UCRL-CONF-212741

LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

DEFLAGRATION-TO-DETONATION TRANSITION IN LX-04 AS A FUNCTION OF LOADING DENSITY, TEMPERATURE, AND CONFINEMENT

H. W. Sandusky, R. H. Granholm, D. G. Bohl, D. E. Hare, K. S. Vandersall, F. Garcia

June 7, 2005

JANNAF Interagency Propulsion Committee Meeting
Charleston, SC, United States
June 13, 2005 through June 17, 2005

Disclaimer

DEFLAGRATION-TO-DETONATION TRANSITION IN LX-04 AS A FUNCTION OF LOADING DENSITY, TEMPERATURE, AND CONFINEMENT

H. W. Sandusky, R. H. Granholm, and D. G. Bohl
NAVSEA Indian Head Division
Indian Head, MD 20640-5035
and
D. E. Hare, K. S. Vandersall, and F. Garcia
Lawrence Livermore National Laboratory
Livermore, CA 94550

ABSTRACT

The potential for deflagration-to-detonation transition (DDT) in LX-04 (85/15 HMX/Viton) is being evaluated as a function of loading density, temperature, and confinement. In the high confinement arrangement, a matrix of tests will be performed with the LX-04 loaded at ~50, 70, 90, and ~99 %TMD; and temperatures of ambient, 160 ^{o}C, and 190 ^{o}C at each loading density. A more limited set of tests at medium confinement will be conducted. As expected, LX-04 does not undergo DDT at near TMD loadings in both medium and high confinement, although the later still results in significant fragmentation. In high confinement at pour density (50.3 %TMD), LX-04 does not transit to detonation at 160 ^{o}C, but does at ambient and 190 ^{o}C with the shortest run distance to detonation (l) at ambient temperature. With a 70 %TMD loading at ambient temperature, l was even less. The limited ambient temperature measurements for l in high confinement are similar to previous data for 91/9 HMX/wax, which has nearly the same %volume of HMX as LX-04.

INTRODUCTION

The objective is to determine if a violent event could occur from accidents in which LX-04 is both damaged and subjected to fire. Violence is based on fragmentation of the confining apparatus, the extreme being from sample detonation. The potential for detonation is the run distance from the ignitor to detonation (l), with short l having the highest potential. Since the LX-04 may be damaged, the loading densities vary from a loose bed of molding powder, which is ~51% of theoretical maximum density (TMD), to intermediate loadings at 70 and 90 %TMD, to highly pressed samples at ~99 %TMD. The test matrix includes temperatures of ambient, 160 ^{o}C (just below the HMX phase transition), and 190 ^{o}C (just above the HMX phase transition). All combinations of density and temperature will be tested in high confinement, which is greater than could ever exist in an accident, to determine any potential for DDT. Some tests will be conducted at a more realistic, medium confinement.

TEST ARRANGEMENTS

The high-confinement apparatus shown in Figure 1 is mostly that used by Bernecker et al.[1] in which the confinement tube, end plates, and threaded rods were all of mild steel. The ignitor end of the tube is sealed with a Viton O-ring in the end plate, whereas the other end of the tube is not sealed and would permit venting during heating. End confinement was somewhat increased with rods of a higher strength Grade B7 alloy steel having fine instead of coarse threads, thereby increasing their cross-sectional area. For withstanding the high temperatures in some of the present tests, the ignitor header was changed from a thermoplastic to Teflon and the insulation on the ignitor leads was changed from varnish to Teflon. When installing the ignitor, the leads were twisted together and bonded into a hole through the end plate with an epoxy having integrity at 190 ^{o}C. The Micro-Measurements M-Bond AE-15 epoxy was the also used to bond strain gages (SGs) and thermocouples to the apparatus. Even though the circumferential strain in a thick-wall tube at failure may be only several percent, high elongation SGs of annealed

Approved for public release; distribution is unlimited.

This work was performed under the auspices of the U.S. Department of Energy by the University of California, Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

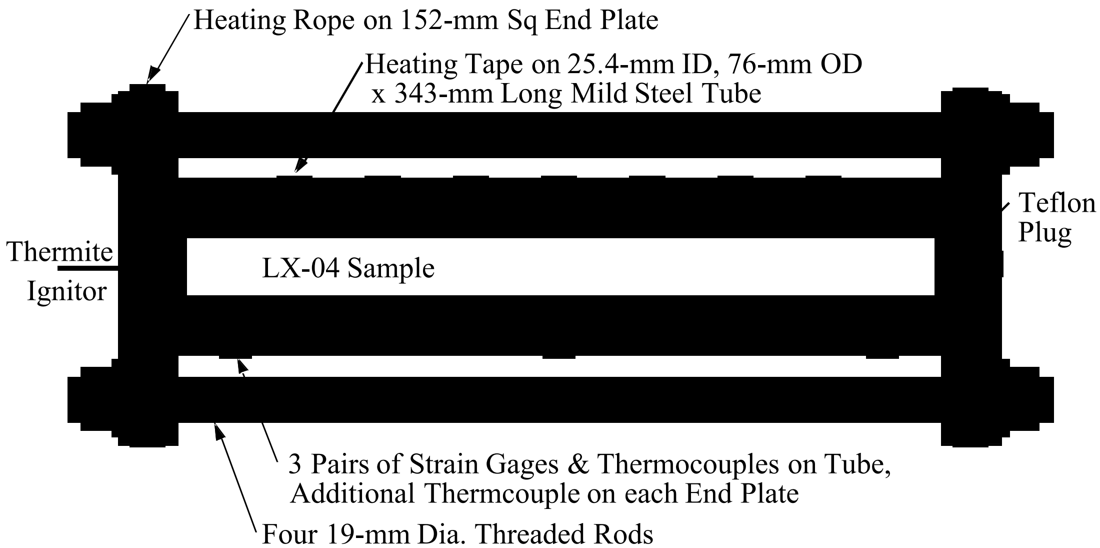

Figure 1. High-Confinement Apparatus

constantan were selected so that the same ones could be used on the medium-confinement apparatus. An interesting deviation from the previous arrangement is the use of a 0.65 g thermite ignitor, which only generates heat instead of the hot particles and gas from the usual ¾ g B/KNO_3 ignitor, so that onset of LX-04 reaction is more like that in thermal explosion. Each end plate and the tube had separate heating elements with the power to them individually controlled, but all were cycled on and off at the same time. With this heating arrangement and the wrapping of the entire apparatus in R13 insulation, the temperature over it varied less than 2 ^{o}C. Photographs of an apparatus with the heating elements installed before and after insulation are shown in Figure 2.

Different loading techniques were required for varying the LX-04 density. Loose beds were loaded by pouring the molding powder into the tube. Because of the high binder content in LX-04, it relaxes so much at an intermediate density that pressing a pellet in a die/ram set, extracting the pellet, and then inserting it into the confinement tube of the apparatus is impractical. The 70 %TMD beds were loaded in 19-mm high increments by remotely pressing directly into the tube, which was shortened to 314.3 mm to accommodate the pressing hardware. At this loading density, the increments were actually pressed to an ~17-mm height but relaxed to 19 mm within the several minutes before the next increment could be loaded. Both ends of the tube had a 9.5-mm deep cavity, one for the ignitor and the other for a plug to prevent relaxation of the LX-04 from the end of the tube during assembly of the apparatus. As soon as the loading was completed, both cavities were filled with Teflon plugs, and the tube was temporarily clamped between end plates until final assembly with an ignitor. A Teflon plug was on the downstream end of the LX-04 loading in all high confinement tests for consistency. The relaxation is less at 90 %TMD, but the tubes will probably still be press loaded incrementally. The advantage of pressing increments versus inserting pellets is the reduced potential for preferential gas flow along the inner wall; however, the mild steel tubes are not strong enough for pressing increments at full density, ~99 %TMD. These tubes were sized so that light pressure was required to insert 25.4-mm high pellets machined at PANTEX from isostatically pressed LX-04. About 60 mg of vacuum grease was on the downstream end of each pellet, which was pressed down with a ram by hand to force some of the grease to the inner tube wall to inhibit gas flow along it. As pressure in the ignitor region begins to increase during a test, more grease will be forced to the wall until pressures are high enough to deform the pellets against the wall.

The medium-confinement apparatus shown in Figure 3 is an adaptation of the design for the STEX test[2] at the Lawrence Livermore National Laboratory in which the tube is brazed to flanges and each end is closed by a cap with a copper ring for sealing. The tube with its flanges and the end caps are 4340 steel hardened to Rc 32, and each end cap is secured to the flange with eight 9.5-mm diameter high-strength

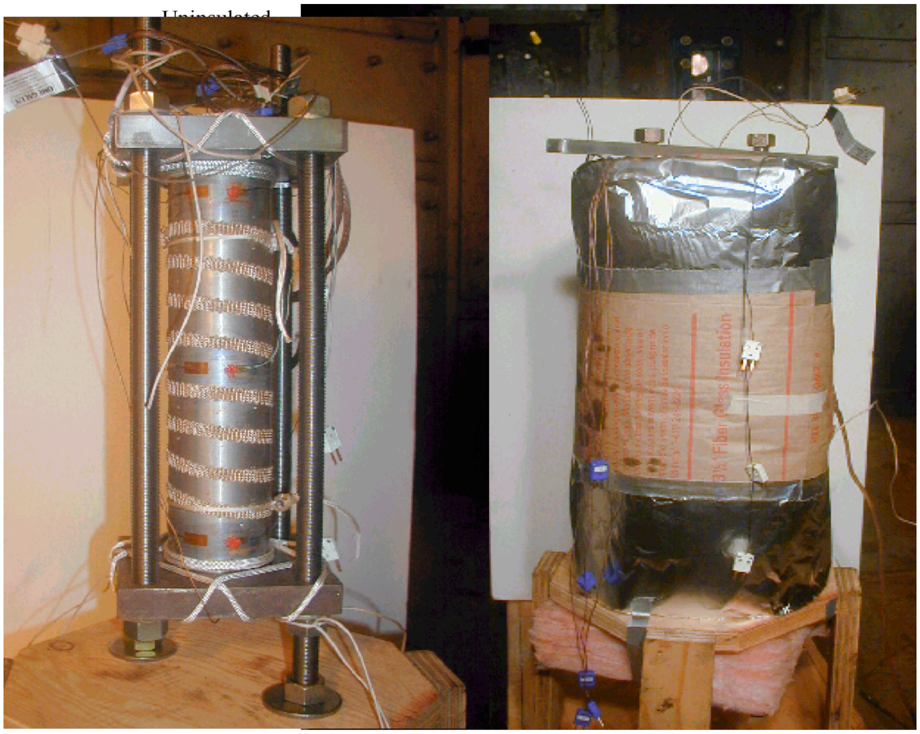

Figure 2. An Assembled High-Confinement Apparatus for a Heated Test Before and After Insulation

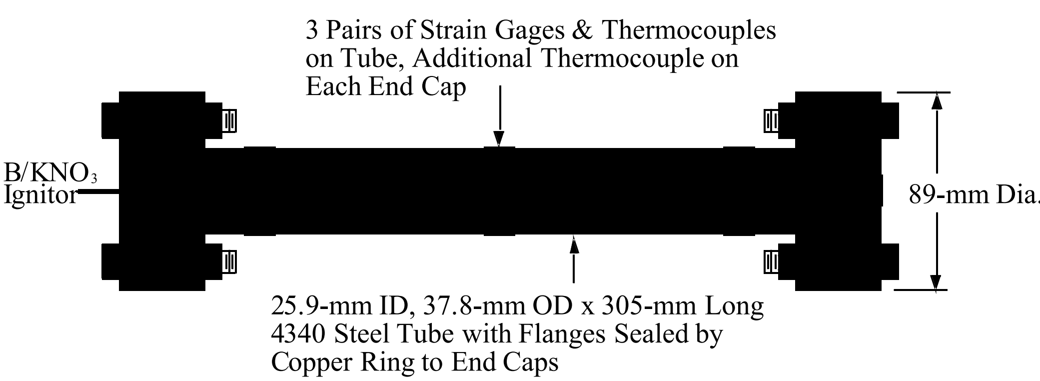

Figure 3. Medium-Confinement Apparatus

bolts. The tube has a 6.0-mm thick wall versus the 25.1-mm thick wall in high confinement arrangement. The thinner wall of hardened steel provides adequate strength for the slow pressure buildup during the early stages of DDT, but has less inertial confinement than the thicker wall in the high confinement apparatus during the rapid pressure buildup in the final stages of DDT. The only two tests conducted to date with this arrangement were at LLNL, one at ambient temperature and the other at 186 ^{o}C, which was obtained with the apparatus in a convection oven. These tests had ~0.45 g of B/KNO$_3$ in the ignitor and were loaded with 25.3-mm diameter LX-04 pellets that had been hydraulically pressed to ~99 %TMD. Because of the 0.3-mm annulus between the pellets and the inner tube wall, a measured amount of an RTV potting compound was added before inserting each pellet. Some pressure was applied to the pellet to force the RTV into the annulus around it. A 23.5-mm long section beyond the ignitor was not loaded with LX-04 for the heated test, corresponding to 8% ullage for accommodating the HMX expansion during its phase change. Only the heated test had a single SG mounted at 41.3 mm from the ignitor interface.

TEST RESULTS

Summaries of the completed tests are listed in Table I. As expected, DDT did not occur with LX-04 at near TMD and ambient temperature for either confinement. The initially near-TMD pellets in the heated medium-confinement test would have had a reduced density of 91 %TMD at 186 ^{o}C if the ullage was completely filled by the phase change in HMX. This did not increase the potential for DDT as indicated by the bulged tube. The high-confinement tests at pour density were dependent on temperature, with DDT at ambient temperature and 190 ^{o}C, but not when heated to 160 ^{o}C. At 190 ^{o}C, l was somewhat longer than at ambient temperature. The only test to date at 70 %TMD was at ambient temperature and had the shortest l of any test.

Table I. Summary of Tests

Confinement	LX-04 Density (%TMD)	Reaction Violence versus Temperature		
		Ambient	160 ^{o}C	190 ^{o}C
High	51.3_{avg}	l = 194 mm	Bulged tube	l = 267 mm
	70	l = ~114 mm		
	90			
	98.6	~20 tube fragments		
Medium	98.6	3 tube fragments		Bulged tube

l = run distance to detonation from the ignitor

Recovered apparatus from the medium-confinement tests had the ends still closed with splits in the tube. The end closures were not nearly as strong as the tube in the high-confinement apparatus, and the downstream end plate was always punched through, even in tests without DDT. In the test at pour density and 160 ^{o}C, the downstream end of that tube had bulged, consistent with the damage to its end plate. This localized tube deformation was from rapid pressurization that may have achieved DDT in a longer tube. In the test at near TMD and ambient temperature, the tube was somewhat uniformly fragmented into ~20 pieces and both end plates were punched. When DDT occurred in the other high-confinement tests, both end plates were punched and the tube was extensively fragmented. The onset of detonation is evidenced by a distinct boundary with micro-cracking and blackening on the inner wall of the tube. Those characteristics persist beyond the onset of detonation, where the tube is broken into <10 long fragments. The ignitor end of the tube was intact in the two pour density tests with DDT and broken into large pieces for the test at 70 %TMD. Between the ignitor region and the onset of detonation, the tube was shattered into small pieces without the characteristic micro-cracking from detonation. This is illustrated in Figure 4 for the pour density test at 190 ^{o}C, where the ignitor end is on the left side in the photograph and only large fragments are approximately located; the many small fragments above and below the ignitor section came from the middle region of the tube.

Strain-time (ε-t) traces for tests that bulge the tube versus undergoing DDT are contrasted in Figures 5 and 6. The sensitivity of SGs for elastic tube expansion is 1.05 %ε/GPa for the medium-confinement tube versus 0.25 %ε/GPa for the high-confinement tube. Elastic expansion ends with yielding at the inner wall for the medium-confinement tube at 0.27 GPa or 0.28 %ε, versus at 0.18 GPa or 0.045 %ε for the high-confinement tube; thus the displayed traces are mostly plastic deformation at high strain rates and would require modeling to relate to interior pressure. In Figure 5 there is a relatively linear increase in tube expansion for more than 6 %ε until either the tube has split and released the gas products or a SG lead connection failed. In Figure 6, the trace of the SG nearest the ignitor increased exponentially in an order of magnitude shorter time than in the previous figure. The next SGs are beyond l and have essentially a step increase in signal with the arrival of the detonation wave, whose average velocity is 5.5 mm/μs. Peak values of ε shown in Figure 6 were limited by oscilloscope settings and were actually several percent on another oscilloscope with less resolution.

Figure 4. Recovered High-Confinement Apparatus from Test at Pour Density and 190 ^{o}C

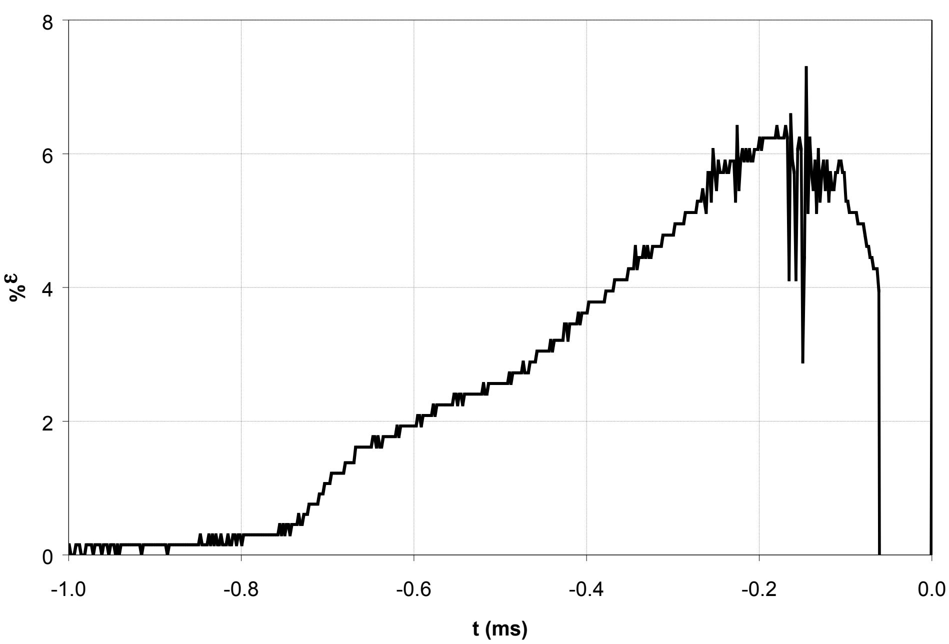

Figure 5. Expansion at 41.3 mm on Medium-Confinement Tube with ~99 %TMD LX-04 Heated to 186 ^{o}C

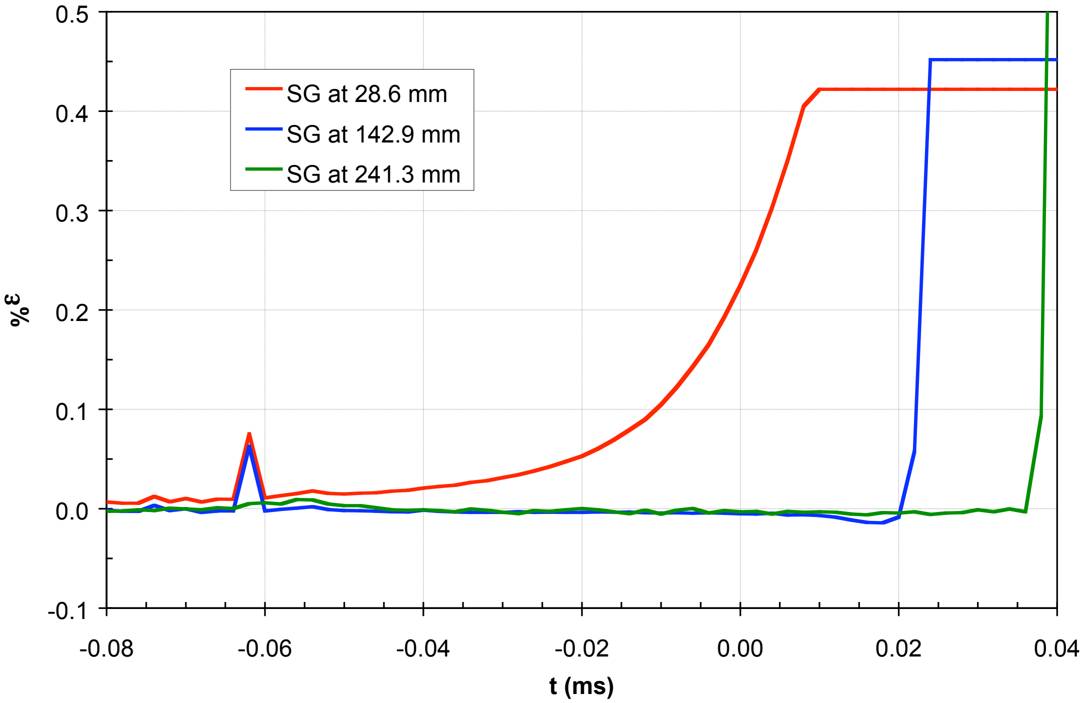

Figure 6. Expansion of High-Confinement Tube with 70 %TMD LX-04 at Ambient Temperature

DISCUSSION

The reduced density from heating near-TMD LX-04 beyond the temperature for the phase change in HMX did not result in an any inner-connected porosity, as indicated by the slow buildup in pressure occurring over ½ ms on the strain-time (ε-t) trace in Figure 5. Without a rapidly accelerating pressure buildup from deflagration to drive a strong compressive wave and then a shock wave, there was no opportunity for shock-to-detonation transition (SDT), the last step of DDT. This is in contrast with the accelerating tube expansion near the ignitor in an order of magnitude less time prior to the onset of detonation shown in Figure 6 for a 70 %TMD bed. Heating a pour density bed to 160 ^{o}C softened the Viton binder, perhaps allowing the porous bed to more easily compact and thereby inhibit deflagration. Further heating a pour density bed to 190 ^{o}C increased the potential for DDT, but l was still more than that at ambient temperature. An even shorter l was attained with a 70 %TMD bed at ambient temperature. In an extensive study[3] on 91/9 RDX/wax, minimum l did not occur until 90 %TMD.

The small fragments from the middle region of the high-confinement tests that underwent DDT may indicate retonation. The absence of the characteristic mico-cracking on the inner tube wall in this region may have been due to a gas layer between the bed and wall from the preceding compressive reaction in that region. Smaller fragments occur because the bed in that region had been compacted to near TMD, whereas the bed beyond l was still at the original loading density. Retonation is not common in DDT, but it occurred[4] for 90/10 HMX/Al at 45.4 %TMD in a plastic tube. Retonation increases the fragment hazards in an accident scenario, as illustrated in Figure 4.

A somewhat related study[5] in steel tubes with 16.3-mm inner diameter, 50.8-mm outer diameter, and strong end closures was performed on Class A and ~200 μm HMX mixed with various percentages of wax. For an 88/12 mixture, l was 273 mm for the Class A HMX and DDT failed for the ~200 μm HMX. For a 91/9 mixture, l was 143 mm for the Class A HMX and 210 mm for the ~200 μm HMX. The latter results are more characteristic of LX-04. Because wax has a 1.00 g/cc density versus 1.85 g/cc for Viton, the 85/15 HMX/Viton mix in LX-04 has 84.7% volume of HMX, nearly the same as the 84.2% volume of HMX in 91/9 HMX/wax. It appears the DDT is based more on the %volume of the energetic ingredient in the mixture than its %weight as normally reported for the formulation.

SUMMARY AND CONCLUSIONS

The tests to date have exhibited a wide range of reaction violence. In high confinement at ambient temperature, l decreased as loading density increased from 51.3 to 70 %TMD; and while DDT failed at near TMD, the reaction is still violent enough to fragment the tube into many pieces. At pour density, 51.3 %TMD, DDT failed when heated to 160 ^{o}C, just below the phase transition in HMX; but DDT occurred when heated to 190 ^{o}C, just above the phase transition in HMX, although with a somewhat longer l than at ambient temperature. Reactions in medium confinement for near TMD loadings were less violent at both ambient temperature and 186 ^{o}C. In high confinement, the ambient temperature data appear most similar to that for 91/9 HMX/wax, which has nearly the same %volume of HMX as LX-04.

REFERENCES

1. Bernecker, R. R., Sandusky, H. W. and Clairmont, A. R., Jr., “Deflagration-to-Detonation Transition (DDT) Studies of a Double-Base Propellant,” Eighth Symposium (International) on Detonation, NSWC MP 86-194, Naval Surface Warfare Center, 1986, pp. 658-668.
2. Wardell, J. and Maienschein, J., “The Scaled Thermal Explosion Experiment”, Twelfth International Detonation Symposium, Aug 2002, to be printed.
3. Bernecker, R. R. and Price, D., “Studies in the Transition from Deflagration to Detonation in Granular Explosives – II. Transitional Characteristics and Mechanisms Observed in 91/9 RDX/Wax,” Combustion and Flame, Vol 22, 1974, pp. 119-129.
4. Bernecker, R. R., Sandusky, H. W. and Clairmont, A. R., Jr., “Deflagration-to-Detonation Transition (DDT) Studies of Porous Explosive Charges in Plastic Tubes,” Seventh Symposium (International) on Detonation, NSWC MP 82-334, Naval Surface Warfare Center, 1981, pp. 119-142.
5. Price, D. and Bernecker, R. R., “Effect of Initial Particle Size on the DDT of Pressed Solid Explosives,” Propellants and Explosives, Vol. 6, 1981, pp. 5-10.