuration, since the run length (deflagration to detonation transition) is larger for the full scale configuration. With that stated, a test with no reaction or slight reaction would, in the scaled configuration, not be conclusive of either a Pass or Fail of the Cap Test because in a greater column length (DDT length) the reaction may turn over into a

detonation. In other words, a scaled *Fail* is equivalent to a full scale *Fail*, but a scaled *Pass* is inconclusive of a *Pass or Fail*.

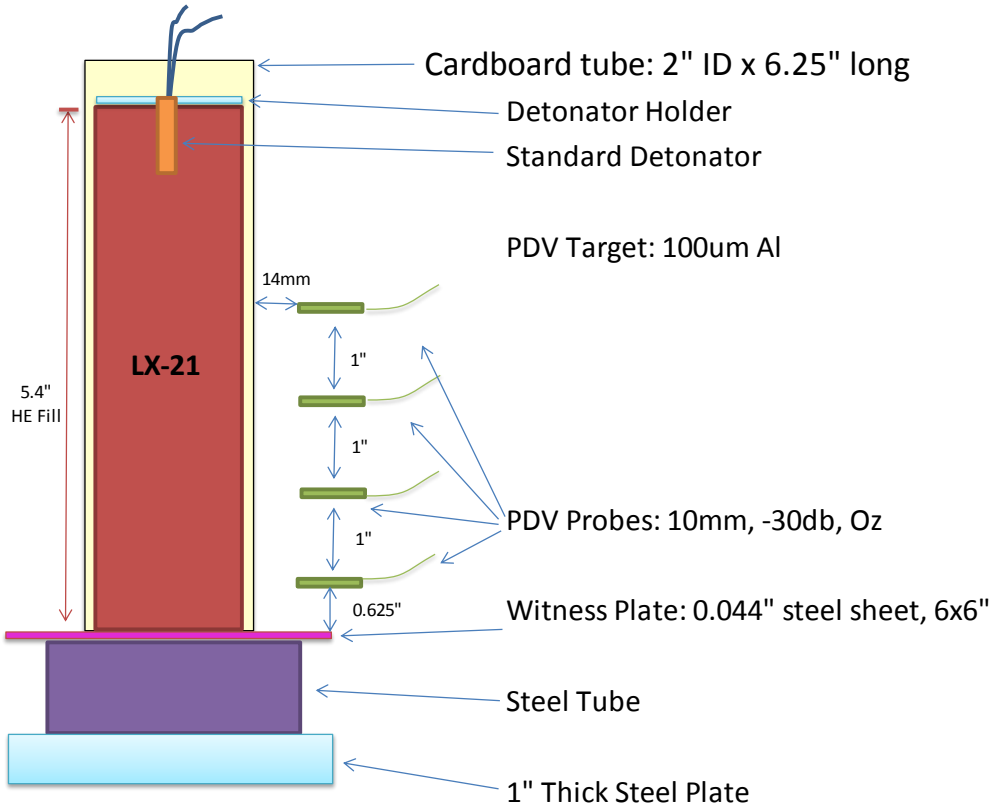

Figure 7: Diagram of scaled cap test for LX-21 evaluation.

In the scaled configuration, a cardboard tube measuring 2 inches in inner diameter and 5.4 inches in HE fill height – the full scale configuration is 3.15 inches diameter and 7-7/8 inches in height – was filled with LX-21. To bracket the *Standard Detonator* defined in the 2012 release of the TB 770-2, both 1.30g/cm3 and 1.40g/cm3 PETN detonators were used to attempt to initiate loose packed LX-21 powder. See Figures 8 to 10 for photos of the test configuration.

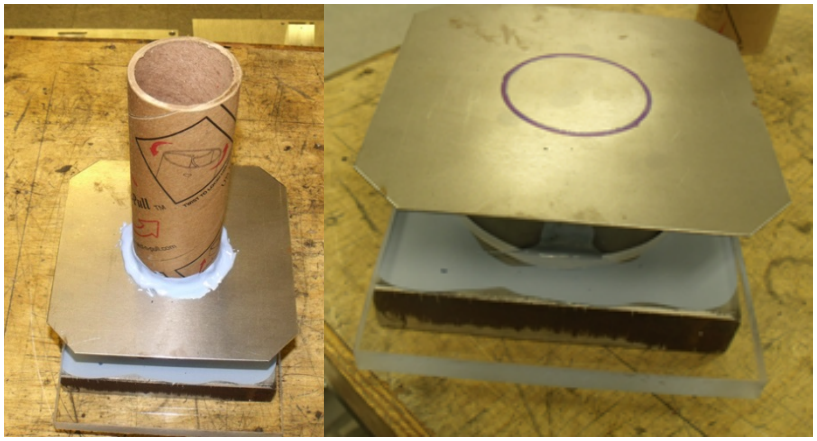

Figure 8: Cardboard tube and witness plate.

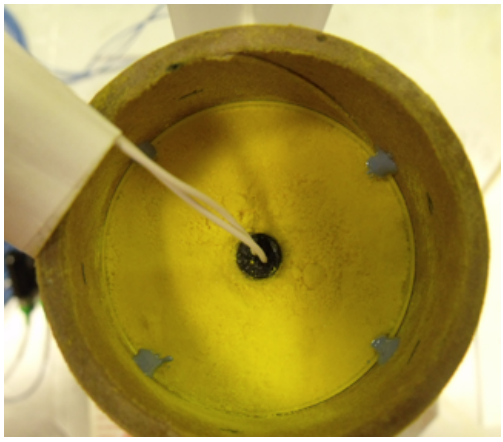

Figure 9: Close-up of detonator in LX-21

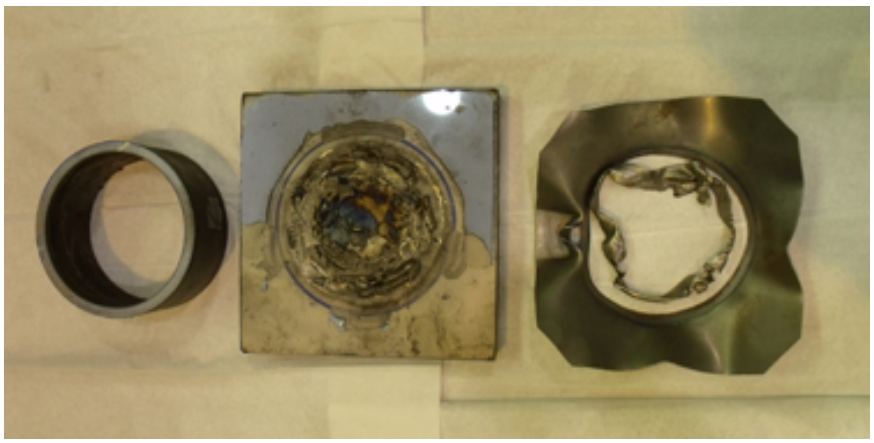

Figure 10: Perforated witness plate.

Table 2: LX-21 Cap Tests

Shot Number (Year)	Detonator PETN Density (g/cm^3)	Average Velocity Probe 3 - 2 (km/s)	Average Velocity Probe 2 – 1 (km/s)	Witness Plate Velocity (km/s)
520 (2013)	1.50	4.2	4.6	Not monitored
1723 (2014)	1.40	1.56	1.56	>1.02
1724 (2014)	1.30	1.57	1.69	>1.05

The LX-21 tests, both with the lower bounding detonator (1.3g/cm3) and the 1.4g/cm3 detonator reacted violently. The witness plates, see figure 10, were perforated – quite literally they were blasted through. Photonic Doppler Velocimetry (PDV) diagnostics monitoring the witness plate velocity gave a velocity of around 1 km/s, indicative of a full order detonation. For the scaled Cap Tests, we also installed Fiber Bragg Grating (FBG) diagnostics to monitor the deflagration or detonation velocity of the loose LX-21 powder bed. This diagnostic gave a detonation velocity of around 3.6 km/s (Figure 11), which would also indicate a detonation of the LX-21 powder.

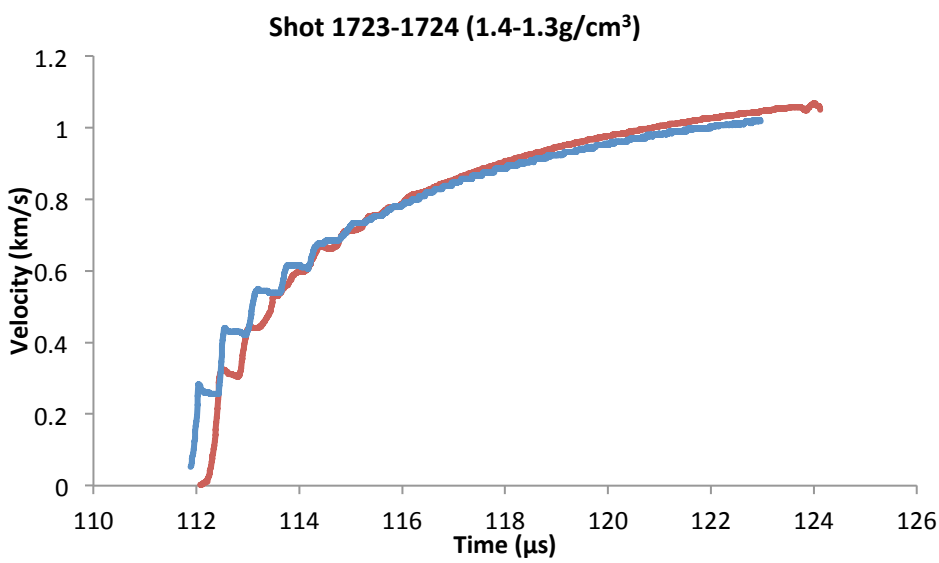

Figure 11: Witness plate velocities for LX-21 Cap Tests (Shots 1723 and 1724).

The instrumented cap test used Fiber Bragg Grating (FBG) sensors to measure the velocity at which the power deflagrated or detonated. For each shot, two FBGs were concatenated to monitor the velocity of the LX-21 powder just after the detonator. The first of the two FBGs was

placed approximately 1mm from the output face of the test detonator. The FBGs were located along the center axis of the tube. They were suspended by two thin, ABS plastic spokes, which, we believe, made negligible perturbations to the firing configuration. The two FBGs were glued together such that 3-4 mm of the gratings overlapped. Figure 12 shows the placement of the FBG and the spokes.

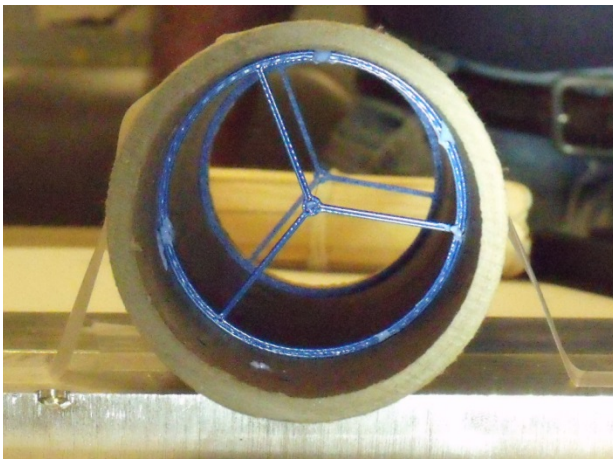

Figure 12: Placement of spokes and FBG.

The raw FBG return data for shot 1723 is show in Figure 13. The first fiber return has three distinct sections; the second fiber return has significant oscillations and areas of 'recovery'. The areas of recovery are the places in which the return signal amplitude increases. The premise behind the FBG diagnostic is that the fiber is destroyed with either the initial detonation wave or in the release behind the detonation wave. This destruction causes a loss of returned signal – there is no physical way – based on the assumptions of operation – that the signal can increase. One could speculate that the FBG is not completely destroyed within the loose powder bed and it recovers momentarily leading to increased signal return…more effort needs to be made to understand the processes by which the FBG functions.

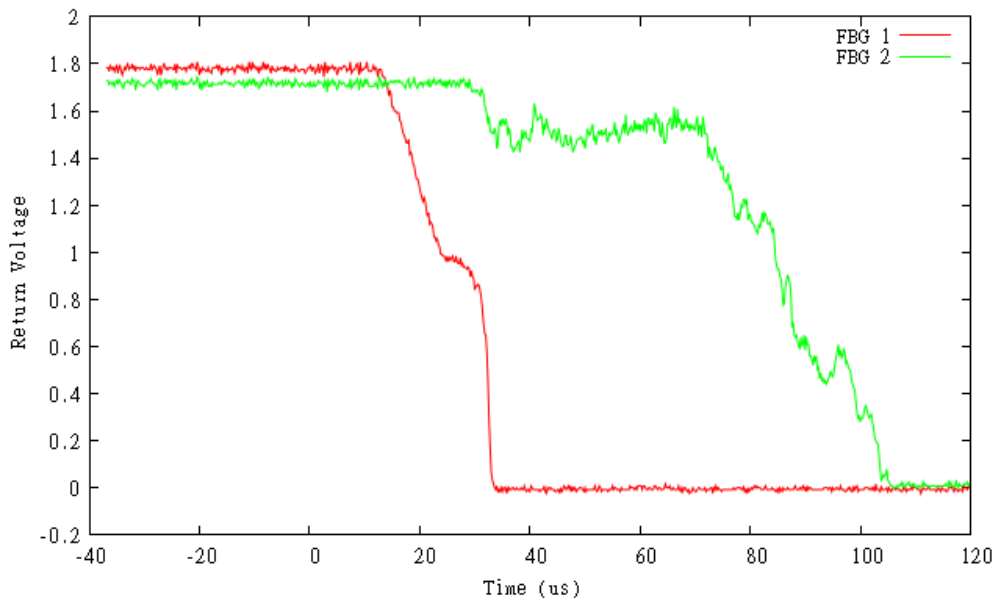

Figure 13: Shot 1723 (1.4g/cc) FBG return signals.

Figure 14 shows the FBG data from Shot 1723 as an X-T diagram with the position on the y-axis. The position in millimeters, is relative to the FBG locations and not an exact location along the LX-21 powder column. The top section of FBG, here located at around 190mm, was located approximately 1mm from the output of the detonator. The data from the two FBGs were analyzed in five separate segments in Figure 15. Each section was fitted using a least squares fit to a first order polynomial. The fits are shown in gray. The slopes of these polynomials are the velocities of the different segments. They are starting from left to right (top of FBG1 to bottom of FBG2) 4.79, 1.88, 27.9, 6.2, 2.0 km/s. Obviously the 27.9 km/s section is non-physical. The wild variation in these data brings into question the efficacy of FBG diagnostics used in this type of configuration.

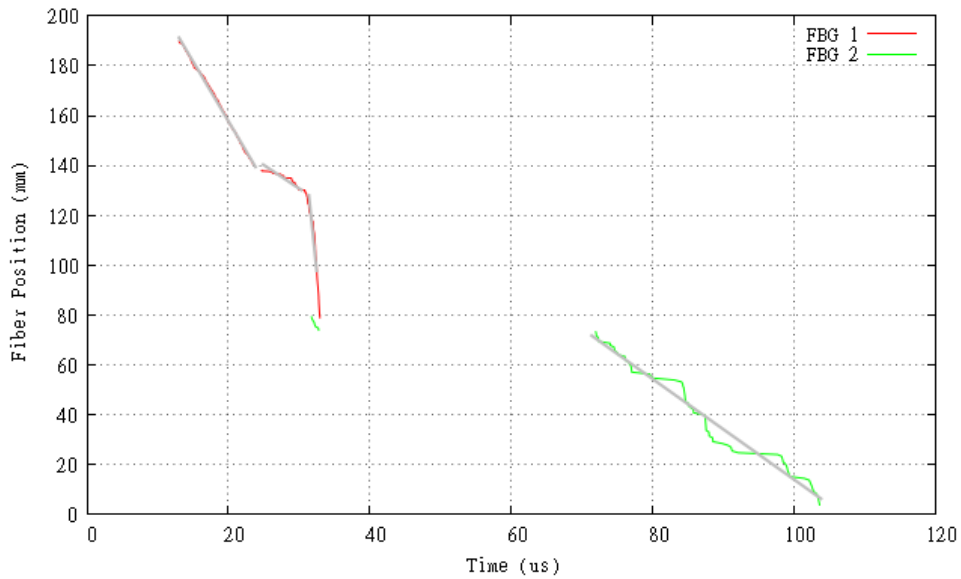

Figure 14: Shot 1724 (1.4g/cc) Position-Time histories from FBG analysis.

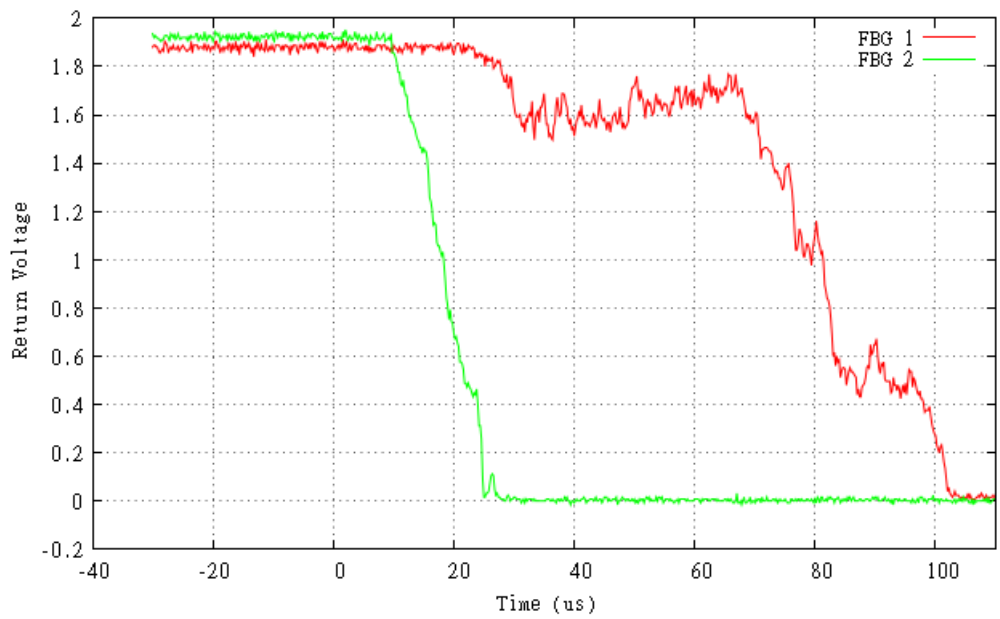

Figure 15: Shot 1724 (1.3g/cc) Raw FBG return signals.

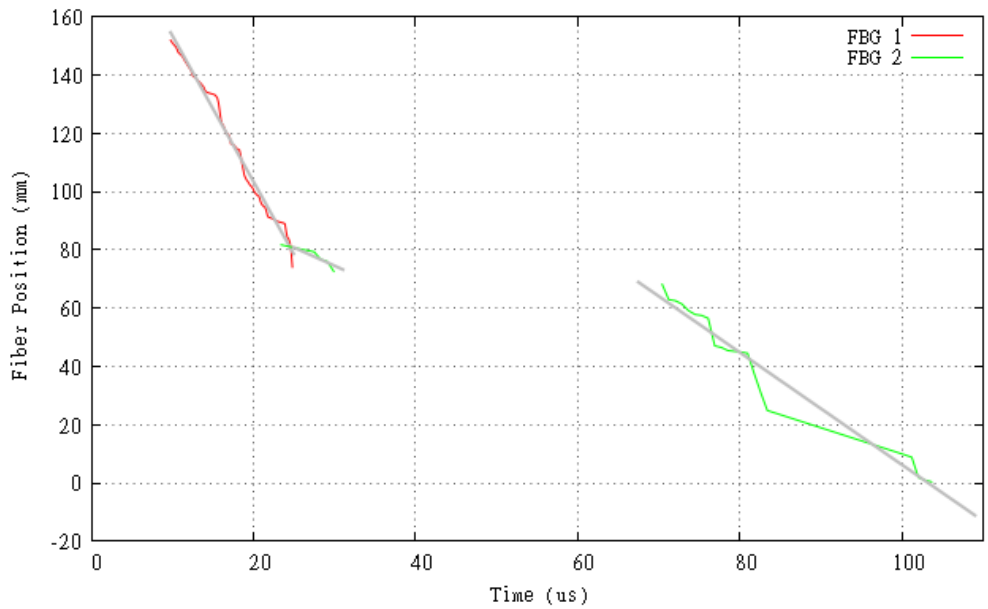

Figure 16: Shot 1724 FBG data. The top portion of the first fiber was ignored in the analysis.

For shot 1724 (Figures 15 and 16), the FBG data were analyzed in three segments. Fitting a first order polynomial to the x-t history from the first fiber produces a slope (velocity) of 5.00 km/s. The second fiber was analyzed in two segments. The first segment, which overlaps the end of the first fiber, gave a velocity of 1.25 km/s. The second section, this is the section after the recovery, produced a velocity of 1.93 km/s.

If the FBG data can be trusted, both shots show an initial high velocity, greater than 4 km/s and show a final velocity around 2km/s. This could mean the material initially detonates, but it does not sustain a detonation for the length of the powder bed. Certainly, the pressure that the witness plate on the end of the column sees is sufficient to perforate it and to accelerate it to over 1 km/s.

TATB

In addition to the LX-21 test fires, a UF-TATB shot was fired as well to demonstrate the construction and validity of the newly designed, EBW-based *Standard Test Detonator*. With UF-TATB, a 1.5g/cm3 PETN load was used as an over test. In the UF-TATB test, there was no appreciable reaction of the UF-TATB material – most of the UF-TATB was recovered from the tank after the shot. Not all of the 250g of TATB was recovered for weighing after the shot; however, there was a quantity of TATB residual that was plastered to the firing chamber walls and HE vacuum filter other equipment that had to be physically removed and was not included in the post material mass. This material could have accounted for differences in the pre and post shot masses. Some of the TATB material near the detonator could have reacted, but there was no physical sign of reacted material after the test. The 1mm steel witness plate used in the TATB test was in no way deformed of perforated.

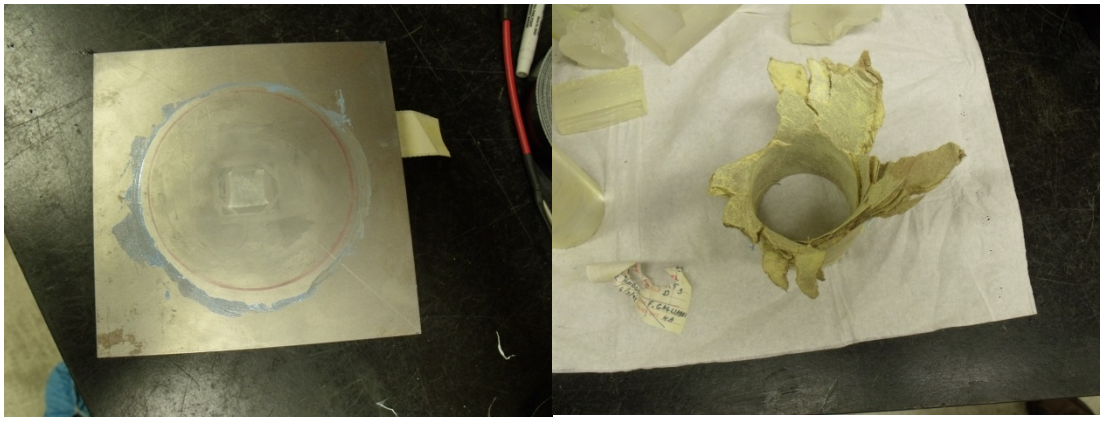

Figure 17: Using the higher output 1.5g/cc RISI detonator, UF-TATB *passed* the cap test.

Conclusion

In short, based on the definition of the Standard Test Detonator in the TB 770-2, the LX-21 formulation tested failed as an insensitive high explosive (IHE). In 2015, we are refocusing our efforts to assess our version of the Standard Test Detonator to prove it does, indeed, meet the TB 770-2 definition before we throw LX-21 out of the IHE category, and in 2015 we intend to test LX-21 against the original Du Pont #8 blasting cap that was used in the initial assessment of TATB-based explosives as IHEs.

References

[1] 2012 Joint Technical Bulletin. Department of Defense Ammunition and Explosives Hazard Classification Procedures. TB 700-2 NAVSEAINST 8020.8c. TO 11A-1-47.

[2] LLNL HE Reference Guide