TECHNICAL REPORT ARBRL-TR-02508

MITIGATION OF IGNITION-INDUCED, TWO-PHASE FLOW DYNAMICS IN GUNS THROUGH THE USE OF STICK PROPELLANTS

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Pressure waves arising in gun chambers from ignition-induced flow dynamics can be deleterious to a weapon system, either catastrophically through the failure of the gun or projectile, or more subtly through degraded ballistic reproducibility or projectile reliability. One way to improve the flow dynamics during the ignition phase of the interior ballistic cycle, and thus to mitigate pressure-wave development, is to increase the permeability of the propellant bed to ignition and combustion gases. A method by which this can

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be accomplished is through the use of stick propellants, which produce natural flow channels when bundled into a charge.

We describe herein an investigation into the effects of stick-propellant grain geometry on the development of pressure waves in guns. Specifically, several slotted- and unslotted-stick M30A1 propellants are considered. A series of preliminary studies of these propellants is briefly described, including closed-bomb testing and computer simulations of one-dimensional charges using a two-phase flow interior ballistic model. We present a detailed description of firing tests at ambient, reduced, and elevated temperatures using these propellants in full-bore, base-ignited, 155-mm bagged charges, specifically designed to promote the formation of pressure waves. By comparison with a previous study, the results indicate improved performance, as evidenced by decreased pressure-wave levels, in progressing from granular to stick propellants. It is also shown, for the lots tested, that the temperature coefficient of pressure, $\Delta P/\Delta T$, is dependent on the geometry, such that the ambient-to-hot coefficient for the slotted-stick propellant is twice that for the unslotted-stick propellant.

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I. INTRODUCTION

Over the past several years, we have gained an increased appreciation of the importance of many nonclassical charge-design parameters in the ignition and flamespread portion of the interior ballistic process. Unfortunately, we have also learned, through a string of gun ammunition malfunctions, that events taking place during this critical time may have a profound impact on the overall interior ballistic performance, sometimes to the point of catastrophic overpressures in the gun. Such areas identified for particular attention include the details of the igniter functioning, propellant-bed permeability, distribution of ullage in the chamber, and packaging components, both inert and energetic. Properly understood and used, each of these areas can be exploited in the design of safe and reliable charges and many studies have been completed or are in progress to accomplish this. The investigation reported herein addressed one particular, critical design area, namely, the propellant-bed permeability, and the extent to which it might be improved through the use of stick propellants.

We have previously discussed[1] the detailed phenomenology of granular propelling charges, an example of which is shown schematically in Figure 1. On that occasion, we drew particular attention to the details of primer impingement on the base of the charge, system dependence of igniter output, convective heating of the grains leading to flamespread, the drag presented to the combustion gases due to the packed propellant bed, excitation of axial pressure waves, movement of the solid phase, and the accompanying potential for fracture of the propellant. Here we wish to address many of those same phenomena, with particular reference to stick propelling charges, an example of which is illustrated schematically in Figure 2. Ideally, we would expect the early part of the cycle to proceed as follows: The primer output strikes a basepad igniter and as the basepad burns, its output impinges upon the base end of the propellant sticks. The igniter gases convectively heat the stick propellant ends to ignition, and then flamespread proceeds easily down the length of the charge, with the motion of hot gases essentially unimpeded by the propellant bed, due to the flow channels offered by the bundled stick propellant. This lack of flow resistance greatly reduces the drag on the solid phase, and hence its movement. The open channels also present a mechanism for equilibration of pressure over the length of the chamber, again reducing the potential for propellant motion and leading to a much-diminished potential of axial pressure waves.

This simplified analysis neglects several of the details that may greatly impact the overall interior ballistic process. For example, it is not known at what point the flame penetrates the perforation. Indeed, the concept of flamespread in a stick propelling charge may not be well-defined. Due to the permeability resulting from the stick geometry, the entire chamber may be bathed by igniter and early combustion gases so that ignition occurs at all points along the length of the charge almost simultaneously. In addition, the propellant sticks may be fractured through a number of mechanisms. The ends

[1] A.W. Horst and T.C. Minor, "Ignition-Induced Flow Dynamics in Bagged-Charge Artillery," ARBRL-TR-02257, Ballistic Research Laboratory, USA ARRADCOM, August 1980 (AD A090681).

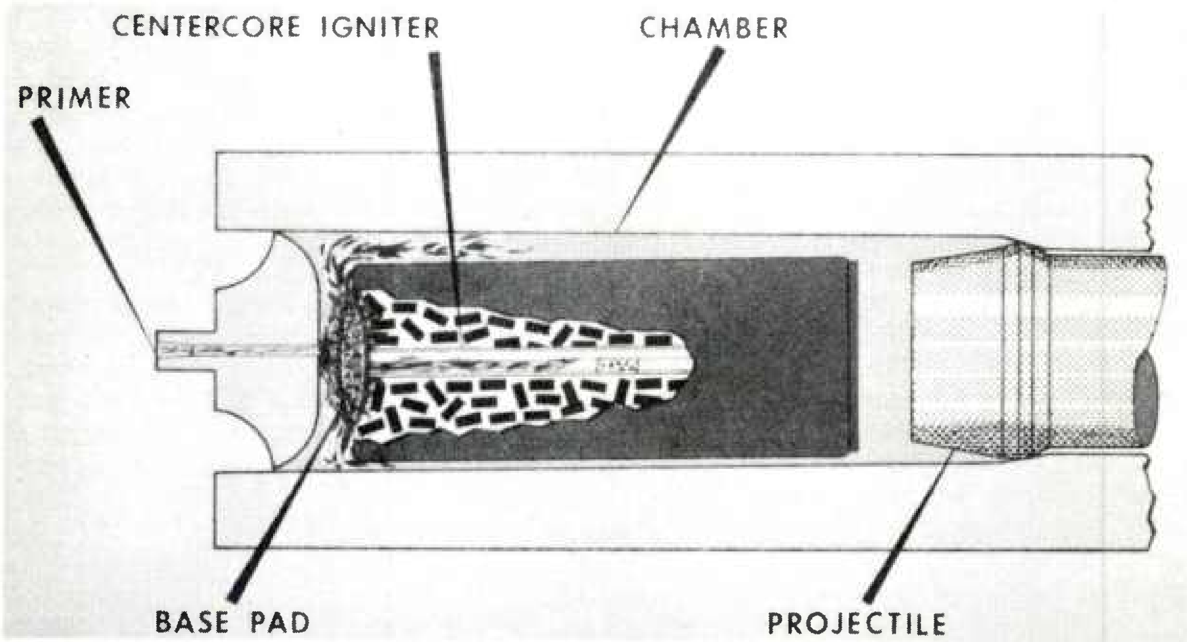

Figure 1. Granular Artillery Propelling Charge

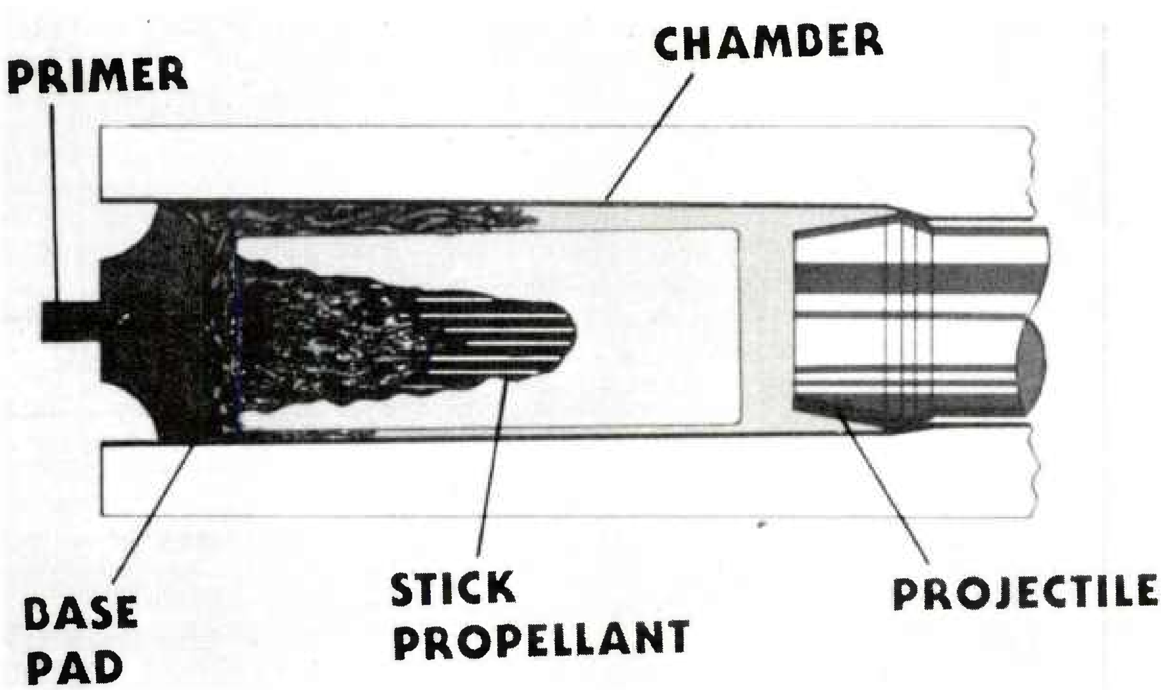

Figure 2. Stick Artillery Propelling Charge

at the charge base may be fractured by the output of a brisant igniter, and the forward end may be fractured by impact of the charge on the projectile base, should the charge move. The grains may also fail due to the internal pressurization of the perforation. In all of these instances, unprogrammed burning surfaces are created, which could lead to locally high pressurization. In addition, the stick grain fragments might obstruct the channels between the sticks, placing the charge in a hydrodynamic configuration similar to a granular charge, with the attendant potential for exacerbation of pressure waves.

A previous study at the Ballistic Research Laboratory[2] investigated the effect of the propellant granulation on ignition and flamespread, as evidenced by the formation of axial pressure waves. Charges employing 7-, 19- and 37-perforation M30A1 propellants, designed to yield performance equal to that of the 155-mm, M203 Propelling Charge, were fired in a full-bore, base-ignited configuration specifically selected to promote the formation of pressure waves. That study demonstrated the importance of grain size to bed permeability, and hence to the evolution of pressure waves, with the larger 37-perforation grains yielding better performance than the 19-perforation grains, which were in turn better than the 7-perforation grains. In addition, it was shown that stacking or even partially stacking the granular propellants increased the bed permeability, effecting a slight decrease in pressure waves. As a logical follow-on to that investigation, this study examined the degree to which stick propellants, with an even more favorable geometry, would mitigate the formation of pressure waves when fired under the same circumstances.

A secondary objective of this study addressed the question of propelling-charge temperature coefficients. It was found[3] that 155-mm, M203 Propelling Charges made with 7-perforation M30A1 Propellants manufactured by Radford Army Ammunition Plant prior to 1977 exhibited temperature coefficients of pressure ($\Delta P/\Delta T$, the ratio of the increase in maximum chamber pressure to the increase in the temperature of the charge at the time of firing) on the order of 0.8 MPa/^{o}C. However, for reasons that are not yet clear, propellants produced by Radford in 1979 had temperature coefficients that were as high as 1.8 MPa/^{o}C. This unexplained increase in the temperature coefficient can have obviously detrimental consequences on system performance at elevated temperatures for charges that are assessed for a specific ambient performance. Since this study had occasion to examine stick propellants produced during both time periods, it seemed an excellent opportunity to determine whether they followed the same production-period dependency of the temperature coefficients as did the granular propellants.

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[2] A.W. Horst, J.R. Kelso, J.J. Rocchio, and A.A. Koszoru, "The Influence of Propellant Grain Geometry on Ignition-Induced, Two-Phase Flow Dynamics in Guns," ARBRL-MR-02989, Ballistic Research Laboratory, USA ARRADCOM, February 1980 (AD A083289).

[3] A.W. Horst, J.R. Kelso, and K.J. White, "Propelling-Charge Temperature Coefficients: Sources of Disparity," Proceedings of 17th JANNAF Combustion Meeting, CPIA Publication 329, Vol. II, pp. 69-86, November 1980.

II. PRELIMINARY STUDIES

A. Propellant Grain Design

Using an updated version of a standard lumped-parameter interior ballistic model,[4] slotted and unslotted, M30A1 stick-propellant grains were designed to yield 155-mm, Zone-8 performance; specifically, the goals were a peak chamber pressure of 328 MPa and a velocity of 826 m/s. The sticks were designed to be 737 mm long, with equal perforation diameter and web. Orders for three propellant lots were placed with Radford Army Ammunition Plant: two slotted-stick lots with webs smaller and larger than the calculated value, and one unslotted-stick lot with the calculated web. Upon production by Radford, the three lots of propellants had webs on the order of six percent larger than those specified. The slotted-stick lots were RAD-PE-480-53 and RAD-PE-480-54, and had the smaller and larger web, respectively. Lot RAD-PE-480-55 was the unslotted lot. In addition to these three lots, there were available two other lots of M30A1 stick propellants 686 mm long, produced for a previous study[5] to replace the 7-perforation propellant in the M203 Propelling Charge. These lots, RAD-PE-472-11 and RAD-PE-472-12, were of special interest since they were extruded from the same die, with Lot RAD-PE-472-11 slotted in the process, but not Lot RAD-PE-472-12. Samples of all five stick propellant lots are shown in Figure 3. Propellant description sheets for all five lots are included in Appendix A.

B. NOVA Simulations

The NOVA Code[6] was used to assess the relative performance in pressure-wave reduction with a stick-propellant charge in comparison with a granular-propellant charge. NOVA consists of a two-phase flow treatment of the interior-ballistic cycle, formulated on the assumption of quasi-one-dimensional flow, i. e., one-dimensional with area change. Since the charges to be examined in this study were to be fired in a full-bore, base-ignited configuration, in order to promote the formation of pressure waves, they were of an appropriate geometry for simulation by the one-dimensional NOVA Code. Input data for the simulations, including propellant burning rate and bore resistance, were independently determined.[7] Figure 4 presents a portion of some NOVA calculations derived from the study mentioned previously[2] that demonstrated the efficacy of 19- and 37-perforation geometries in reducing

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[4] P.G. Baer and J.M. Frankle, "The Simulation of Interior Ballistic Performance of Guns by Digital Computer Program," R 1183, Ballistic Research Laboratories, December 1962 (AD 299980).

[5] S. Weiner, "Investigation of Stick Propellant for 155-mm Howitzer, XM198," Interim Memorandum Report, Picatinny Arsenal, Dover, NJ, July 1975.

[6] P.S. Gough, "The NOVA Code - A User's Manual," PGA-TR-79-5, Paul Gough Associates, Portsmouth, NH, September 1979.

[7] A.W. Horst and T.R. Trafton, "NOVA Code Simulation of a 155-mm Howitzer: An Update," ARBRL-MR-02967, Ballistic Research Laboratory, USA ARRADCOM, October 1979 (AD A079893).

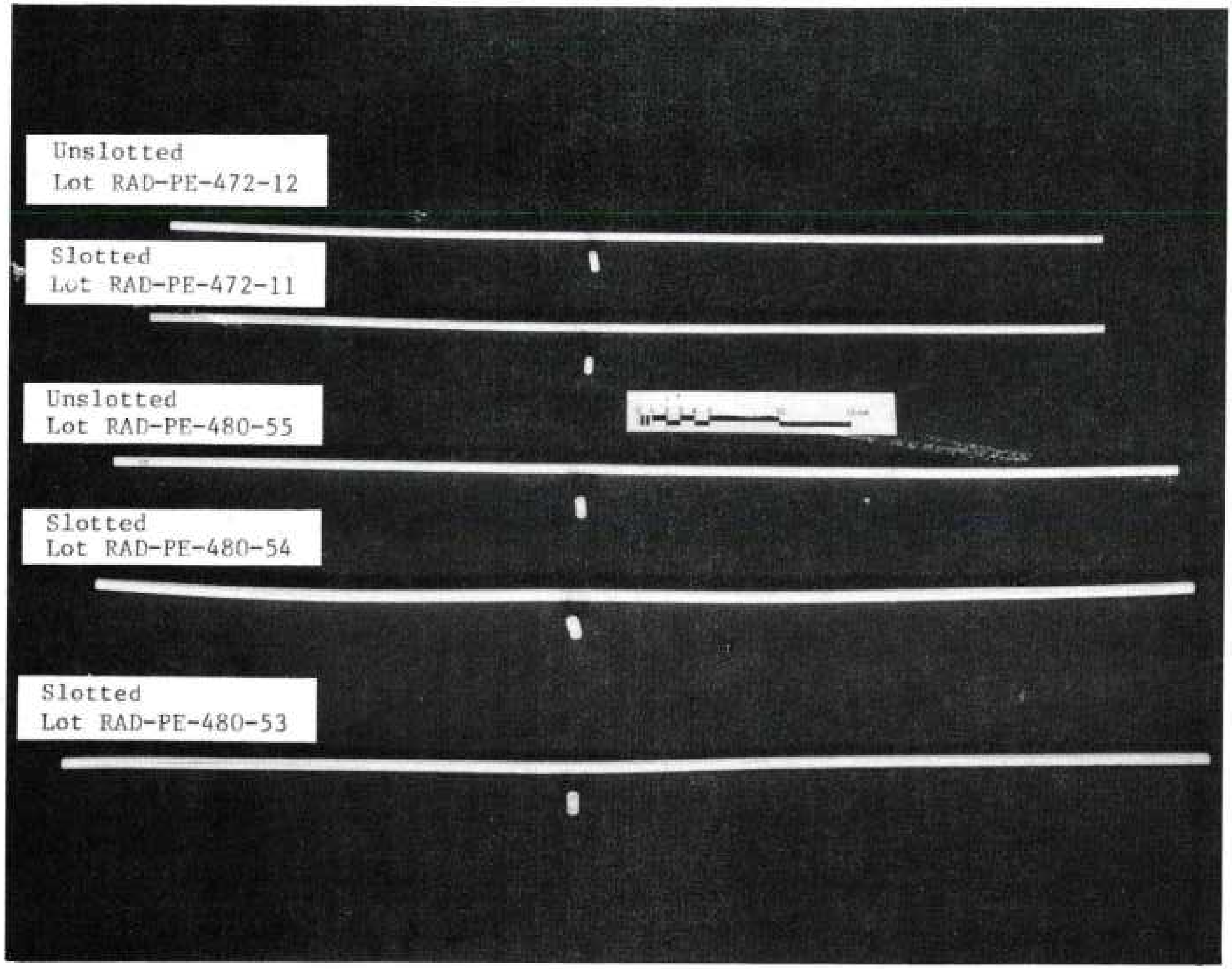

Figure 3. Sample Slotted- and Unslotted-Stick Propellants

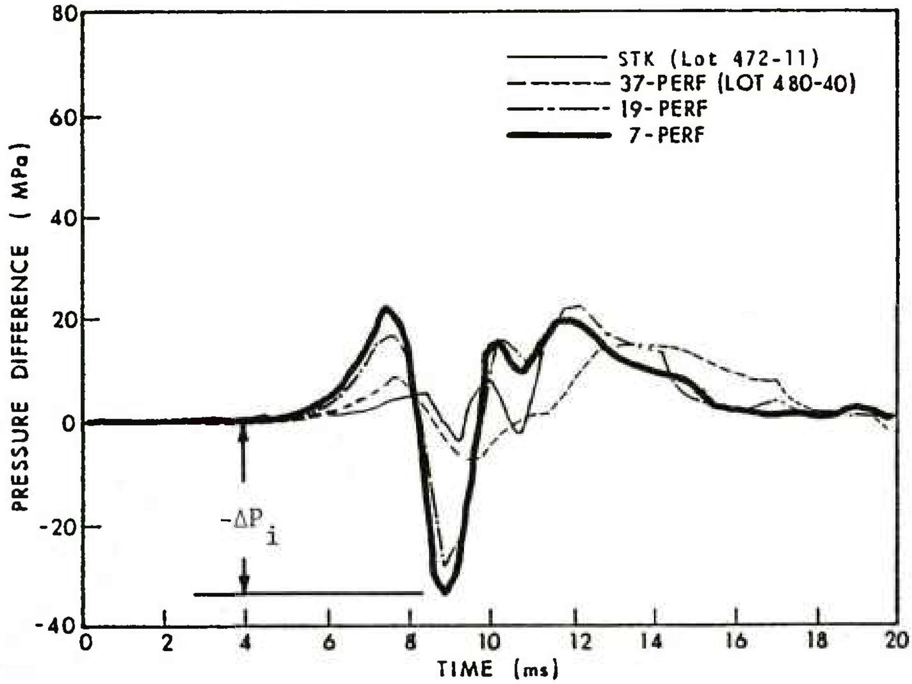

Figure 4. Comparison of NOVA Predictions for Pressure-Difference Profiles (Reference 2)

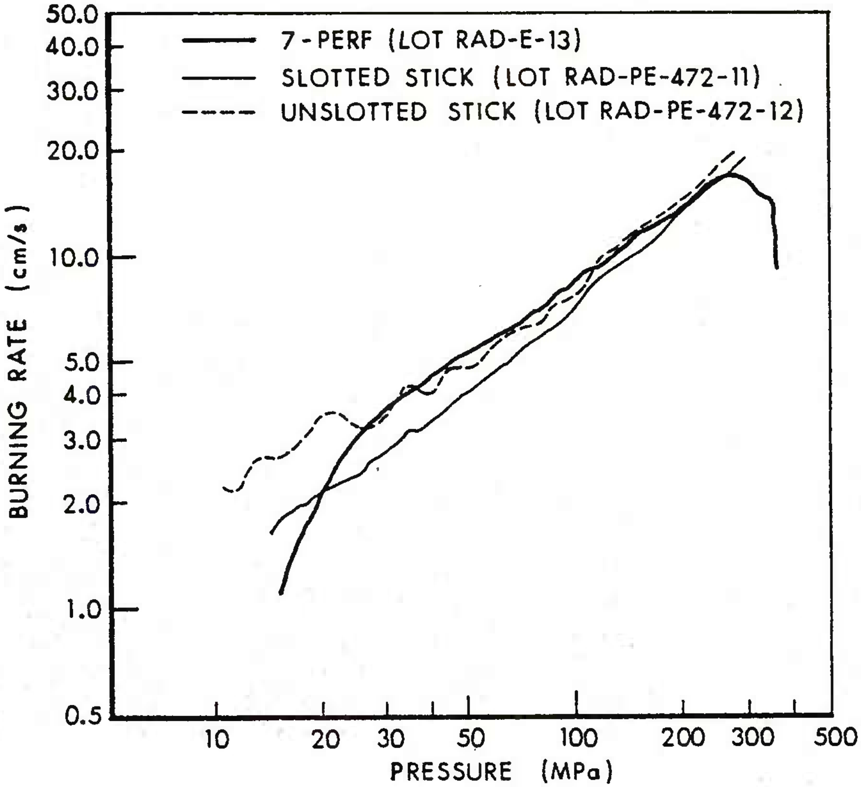

Figure 5. Closed-Bomb Burning Rates for Stick and Seven-Perforation M30A1 Propellants

pressure waves. These traces simulate the record that would be obtained if the pressure measured at the front of the chamber were subtracted from that measured at the breech. The initial reverse-pressure gradient, shown as $-\Delta P_i$, is used as a quantifier of the severity of the pressure waves. To the previous curves, we have added the NOVA prediction for one of the stick propellants used in this study. The progressive improvement in the reduction of pressure-wave levels from the smaller 7-perforation to the larger 37-perforation grain is readily apparent. Furthermore, the improvement that we would intuitively expect with the very favorable, low-drag stick configuration is borne out by the calculation.

C. Closed-Bomb Studies

Closed-bomb tests[8] were conducted for each of the five stick-propellant lots examined in this study. The results from two of the lots, one slotted and one unslotted, are shown in Figure 5. Each trace is a composite of three firings in the bomb. For comparison, the burning rate for a standard seven-perforation M30A1 propellant for the 155-mm, M203 Propelling Charge is also shown. For these burning rate determinations, the sticks were cut into 229-mm lengths in order to be accommodated by the 700-cm^3 bomb. A 2-g FFFG igniter was employed for each shot. For all of the lots, the unslotted-stick propellants displayed a higher apparent burning rate than did the slotted-stick propellants, particularly below approximately 70-100 MPa. These results had little bearing on the charge assessment, however, since most of the burning rate data became available only after the completion of the howitzer firing program.

III. 155-mm HOWITZER FIRINGS

A. Fabrication of Charges

The full-bore, stick charges were fabricated using components from 155-mm, M203E1 Propelling Charges. The bag, from which the lead and wear-reducing liners had been removed, was modified by inserting a tapered wedge of cloth into its circumference to form a sleeve with a base of 170-mm diameter at the spindle end and a 160-mm diameter opening at the other end. The "kidney," or central cloth sleeve which holds the centercore-igniter assembly, was also removed. Stick propellant packs so densely that the mass required for Zone-8 ballistics when simply bundled together would have produced a package that was considerably subcaliber. In order to obtain a fair test of the effect of this stick-propellant geometry on flow dynamics for comparison to the earlier granular-propellant studies,[2] it was necessary to load the stick propellant to approximately the same initial porosity as the granular; i. e., some way was required to spread the sticks radially so that the charge was full-bore. This was accomplished by making a linear train of sticks laid side by side, taping them into a "venetian-blind" configuration, and rolling the propellant into a bundle with thin strips of cardboard interleaved in the spiral so that the final full-bore dimensions resulted. This roll of propellant sticks was placed inside the modified bag and the end cap was affixed and sewn closed.

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[8] J.O. Doali, R.E. Bowman, and A.A. Juhasz, Ballistic Research Laboratory, USA ARRADCOM, unpublished data, August 1979, January 1980.

Basepads were prepared by altering the standard 8-inch M2 basepads. A circular pouch, 38 mm in diameter, was sewn in the center. Fourteen grams of Class-5 Black Powder were inserted into this pouch and the balance of the basepad was filled with 56 g of Clean Burning Igniter (CBI). The finished basepads were tied to the larger end of the loaded charges and the whole assembly tightly laced and adjusted to final full-bore dimensions with a lacing jacket. Flash-reducer bags were not added to the charges. Figure 6 schematically depicts the charges as fired in this study.

B. Test Procedures

All firings were conducted at the Ballistic Research Laboratory in a 155-mm, M185 Cannon, modified to provide a chamber configuration similar to that of the M199 Cannon. As shown in Figure 7, multiple-station pressure-time data and differential pressures were measured using Kistler 607C3 piezoelectric transducers. These gages were calibrated before, during, and after the testing. Solenoid coils placed approximately 20 m and 35 m from the muzzle were used to determine projectile velocities. Ignition delays were recorded by measuring the interval between the time the firing voltage was applied to the gun and the time at which the signal recorded by the spindle-pressure gage began to rise.

All charges were conditioned in plastic bags at the desired temperatures for at least 24 hours prior to firing. With the exception of one round, no more than three minutes elapsed between the time at which the charge was removed from the conditioning box and the shot. For all but the last series (shortened-stick charges), the charges were loaded into the cannon chamber with zero standoff distance between the spindle face and the base of the charge to increase the likelihood of strong base ignition and large pressure waves. Hardware availability necessitated the change to a 25-mm standoff for the firings of the shorter, lower-local-porosity charges. In initial probe firings, charge weights were assessed such that the maximum spindle pressures were nearly equivalent to that of the 155-mm, M203 Propelling Charge at ambient conditions, or about 330 MPa. These assessed weights were employed throughout the balance of the program. Inert M101 Projectiles were used for the duration of the study.

C. Firing Results

We now present data obtained in the 155-mm, full-bore firings of each of the lots of stick propellants. In each of the tabular compilations that follow, the results shown are averages of three to five shots, with sample standard deviations shown in parentheses. Complete round-by-round data are given in Appendix B for all of the stick-propellant shots as well as for 155-mm, M203 control rounds. Pressure-time and differential-pressure plots from each shot are included in Appendix C.

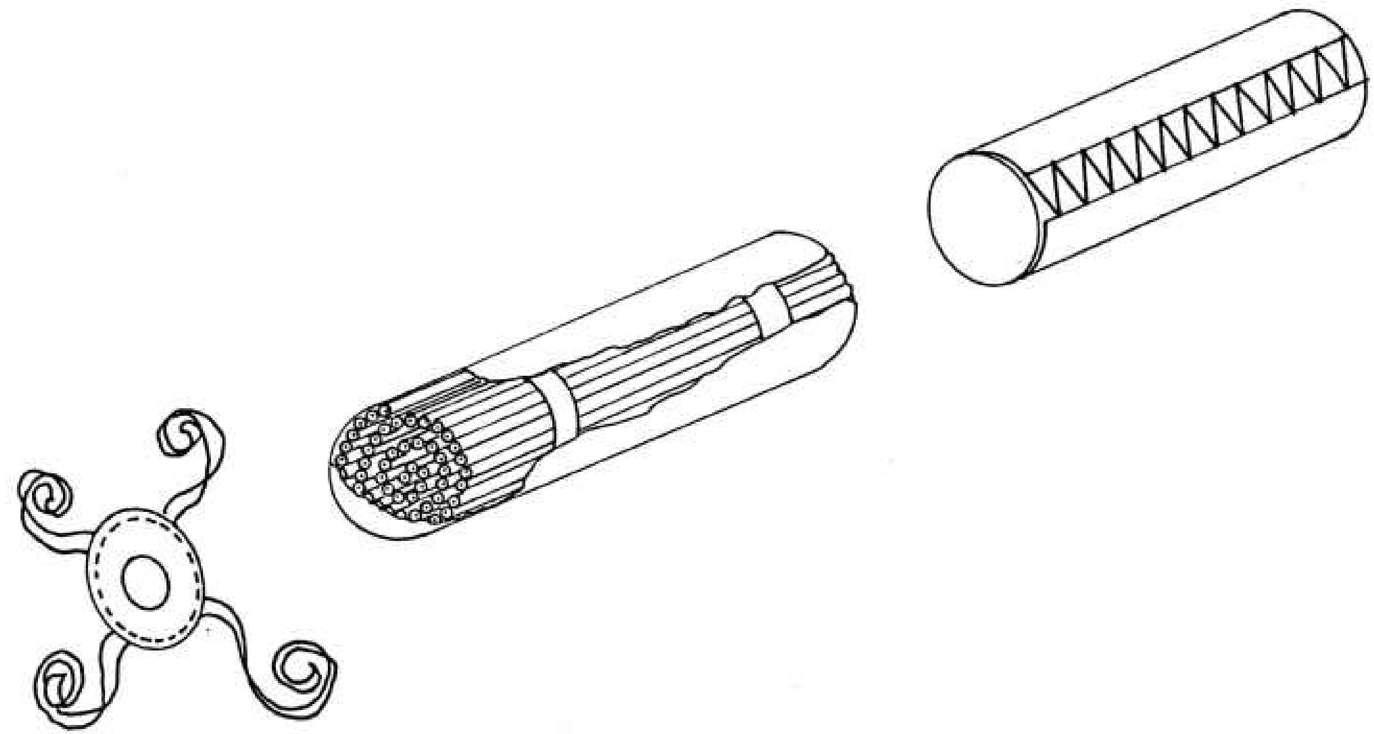

Figure 6. Exploded View of Test Charge

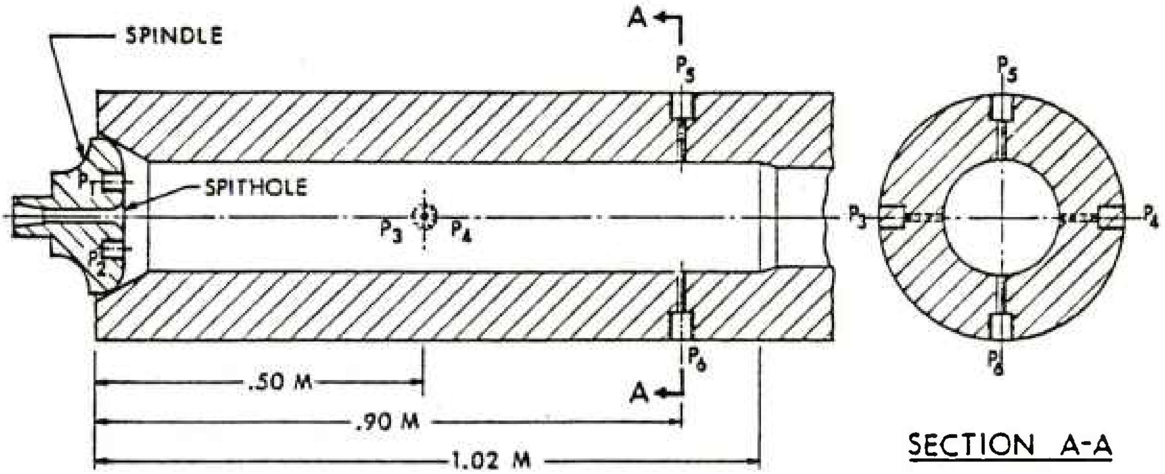

Figure 7. Locations of Pressure Taps in Modified M185 Cannon

We first direct our attention to the ambient, baseline firings for each of the stick-propellant lots. In Table 1, we note the very low level of pressure waves for all of the lots, although Lot RAD-PE-480-55, an unslotted propellant, had a pressure-wave level that was higher than the others. For comparison, we recall that the smallest average initial reverse-pressure gradient attained with the same configuration in the previous granular-propellant study[2] was on the order of 35 MPa, and that was achieved with 37-perforation propellant. Similar firings with standard 7-perforation propellant yielded an average level of nearly 90 MPa. It is clear, then, and in accord with our intuition, that the improved permeability of the stick propellant bed to passage of igniter and propellant gases significantly affects the flow dynamics of the early portion of the interior ballistic cycle and thus greatly reduces the attendant level of pressure waves. With the exception of the muzzle velocity, discussed below, there is no apparent dependence of any of the variables measured on the geometry, slotted or unslotted.

Some further observations are in order regarding these stick-propellant results. Firstly, the variability in the ignition delays are rather high. Presumably, this is due to the great amount of interstitial ullage within the charge, allowing igniter gases to bleed through the charge, resulting in reduced pressurization at the base of the charge and lengthening the time before the rear of the charge is ignited.

TABLE 1. FIRING DATA FOR FULL-LENGTH STICK PROPELLANTS AT AMBIENT TEMPERATURE

Propellant Lot	Charge Wt (kg)	Temp (^{o}C)	Muzzle Velocity (m/s)	P_{max} (MPa)	$-\Delta P_i$ (MPa)	Ignition Delay (ms)
Slotted 472-11	11.11	21	822 (6.2)	329 (5.0)	1.7 (1.5)	90 (24.1)
Unslotted 472-12	10.34	21	797 (5.8)	336 (5.7)	1.8 (1.2)	57 (28.2)
Slotted 480-53	11.93	21	840 (2.1)	326 (2.9)	1.7 (0.9)	111 (11.2)
Slotted 480-54	12.67	21	842 (2.9)	328 (3.3)	1.3 (0.9)	59 (12.4)
Unslotted 480-55	10.79	21	810 (5.4)	325 (7.1)	4.5 (2.3)	60 (15.1)

More importantly, however, it is apparent that we do not fully understand the behavior of the long stick propellant grain during burning. This is seen by comparison of these results with those of nominal 155-mm, M203 performance (11.8 kg, 826 m/s, 330 MPa). The results from Lot RAD-PE-472-11, which was made to be a direct replacement for the 7-perforation, granular propellant of the M203, indicate essentially equivalent ballistics at a lower charge weight, this in spite of the degressivity of the stick geometry as compared to the 7-perforation geometry. The net effect of the stick combustion is to mimic progressivity through enhanced burning in the long perforation, possibly through one or both of two mechanisms. An increased burning rate may result from erosive burning in the perforation as gases move from the perforation to the exterior of the stick through the end or slot of the stick. In addition, the combustion within the perforation, and the inability of the gases to escape as quickly as they are liberated, may lead to an internal pressure that is in excess of that outside the grain, promoting a greater gas-mass generation rate. We also note that Lot RAD-PE-472-12, the unslotted-stick propellant made from the same die as the slotted RAD-PE-472-11, yielded a significantly lower charge weight and velocity at an equivalent pressure, indicating perhaps that pressurization in the perforation, with no relief through the slot, ruptured the grains relatively early in the cycle, creating unprogrammed burning surface and destroying the subsequent benefits of enhanced burning.

Finally, in Appendix B we note that the gradient of the peak pressures between the rear and midchamber locations is significantly smaller than that between the midchamber and forward locations, especially in comparison with the granular, M203 control firings. Possibly, this can be interpreted as a result of the stick charge remaining at the rear of the chamber, a scenario consistent with the relatively smaller drag exerted on the propellant sticks by the igniter and combustion gases.

Table 2 provides the firing results for the full-length stick propellants packaged in the full-bore configuration at the high-temperature extreme. We note that even though the results at ambient conditions yielded very low values for $-\Delta P_i$, the $-\Delta P_i$'s at these elevated temperatures are equivalent or even smaller in all cases. Indeed, no negative excursions of the pressure-difference traces were found with two of the lots at these temperatures. The peak chamber pressures increased in comparison to those obtained at ambient temperature, but not uniformly for all the lots, with the slotted-stick propellants showing a larger increase than the unslotted-stick propellants. This phenomenon will be discussed more fully below. Not surprisingly, the ignition delays at these higher temperatures were considerably shorter than those at ambient conditions, and the variability in the ignition delay shortened somewhat. The elevated temperatures resulted in an increased rate of evolution of igniter and combustion gases sufficient to overcome the effects of the large interstitial volume alluded to previously.

In Appendix B, we again note the relative magnitudes of the gradients of the peak pressures between the rear and midchamber locations and between the midchamber and forward locations. As with the ambient tests, this phenomenon is probably an indication that the stick charges remained near the rear of the chamber in the early portion of the interior ballistic cycle.

TABLE 2. FIRING DATA FOR FULL-LENGTH STICK PROPELLANTS AT ELEVATED TEMPERATURES

Propellant Lot	Charge Wt (kg)	Temp (°C)	Muzzle Velocity (m/s)	P_{max} (MPa)	$-\Delta P_i$ (MPa)	Ignition Delay (ms)
Slotted 472-11	11.11	62	858 (6.1)	406 (9.1)	1.9 (0.9)	35 (7.6)
Unslotted 472-12	10.34	62	825 -	372 (1.9)	2.1 (1.4)	35 (8.0)
Slotted 480-53	11.93	63	882 (2.4)	404 (4.3)	0.0 (0.0)	30 (2.4)
Slotted 480-54	12.67	63	899 (1.0)	414 (3.1)	0.0 (0.0)	37 (8.5)
Unslotted 480-55	10.79	63	832 (3.2)	350 (6.1)	1.2 (0.9)	30 (5.0)

Table 3 presents the results from the low-temperature firings. Here again, the $-\Delta P_i$'s are very low, with the exception of that recorded by Lot RAD-PE-472-12. In comparison with the ambient results, the pressures were reduced uniformly for all of the lots. Again, with the exception of the one lot, an examination of the peak pressures, the initial reverse-pressure gradients, and the sample standard deviations of the peak pressures indicates that there was no gross propellant fracture. Note, however, that there are some modes of propellant fracture that might not increase the surface area significantly, and thus would not be apparent in these data. One of the most noticeable results from these cold-temperature firings is the very long ignition delays and their great variability. The low burning rate of the M30A1 propellant at this reduced temperature, coupled with the low pressure due to access of the igniter and early combustion gases to the large interstitial volume, delayed charge ignition almost to the point of hangfires for some of the lots.

TABLE 3. FIRING DATA FOR FULL-LENGTH STICK PROPELLANTS AT REDUCED TEMPERATURES

Propellant Lot	Charge Wt (kg)	Temp (°C)	Muzzle Velocity (m/s)	P_{max} (MPa)	$-\Delta P_i$ (MPa)	Ignition Delay (ms)
Slotted 472-11	11.11	-53	768 (4.5)	265 (6.2)	3.0 (0.6)	171 (53.2)
Unslotted 472-12	10.34	-53	755 (3.7)	279 (2.9)	9.6 (3.5)	203 (124.8)
Slotted 480-53	11.93	-54	776 (3.0)	270 (2.5)	0.4 (0.8)	291 (132.6)
Slotted 480-54	12.67	-54	780 (3.4)	272 (4.0)	0.9 (0.8)	294 (16.3)
Unslotted 480-55	10.79	-54	759 (4.6)	276 (7.6)	1.5 (1.4)	425 (73.6)

Table 4 displays the temperature coefficients $\Delta P/\Delta T$ for the five stick-propellant lots investigated. Recall that the prime motivation at the beginning of the study was not to investigate geometry-induced differences in the temperature coefficient, although such a determination was certainly of interest. Rather, the objective was to determine if there was a production-period dependency as had been noted with granular M30A1 propellants.[3] What emerged from these tests was not a production-period difference, which would have been manifested by a disparity of the coefficients of the RAD-PE-480 and RAD-PE-472 lots, but indeed a dependency of the coefficient on the geometry, i. e., on the presence of the slot. While the cold-to-ambient coefficients are essentially the same for all the lots, regardless of geometry, the ambient-to-hot coefficients for the slotted lots are on the order of twice those of the unslotted lots. It is possible that the slotted-stick propellants, being pliable when hot, may suffer closure of the slot either through compression from neighboring grains (or packaging in this case) or pressurization by interstitial igniter and early combustion gases before they penetrate the perforation. Later, as the perforation is pressurized, the slotted propellant may rupture in instances where the unslotted propellant might not, due to the lower hoop strength of the slotted stick. Such a rupture of the slotted-stick propellant, and its absence in unslotted-stick propellant, could lead to increases in the area of the burning surfaces and hence higher pressures in the former case. We caution, however, that further investigations into this phenomenon are necessary since these data were gathered for small sample sizes with only a single propellant composition.

TABLE 4. STICK PROPELLING CHARGE TEMPERATURE COEFFICIENTS

Propellant Lot	Amb → Hot $\Delta P/\Delta T$ (MPa/°C)	Cold → Amb $\Delta P/\Delta T$ (MPa/°C)
Slotted 472-11	1.88	0.86
Unslotted 472-12	0.88	0.77
Slotted 480-53	1.86	0.75
Slotted 480-54	2.05	0.75
Unslotted 480-55	0.60	0.65

The preceding tests demonstrated the clear superiority of stick propellant, as compared to granular propellant, in reducing ignition-induced pressure waves. As a further investigation of the efficacy of stick propellants in improving the interior ballistic hydrodynamic environment, stick charges were tested in a more stringent flow configuration, one in which the local loading density was increased and the size of the channels between the sticks reduced. We present, in Table 5, data for shortened-stick, higher-local-loading-density charges, fired at 21 °C. For these shots, the sticks from Lots RAD-PE-472-11 and RAD-PE-472-12 were cut to a length of 533 mm. The charges were fabricated to full-bore dimensions in the same manner as before, necessitating a more tightly packed spiral, so that the cross-sectional loading density was increased by approximately 22 percent. Hardware availability made it necessary to employ a different spindle for these tests than had been used previously, with the result that the charges could be fired only with a 25-mm standoff. Since these charges were both considerably shorter and denser in cross-section than the ones fired before, a cardboard spacer was placed between the charges and the projectile base in an attempt to preclude charge movement. We note that the level of pressure waves rose for the unslotted propellant, and there are some breaks on the pressure-time records for this lot. However, the level of pressure waves generally remains low, especially in comparison to the earlier granular results,[2] indicative of the truly permeable nature of a stick-propellant bed. The peak pressures and muzzle velocities are substantially higher than those obtained with the same charge weights in the full-length charges. This result must be attributable in some way to the increased packing density of the propellant, since it is incredible that the slight reduction in volume produced by the new spindle and cardboard spacer could be the source of the increase. In addition, we do note one effect which almost certainly resulted from the more closely packaged sticks: The ignition delays are substantially reduced in comparison with the less tightly packed sticks. This reduction is due to the smaller interstitial volume to which the igniter and early combustion gases have access, leading to higher early pressures at the base of the charge and thus more prompt ignition.

TABLE 5. FIRING DATA FOR SHORTENED-STICK PROPELLANTS

Propellant Lot	Charge Wt (kg)	Temp (°C)	Muzzle Velocity (m/s)	P_{max} (MPa)	$-\Delta P_i$ (MPa)	Ignition Delay (ms)
Slotted 472-11	11.11	21	849 (0.9)	357 (4.4)	2.0 (2.1)	25 (3.1)
Unslotted 472-12	10.34	21	818 (2.8)	346 (8.7)	7.4 (4.0)	24 (3.4)

IV. CONCLUSIONS

We have presented results from an experimental investigation to determine the extent to which stick propellants, due to their very low drag on igniter and early combustion gases, mitigate the evolution of pressure waves in charge assemblies specifically designed to promote the formation of such waves. Particular findings from this study include:

a. As evidenced by the reduced level of pressure waves, stick propellants, both slotted and unslotted, do indeed offer a greatly improved flow environment in comparison to granular propellants, even large 37-perforation grains. This result holds even when the local loading density is increased, i. e., when the permeability of the charge is decreased.

b. An increased efficiency, perhaps the result of an artificial progressivity of the slotted-stick propellant, was noted in that a given velocity could be obtained at the same pressure as with a 7-perforation grain, but at a significantly lower charge weight than would be required for granular propellant. Some enhanced burning in the perforation, due either to erosive effects or increased combustion linked to higher internal pressure, was advanced as the likely source of this phenomenon. A similar result was not found with unslotted-stick propellant. In this case, it was suggested that the grain, due to internal pressurization, ruptured before the effect noted with the slotted-stick propellant could be realized.

c. The temperature coefficient of pressure, $\Delta P/\Delta T$, exhibited a strong dependence on the stick geometry. While the ambient-to-cold coefficient was the same for both slotted and unslotted geometries, the ambient-to-hot coefficient was found to be a factor of two greater for the slotted geometry than for the unslotted configuration. It was hypothesized that this phenomenon may be traceable to the relative mechanical strengths of the two geometries, and rupture of the hot-conditioned slotted-stick propellants under conditions in which the unslotted-stick propellants remained intact. We caution, however, that this result was obtained with a single propellant composition and with small sample sizes.

d. With the possible exception of one firing series (Lot RAD-PE-472-12, cold) gross fracture of the propellant sticks is not supported by an analysis of either the levels of peak pressures and initial reverse-pressure gradients or variability in peak pressures, even at cold temperatures. We note, however, that there are some rupture scenarios, such as lengthwise splitting of the sticks, that may occur and not produce anomalies in these data.

e. There was some evidence, clouded by a change of experimental apparatus during the testing, that the loading configuration may significantly affect the overall performance of a stick-propellant charge, both slotted and unslotted, in terms of peak pressure and muzzle velocity.

f. The long ignition delays measured in this study are probably an artifact of the particular charge configuration chosen for this study. Gases generated by the basepad had access to a large interstitial volume, rather than remaining in the rear of the charge to promote rapid ignition of the charge. In the charges with a relatively smaller interstitial volume, the ignition delays decreased significantly.

As anticipated prior to the start of this study, stick propellant offers the best propellant-design approach to the mitigation of pressure waves. Since the completion of this study, other investigators have similarly demonstrated the efficacy of stick propellants for the reduction of ignition-induced, flow-dynamic phenomena.[9-11] While the advantages of stick over granular propellants have been demonstrated, there still remain several areas of concern before their routine application to propelling-charge design. These areas include stick combustion, including enhanced burning in the perforation, stick fracture, interior ballistic hydrodynamic effects, erosion, manufacturing, cost, and stick blending to achieve a particular charge assessment. Investigations are currently underway at the Ballistic Research Laboratory into the first three of these areas,[12,13] and a Product Improvement Program for the 155-mm, M203 Propelling Charge will address many of the others.

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[9] T.C. Smith, "Experimental Gun Testing of High Density Multiperforated Stick Propellant Charge Assemblies," Proceedings of 17th JANNAF Combustion Meeting, CPIA Publication 329, Vol. II, pp. 87-95, November 1980.

[10] A. Grabowsky, S. Weiner, and A.J. Beardell, "Closed Bomb Testing of Stick Propellant for Gun Firing Simulation," Proceedings of 17th JANNAF Combustion Meeting, CPIA Publication 329, Vol. II, pp. 119-124, November 1980.

[11] F.W. Robbins, J.A. Kudzal, J.A. McWilliams, and P.S. Gough, "Experimental Determination of Stick Charge Flow Resistance," Proceedings of 17th JANNAF Combustion Meeting, CPIA Publication 329, Vol. II, pp. 97-118, November 1980.

[12] F.W. Robbins and A.W. Horst, "A Simple Theoretical Analysis and Experimental Investigation of Burning Processes for Stick Propellant," Proceedings of 18th JANNAF Combustion Meeting, CPIA Publication 347, Vol. II, pp. 25-34, October 1981.

[13] F.W. Robbins, "Continued Study of Stick Propellant Combustion Processes," Proceedings of 19th JANNAF Combustion Meeting, CPIA Publication 366, Vol. I, pp. 443-459, October 1982.

ACKNOWLEDGMENTS

The author is grateful to the many individuals who contributed to this study. Messrs. A.W. Horst, F.W. Robbins, and K.J. White explored stick-propellant combustion mechanisms with the author in numerous discussions. Mr. Horst provided assistance in conducting the NOVA calculations for the stick propellants. The closed-bomb testing was performed and nicely reported by Messrs. J.O. Doali, R.E. Bowman, and A.A. Juhasz. Messrs. A.A. Koszoru and Horst assisted in fabrication of the experimental charges, and the firing program proper was conducted with the able assistance of Messrs. Koszoru, J.W. Evans, J.E. Bowen, J.R. Hewitt, J.L. Stabile, and C.R. Ruth. Mr. Koszoru prepared the data of Appendix C for final display. The author is also grateful to Mr. R.S. Westley, LCWSL, who provided quantities of two lots of stick propellants for testing in the howitzer.

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11. F.W. Robbins, J.A. Kudzal, J.A. McWilliams, and P.S. Gough, "Experimental Determination of Stick Charge Flow Resistance," Proceedings of 17th JANNAF Combustion Meeting, CPIA Publication 329, Vol. II, pp. 97-118, November 1980.

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13. F.W. Robbins, "Continued Study of Stick Propellant Combustion Processes," Proceedings of 19th JANNAF Combustion Meeting, CPIA Publication 366, Vol. I, pp. 443-459, October 1982.

APPENDIX A

PROPELLANT DESCRIPTION SHEETS

PROPELLANT DESCRIPTION SHEET

U S Army Lot No. RAD-PE-472-11 of 19 75 Composition No. SLOTTED STICK FOR 155MM HOWITZER M109A1

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA Packed Amount 17,170 Pounds

Contract No. DAAA09-71-C-0329 Date 6-30-71 Specification No. COR Ltr. SARRA-IE- Dtd 6/27/75

NITROCELLULOSE

ACCEPTED BLEND NUMBERS

A35637, A35639, and A35644

	Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
Maximum	12.62 %	45+ Mins	30+ Mins
Minimum	12.52 %	40 Mins	30 Mins
Average	12.59 %	42.5+ Mins	30+ Mins
Explosion			Mins

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound NC/Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds ACETONE per 100 Pounds Solvent.

Percentage Remix to Whole 28

Temperatures °C From	To	PROCESS-SOLVENT RECOVERY AND DRYING	Time Days	Hours
Ambient		LOAD FAD AT AMBIENT TEMPERATURE & HOLD 24 HOURS		24
104	104	INCREASE TEMPERATURE FROM AMBIENT TO 104°F IN 5 HOURS		19
131	131	HOLD TEMPERATURE AFTER INCREASE FROM 104°F IN 5 HOURS		43
140	140	HOLD TEMPERATURE AFTER INCREASE FROM 131°F IN 5 HOURS		40
140	140	DRYING AFTER SAWING USING ALCOHOL AND WATER COOLANT		60

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION Constituent	Percent Formula	Percent Tolerance	Percent Measured	STABILITY AND PHYSICAL TESTS	Formula	Actual
NITROCELLULOSE	28.00	±1.30	27.35	Heat Test S.P. 120°C	NO CC 40'	60'+
NITROGLYCERIN	22.50	±1.00	22.38	NO FUMES	-	60'
NITROGUANIDINE	47.00	+1.00	47.80	Form of Propellant		CYLD
ETHYL CENTRALITE	1.50	±0.10	1.45	NO.OF PERFORATIONS	1	1
POTASSIUM SULFATE	1.00	±0.30	1.02	NO. OF SLOTS	1	1
TOTAL	100.00		100.00	ABSOLUTE DENSITY		
TOTAL VOLATILES	0.50	MAX.	0.22	GM/CC	1.687	1.682
GRAPHITE	0.15	MAX.	N/A			
				GRAIN WEIGHT,		
				AVG. GMS.	36.09*	36.1
				STD. DEV. GMS.		0.82
				*BASED ON PREVIOUS LOT RESULTS		

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test	RAD-PE-472-11	+90	91.49	100.91
	RAD-PE-472-11	-40	79.51	98.82
Standard	RAD-E-1	+90	100.00%	100.00%

Remarks

FIRED IN ACCORDANCE WITH MIL-STD-286B, METHOD 801.1, IN A NOMINAL SIZE 700CC CLOSED BOMB. TEST PROPELLANT LENGTHS OF 13.5 INCHES WERE USED.

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Mean Variation in % of Mean Dimensions: Spec.	Actual
Length (L)	27.0 ± 1/4	27.0	27.01	6.25MAX	0.09
Diameter (D)		0.291	0.2587	6.125MAX	2.06
Perf. Dia. (d)	-	0.068	0.0611		
SLOT					
INNER CHORD	N/A	N/A	0.0074		
OUTER CHORD	N/A	N/A	0.0139		
AVE WEB	0.100 Nom.	0.1115	0.0988		
Web Difference/ Std. Dev. in % of Web Average					
L/D			107.61		
D/d			4.65		

DATES

- Packed 9/25/75
- Sampled 9/25/75
- Test Finished 10/14/75
- Offered 10/14/75
- Description Sheets Forwarded 10/15/75

Type of Packing Container Wood Box - 327199

Remarks 286 boxes @ 60 lbs. net each

10 pound sample

Contractor's Representative R. A. Williams

Government Quality Assurance Representative J. E. Bland

SMU FORM 10479 MARCH 1971

PROPELLANT DESCRIPTION SHEET

U S Army Lot No. RAD-PE472-12 of 19 75 Composition No. M30A1, Unslotted Stick Propellant

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA Packed Amount 3,036 Pounds

Contract No. DAAA09-71-C-0329 Date 6-30-71 Specification No. COR LETTER SARRA-IE, dated 6/27/75

NITROCELLULOSE

ACCEPTED BLEND NUMBERS

A35637, A353639, and A35644

	Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
Maximum	12.62 %	45+ Mins	30+ Mins
Minimum	12.52 %	40 Mins	30 Mins
Average	12.59 %	42.5+ Mins	30+ Mins
			Explosion ___ Mins

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound NC/Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds acetone per 100 Pounds Solvent.

Percentage Remix to Whole 28

Temperatures °C From	To	PROCESS-SOLVENT RECOVERY AND DRYING	Time Days	Hours
Ambient		Load FAD at ambient temperature and hold 24 hours		24
104	104	Increase temperature from ambient to 104°F in 5 hours		19
131	131	Hold temperature after increase from 104°F in 5 hours		43
140	140	Hold temperature after increase from 131°F in 5 hours		40
140	140	Drying after sawing using alcohol and water coolant		60

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION

Constituent	Percent Formula	Percent Tolerance	Percent Measured
Nitrocellulose	28.00	± 1.30	28.11
Nitroglycerin	22.50	± 1.00	22.08
Nitroguanidine	47.00	± 1.00	47.37
Ethyl Centralite	1.50	± 0.10	1.46
Potassium Sulfate	1.00	± 0.30	0.98
TOTAL	100.00		100.00
Total Volatiles	0.50	Max	0.14

STABILITY AND PHYSICAL TESTS

	Formula	Actual
Heat Test SP, 120°C	No CC 40	60'
No Fumes		60'
Form of Propellant		Cyld
No. Perforations	1	1
No. Slots	0	0
Absolute Density gm/cc	1.687	1.681
Grain Weight, Avg gms	36.09*	35.85
Std Dev, gms		1.099

*Based on previous lot results

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test	RAD-PE-472-12	+90	97.31	100.34
	RAD-PE-472-12	-40	89.27	98.51
Standard	RAD-E-1	+90	100.00%	100.00%

Remarks: Fired in accordance with MIL-STD-286B, Method 801.1, in a nominal size 700cc closed bomb. Test propellant lengths of 13.5 inches were used.

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Mean Variation in % of Mean Dimensions Spec	Actual
Length (L)	27.0 ± 1/4	27.0	27.026	6.25max	0.065
Diameter (D)		0.291	0.2439	3.125max	2.565
Perf Dia (d)		0.063	0.0511		
Avg. Web	0.100 nom	0.1115	0.0994		
Web Difference/Std Dev in % of Web Average					
L/D					
D/d					

DATES

- Packed 10-9-75
- Sampled 10-9-75
- Test Finished 10/22/75
- Offered 10/24/75
- Description Sheets Forwarded 10/24/75

Type of Packing Container: Recon Drums - 387282 Cylinders - 327283

Remarks: 23 boxes @ 132 lbs. net each

This lot meets all requirements of the applicable specification.

Contractor's Representative: R. A. Williams

Government Representative: J. E. Bland

MU FORM 1047R MARCH 1971

PROPELLANT DESCRIPTION SHEET

U.S. Army Lot No. RAD-PE-480-53 of 19 79 Composition No. M30A1, Slotted Stick Propellant

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA Packed Amount 472 Pounds
Contract No. DAAA09-71-C-0329 Date 6-30-71 Specification No. COR letter SARRA-IE, dated 11/27/78

NITROCELLULOSE

Accepted Blend Numbers	Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
C-36277	Maximum ____ %	____ Mins	____ Mins
	Minimum ____ %	____ Mins	____ Mins
	Average 12.55 %	45+ Mins	30+ Mins
			Explosion ____ Mins

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound ~~XX~~/Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds acetone per 100 Pounds Solvent

Percentage Remix to Whole 15

Temperatures °F From	To	PROCESS-SOLVENT RECOVERY AND DRYING	Time Days	Hours
Ambient	Ambient	Load at ambient and hold		24
Ambient	104	Increase temperature to 104°F		5
104	104	Maintain temperature at 104°F		19
104	131	Increase temperature to 131°F		5
131	131	Maintain temperature at 131°F		43
131	140	Increase temperature to 140°F and hold 40 hours		5 + 40

TESTS OF FINISHED PROPELLANT

Propellant Composition: Constituent	Percent Formula	Percent Tolerance	Percent Measured	Stability and Physical Tests	Formula	Actual
Nitrocellulose	28.00	± 1.30	28.62	Heat Test SP 120°C	No CC 40'	60'+
Nitroglycerin	22.50	± 1.00	21.84	No Fumes		60'
Nitroguanidine	47.00	± 1.00	47.04	Form of Propellant Slotted Stick		Cyld
Ethyl Centralite	1.50	± 0.10	1.44	No. Perforations	1	1
Potassium Sulfate	1.00	± 0.30	1.06	Type II		
TOTAL	100.00		100.00	Absolute Density		
Total Volatiles	0.50	Max	0.04	g/cc	N/A	1.688
				Grain Wt. Avg g		
				per 29" stick		49.134

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test	RAD-PE-480-53	+90	88.71	101.03
	RAD-PE-480-53	-40	79.62	99.25
Standard	E-14-73	+90	100.00%	100.00%
Remarks	Fired in accordance with MIL-STD-286, Method 801.1; 0.2 g/cc loading density, nom. 700 cc closed bomb			

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Std Dev. ~~XXXX~~ in % of Mean Dimensions: Spec.	Actual
Length (L)	29.0 Nom		29.025	6.25Max	0.07
Diameter (D)	0.300 Nom	0.333	0.305	3.125Max	1.63
Perf Dia (d)	0.100 Nom	0.100	0.091		
Web, Avg	0.100 Nom		0.107		
Slot-Inner		N/A	0.007		
-Outer		N/A	0.008		
Web Difference/ Std. Dev. in % of Web Average	20 Max	N/A	4.69		
L/D		N/A			
D/d	3 Nom		3.25		

DATES

Packed	4/11/79
Sampled	4/11/79
Test Finished	4/23/79
Offered	4/30/79
Description Sheets Forwarded	5/7/79

Type of Packing Container: Wood boxes - 327199

Remarks: 7 boxes at 60 pounds each
1 box at 52 pounds

THIS LOT MEETS SPECIFICATIONS.

Contractor's Representative: C. B. Smith (signed) C. B. Smith

Government Quality Assurance Representative: J. E. Bland (signed)

AMU FORM 1C470 MARCH 1971

PROPELLANT DESCRIPTION SHEET

U.S. Army Lot No. RAD-PE-480-54 of 19 79 Composition No. M30A1, Slotted Stick Propellant

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA Packed Amount 480 Pounds

Contract No. DAAA09-71-C-0329 Date 6-30-71 Specification No. COR letter SAARA-IE, dated 11/22/78

NITROCELLULOSE

Accepted Blend Numbers: C-36277

Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
Maximum ___ %	___ Mins	___ Mins
Minimum ___ %	___ Mins	___ Mins
Average 12.55 %	45+ Mins	30+ Mins
		Explosion ___ Mins

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound dry weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds Acetone per 100 Pounds Solvent

Percentage Rework in Whole 15

PROCESS-SOLVENT RECOVERY AND DRYING

Temperatures °F From	To	Process	Time Days	Hours
Ambient	Ambient	Load at ambient and hold		24
Ambient	104	Increase temperature to 104°F		5
104	104	Maintain temperature at 104°F		19
104	131	Increase temperature to 131°F		5
131	131	Maintain temperature at 131°F		43
131	140	Increase temperature to 140°F and hold 40 hours		5 + 40

TESTS OF FINISHED PROPELLANT

Propellant Composition: Constituent	Percent Formula	Percent Tolerance	Percent Measured	Stability and Physical Tests	Formula	Actual
Nitrocellulose	28.00	± 1.30	28.58	Heat Test SP 120°C	No CC 40'	60'+
Nitroglycerin	22.50	± 1.00	21.13	No Fumes		60'
Nitroguanidine	47.00	± 1.00	47.79	Form of Propellant Slotted Stick		Cyld
Ethyl Centralite	1.50	± 0.10	1.46	No. Perforations	1	1
Potassium Sulfate	1.00	± 0.30	1.04	Type II		
TOTAL	100.00		100.00	Absolute Density,		
Total Volatiles	0.50	Max	0.01	g/cc	N/A	1.683
				Grain Weight Avg		
				per 29" Stick		55.599

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test	RAD-PE-480-54	+90	81.24	100.37
	RAD-PE-480-54	-40	72.79	98.63
Standard	E-14-73	+90	100.00%	100.00%

Remarks: Fired in accordance with MIL-STD-286, Method 801.1; 0.2 g/cc loading density. Nom. 700 cc closed bomb.

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Std. Dev. in % of Mean Dimensions Spec	Actual
Length (L)	29.0 Nom		29.006	6.25Max	0.06
Diameter (D)	0.318 Nom	0.353	0.322	3.125Max	1.51
Perf Dia. (d)	0.106 Nom	0.106	0.098		
Web, Avg	0.106 Nom		0.112		
Slot					
Inner			0.011		
Outer			0.009		
Web Difference/Std. Dev. in % of Web Average	20 Max	N/A	5.71		
L/D		N/A			
D/d	3 Nom		3.28		

DATES

- Packed 4/11/79
- Sampled 4/11/70
- Test Finished 4/23/79
- Offered 4/30/79
- Description Sheets Forwarded 5/7/79

Type of Packing Container: Wood boxes 327199

Remarks: 8 boxes at 60 pounds each.
This lot meets specifications with the exception of percent nitroglycerin.

Contractor's Representative: C. B. Smith (signed) C. B. Smith

Government Quality Assurance Representative: J. E. Bland (signed)

RAAP FORM 10078 MARCH 1971

PROPELLANT DESCRIPTION SHEET

U.S. Army Lot No. RAD-PE-480-55 of 19 79 Composition No. M30A1, Unslotted Stick Propellant

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA Packed Amount 480 Pounds

Contract No. DAAA09-71-C-0329 Date 6-30-71 Specification No. COR letter SARRA-IE, dated 11/22/78

NITROCELLULOSE

Accepted Blend Numbers		Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
C-36277	Maximum	%	Mins	Mins
	Minimum	%	Mins	Mins
	Average	12.55 %	45+ Mins	30+ Mins
				Explosion Mins

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound NC/Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds acetone per 100 Pounds Solvent

Percentage Remix to Whole 15

Temperatures °F From	To	PROCESS-SOLVENT RECOVERY AND DRYING	Time Days	Hours
Ambient	Ambient	Load at ambient and hold		24
Ambient	104	Increase temperature to 104°F		5
104	104	Maintain temperature at 104°F		19
104	131	Increase temperature to 131°F		5
131	131	Maintain temperature at 131°F		43
131	140	Increase temperature to 140°F and hold 40 hours		5 + 40

TESTS OF FINISHED PROPELLANT

Propellant Composition: Constituent	Percent Formula	Percent Tolerance	Percent Measured	Stability and Physical Tests	Formula	Actual
Nitrocellulose	28.00	± 1.30	28.19	Heat Test SP 120°C	No CC 40'	60'+
Nitroglycerin	22.50	± 1.00	22.04	No Fumes		60'
Nitroguanidine	47.00	± 1.00	47.10	Form of Propellant Unslotted Stick		Cyld
Ethyl Centralite	1.50	± 0.10	1.63	No. Perforations	1	1
Potassium Sulfate	1.00	± 0.30	1.04	Type II		
TOTAL	100.00		100.00	Absolute Density,		
Total Volatiles	0.50	Max	0.16	g/cc		1.683
				Grain Weight Avg		44.721
				per 29" Stick		

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test	RAD-PE-480-55	+90	91.90	99.42
	RAD-PE-480-55	-40	85.96	98.31
Standard	E-14-73	+90	100.00%	100.00%

Remarks: Fired in accordance with MIL-STD-286, Method 80.1.; 0.2g/cc loading density, nom. 700 cc closed bomb.

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Std Dev in % of Mean Dimensions: Spec.	Actual
Length (L)	29.0 Nom		29.029	6.25Max	0.11
Diameter (D)	0.288 Nom	0.320	0.287	3.125Max	1.22
Perf Dia (d)	0.096 Nom	0.098	0.087		
Wev Avg	0.096 Nom		0.1005		
Web Difference/ Std. Dev. in % of Web Average	20 Max		4.84		
L/D		N/A			
D/d	3 Nom		3.30		

DATES

Packed 4/11/79

Sampled 4/11/79

Test Finished 4/23/79

Offered 4/30/79

Description Sheets Forwarded 5/7/79

Type of Packing Container: Wood boxes - 327199

Remarks: 8 Boxes at 60 pounds each

This lot meets specifications with the exception of ethyl centralite.

Contractor's Representative: C. B. Smith (signed) C. B. Smith

Government Quality Assurance Representative: J. E. Bland (signed) James E. Bland

RAD FORM 10470 MARCH 1971

APPENDIX B

TABULATION OF FIRING DATA

APPENDIX B
TABULATION OF FIRING DATA

IDENT NO	PROPELLANT & LOT	CONFIGURATION & LOAD	CHG WT (kg)	CHG TEMP (°C)	PROJ WT (kg)	STAND OFF (mm)	SEAT (cm)	VELOCITY (m/s)	MAX CHAMBER PRESS SPIN (MPa)	MID (MPa)	FOR (MPa)	$-\Delta P_i$ (MPa)	IGNITION DELAY (ms)
22	M30A1 Unslot Stick RAD-PE-	Full Bore Spiral Length 68.6 cm	10.34	21	43.54	0	90.0	789	328	319	295	2.3	94
23	472-12	No spacer			43.63		90.1	797	340	330	307	2.3	63
24					43.04		90.1	803	340	331	305	2.6	37
25					43.04		90.1	798	336	328	301	0.0	33
							(Avg)	797	336	327	302	1.8	57
							(Std Dev)	5.8	5.7	5.5	5.3	1.2	28.2
26	M30A1 Slot Stick RAD-PE-	Full Bore Spiral Length 68.6 cm	11.11	21	42.77	0	90.0	829	334	324	296	0.0	70
27	472-11	No spacer			43.49		90.0	820	330	lost	294	1.8	lost
28					43.27		90.0	814	322	312	286	3.7	84
29					42.95		90.0	823	328	lost	290	1.3	117
							(Avg)	822	329	318	292	1.7	90
							(Std Dev)	6.2	5.0	---	4.4	1.5	24.1

IDENT NO	PROPELLANT & LOT	CONFIGURATION & LOAD	CHG WT (kg)	CHG TEMP (°C)	PROJ WT (kg)	STAND OFF (mm)	SEAT (cm)	VELOCITY (m/s)	MAX CHAMBER PRESS SPIN (MPa)	MID (MPa)	FOR (MPa)	$-\Delta P_i$ (MPa)	IGNITION DELAY (ms)
30	M30A1 Slot Stick RAD-PE-472-11	Full Bore Spiral Length 68.6 cm No spacer	11.11	62	42.59	0	90.2	866	414	406	368	1.9	28
31					43.49		90.1	852	395	384	344	0.0	45
32					43.08		90.2	859	407	396	360	0.0	30
33					43.36		90.1	855	403	393	341	1.1	35
							(Avg)	858	406	395	353	0.8	35
							(Std Dev)	6.1	9.1	9.1	12.9	0.9	7.6
34	M30A1 Unslot Stick RAD-PE-472-12	Full Bore Spiral Length 68.6 cm No spacer	10.34	62	43.58	0	90.4	lost	373	363	335	4.1	32
35					43.40		90.1	lost	371	360	334	1.3	26
36					43.31		90.3	823	369	359	330	1.0	45
37					43.22		90.1	825	373	363	335	2.0	36
							(Avg)	825	372	361	334	2.1	35
							(Std Dev)	---	1.9	2.1	2.4	1.4	8.0

IDENT NO	PROPELLANT & LOT	CONFIGURATION & LOAD	CHG WT (kg)	CHG TEMP (°C)	PROJ WT (kg)	STAND OFF (mm)	SEAT (cm)	VELOCITY (m/s)	MAX CHAMBER PRESS SPIN (MPa)	MID (MPa)	FOR (MPa)	$-\Delta P_i$ (MPa)	IGNITION DELAY (ms)
44	M30A1 Slot Stick RAD-PE-	Full Bore Spiral Length 68.6 cm	11.11	-53	43.08	0	90.2	767	267	NA	241	3.3	237
45	472-11	No spacer			43.17		90.1	768	263	NA	238	3.5	152
46					43.27		90.1	773	272	NA	241	2.1	111
47					43.22		90.4	762	260	NA	236	3.1	184
							(Avg)	768	265	---	239	3.0	171
							(Std Dev)	4.5	6.2	---	2.5	0.6	53.2
48	M30A1 Unslot Stick RAD-PE-	Full Bore Spiral Length 68.6 cm	10.34	-53	43.31	0	90.2	760	275	NA	261	13.5	148
49	472-12	No spacer			43.36		90.1	755	279	NA	258	5.3	386
50					43.54		90.0	751	282	NA	262	11.1	169
51					43.22		90.2	754	279	NA	256	8.5	108
							(Avg)	755	279	---	259	9.6	203
							(Std Dev)	3.7	2.9	---	2.8	3.5	124.8

NA = Not acquired on-line
Missed acquisition window due to variations in ignition delays

IDENT NO	PROPELLANT & LOT	CONFIGURATION & LOAD	CHG WT (kg)	CHG TEMP (°C)	PROJ WT (kg)	STAND OFF (mm)	SEAT (cm)	VELOCITY (m/s)	MAX CHAMBER PRESS SPIN (MPa)	MID (MPa)	FOR (MPa)	$-\Delta P_i$ (MPa)	IGNITION DELAY (ms)
72	M30A1 Slot Stick RAD-PE-480-54	Full Bore Spiral Length 73.7 cm No spacer	12.67	21	43.08	0	90.3	845	328	324	308	2.1	65
73							90.3	841	332	328	310	1.2	61
75							90.4	838	325	321	305	1.7	69
76							90.2	843	325	321	305	0.0	41
							(Avg)	842	328	324	307	1.3	59
							(Std Dev)	2.9	3.3	3.3	2.4	0.9	12.4
77	M30A1 Slot Stick RAD-PE-480-53	Full Bore Spiral Length 73.7 cm No spacer	11.93	21	43.08	0	90.3	840	328	321	308	1.5	99
78							90.1	837	323	316	302	0.9	114
79							90.4	842	328	323	310	2.6	121
80							90.4	840	lost	lost	lost	lost	lost
							(Avg)	840	326	320	307	1.7	111
							(Std Dev)	2.1	2.9	3.6	4.1	0.9	11.2

IDENT NO	PROPELLANT & LOT	CONFIGURATION & LOAD	CHG WT (kg)	CHG TEMP (^{o}C)	PROJ WT (kg)	STAND OFF (mm)	SEAT (cm)	VELOCITY (m/s)	MAX CHAMBER PRESS SPIN (MPa)	MID (MPa)	FOR (MPa)	$-\Delta P_i$ (MPa)	IGNITION DELAY (ms)
85	M30A1 Unslot Stick RAD-PE-480-55	Full Bore Spiral Length 73.7 cm No spacer	10.79	21	43.08	0	90.2	804	320	312	301	4.4	54
86							90.2	809	324	316	305	2.6	51
87							90.3	817	335	325	313	7.7	51
88							90.3	810	320	313	301	3.3	82
							(Avg)	810	325	317	305	4.5	60
							(Std Dev)	5.4	7.1	5.9	5.7	2.3	15.1
92	M30A1 Slot Stick RAD-PE-480-54	Full Bore Spiral Length 73.7 cm No spacer	12.67	63	43.08	0	90.2	898	413	402	378	0.0	29
94							90.3	900	418	406	379	0.0	46
95							90.4	900	411	401	378	0.0	43
96							90.4	899	412	402	378	0.0	31
							(Avg)	899	414	403	378	0.0	37
							(Std Dev)	1.0	3.1	2.2	0.5	0.0	8.5

IDENT NO	PROPELLANT & LOT	CONFIGURATION & LOAD	CHG WT (kg)	CHG TEMP (°C)	PROJ WT (kg)	STAND OFF (mm)	SEAT (cm)	VELOCITY (m/s)	MAX CHAMBER PRESS SPIN (MPa)	MID (MPa)	FOR (MPa)	$-\Delta P_i$ (MPa)	IGNITION DELAY (ms)
97	M30A1 Slot Stick RAD-PE-480-53	Full Bore Spiral Length 73.7 cm No spacer	11.93	63	43.08	0	90.2	885	405	394	372	0.0	32
98							90.3	880	410	382	377	0.0	27
99							90.2	880	401	392	370	0.0	32
100							90.4	881	401	390	367	0.0	30
							(Avg)	882	404	390	372	0.0	30
							(Std Dev)	2.4	4.3	5.3	4.2	0.0	2.4
101	M30A1 Unslot Stick RAD-PE-480-55	Full Bore Spiral Length 73.7 cm No spacer	10.79	63	43.08	0	90.3	829	345	336	321	2.5	37
102							90.3	835	354	345	330	0.7	31
103							90.4	835	356	348	331	0.7	27
104							90.5	830	344	334	317	0.9	26
							(Avg)	832	350	341	325	1.2	30
							(Std Dev)	3.2	6.1	6.8	6.8	0.9	5.0

IDENT NO	PROPELLANT & LOT	CONFIGURATION & LOAD	CHG WT (kg)	CHG TEMP (°C)	PROJ WT (kg)	STAND OFF (mm)	SEAT (cm)	VELOCITY (m/s)	MAX CHAMBER PRESS SPIN (MPa)	MID (MPa)	FOR (MPa)	$-\Delta P_1$ (MPa)	IGNITION DELAY (ms)
107	M30A1 Slot Stick RAD-PE-480-54	Full Bore Spiral Length 73.7 cm No spacer	12.67	-54	43.08	0	90.4	782	276	265	250	0.0	lost
108							90.5	775	268	259	247	1.2	305
109							90.4	782	273	264	253	1.5	282
110							90.4	781	lost	lost	lost	lost	lost
							(Avg)	780	272	263	250	0.9	294
							(Std Dev)	3.4	4.0	3.2	3.0	0.8	----
111	M30A1 Slot Stick RAD-PE-480-53	Full Bore Spiral Length 73.7 cm No spacer	11.93	-54	43.08	0	90.4	779	271	262	250	0.0	252
112							90.5	772	267	257	247	1.5	134
113							90.5	777	273	264	251	0.0	450
114							90.5	777	270	261	248	0.0	327
							(Avg)	776	270	261	249	0.4	291
							(Std Dev)	3.0	2.5	2.9	1.8	0.8	132.6

IDENT NO	PROPELLANT & LOT	CONFIGURATION & LOAD	CHG WT (kg)	CHG TEMP (°C)	PROJ WT (kg)	STAND OFF (mm)	SEAT (cm)	VELOCITY (m/s)	MAX CHAMBER PRESS SPIN (MPa)	MID (MPa)	FOR (MPa)	$-\Delta P_i$ (MPa)	IGNITION DELAY (ms)
116*	M30A1 Unslot Stick RAD-PE-480-55	Full-Bore Spiral Length 73.7 cm No spacer	10.79	-54	43.08	0	90.4	765	285	272	266	3.5	341
117							90.5	760	279	267	261	0.8	394
118							90.6	756	269	257	253	0.7	454
119							90.5	755	270	260	254	0.9	511
							(Avg)	759	276	264	259	1.5	425
							(Std Dev)	4.6	7.6	6.8	6.1	1.43	73.6

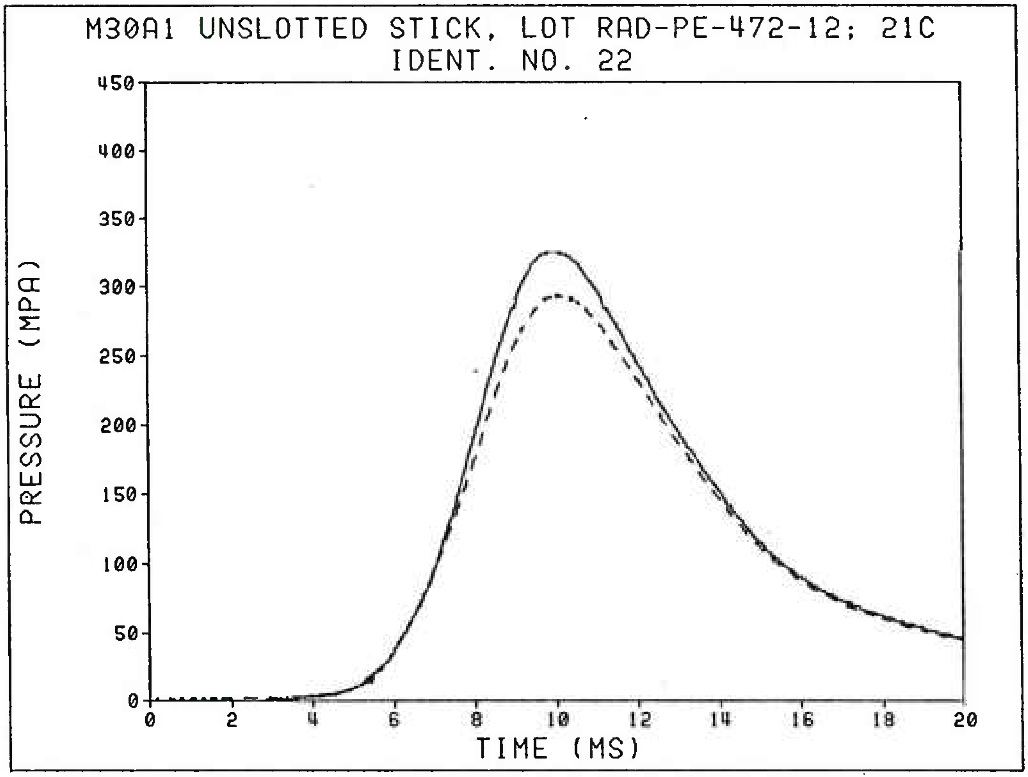
* Charge in chamber 7 minutes before firing

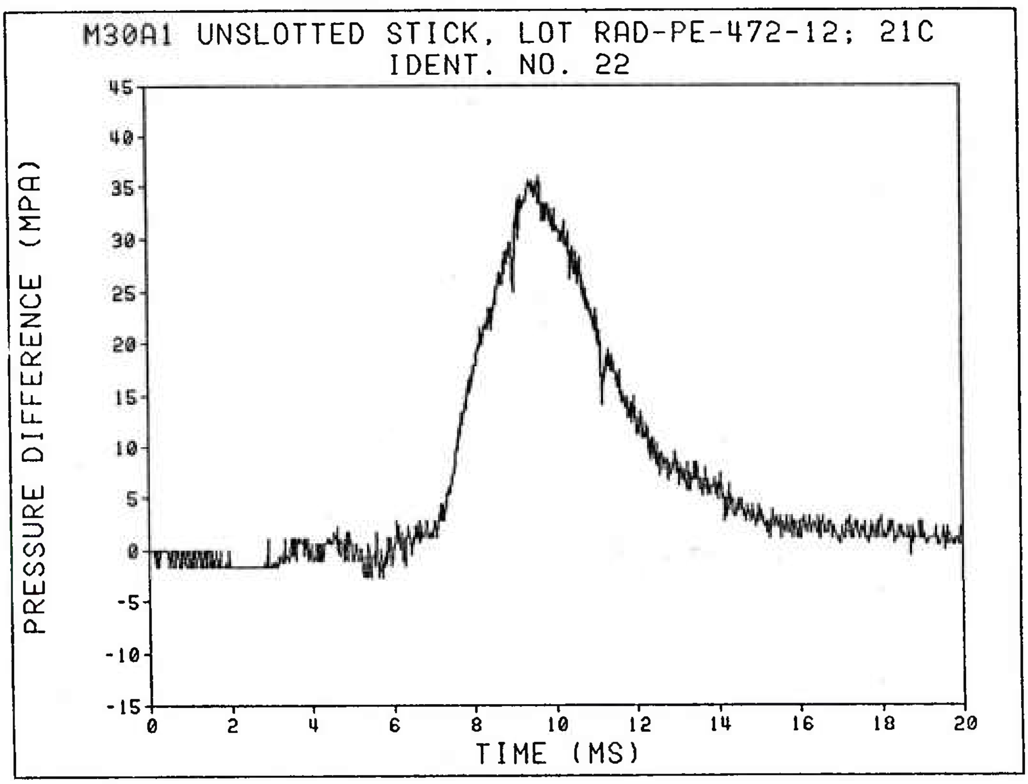
IDENT NO	PROPELLANT & LOT	CONFIGURATION & LOAD	CHG WT (kg)	CHG TEMP (^{o}C)	PROJ WT (kg)	STAND OFF (mm)	SEAT (cm)	VELOCITY (m/s)	MAX CHAMBER PRESS SPIN (MPa)	MID (MPa)	FOR (MPa)	$-\Delta P_i$ (MPa)	IGNITION DELAY (ms)
135	M30A1 Slot Stick RAD-PE-	Full Bore Spiral Length 53.3 cm	11.11	21	43.08	25	90.5	848	356	354	322	2.6	29
136	472-11	Spacer						848	355	355	328	0.0	24
137								848	356	354	329	5.3	27
138								850	365	363	337	0.5	26
139								849	354	353	327	1.5	21
							(Avg)	849	357	356	329	2.0	25
							(Std Dev)	0.9	4.4	4.1	5.4	2.1	3.1
141	M30A1 Unslot Stick RAD-PE-	Full Bore Spiral Length 53.3 cm	10.34	21	43.08	25	90.5	817	344	339	324	4.8	29
142	472-12	Spacer						819	342	337	329	3.6	23
143								822	358	348	340	12.3	22
144								815	338	331	316	8.7	22
								816	lost	lost	lost	lost	lost
							(Avg)	818	346	339	327	7.4	24
							(Std Dev)	2.8	8.7	7.0	10.0	4.0	3.4

IDENT NO	PROPELLANT & LOT	CONFIGURATION & LOAD	CHG WT (kg)	CHG TEMP (°C)	PROJ WT (kg)	STAND OFF (mm)	SEAT (cm)	VELOCITY (m/s)	MAX CHAMBER PRESS SPIN (MPa)	MID (MPa)	FOR (MPa)	$-\Delta P_i$ (MPa)	IGNITION DELAY (ms)
145	M203 IND-77L-069805	Nominal		21	43.08	25	90.5	835	327	320	312	0.4	58
146								832	325	319	312	0.0	75
147								835	329	319	315	8.5	50
148								835	326	317	312	0.1	72
149								832	318	310	306	2.3	63
							(Avg)	834	325	317	311	2.3	64
							(Std Dev)	1.6	4.2	4.1	3.3	3.6	10.2

APPENDIX C

PLOTS OF SPINDLE PRESSURE (SOLID LINE),
FORWARD PRESSURE (DASHED LINE),
AND PRESSURE DIFFERENCE VERSUS TIME


M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; 21C
IDENT. NO. 22
PRESSURE (MPA)
0
50
100
150
200
250
300
350
400
450
TIME (MS)
0
2
4
6
8
10
12
14
16
18
20


M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; 21C
IDENT. NO. 22
PRESSURE DIFFERENCE (MPA)
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-10
-5
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5
10
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35
40
45
TIME (MS)
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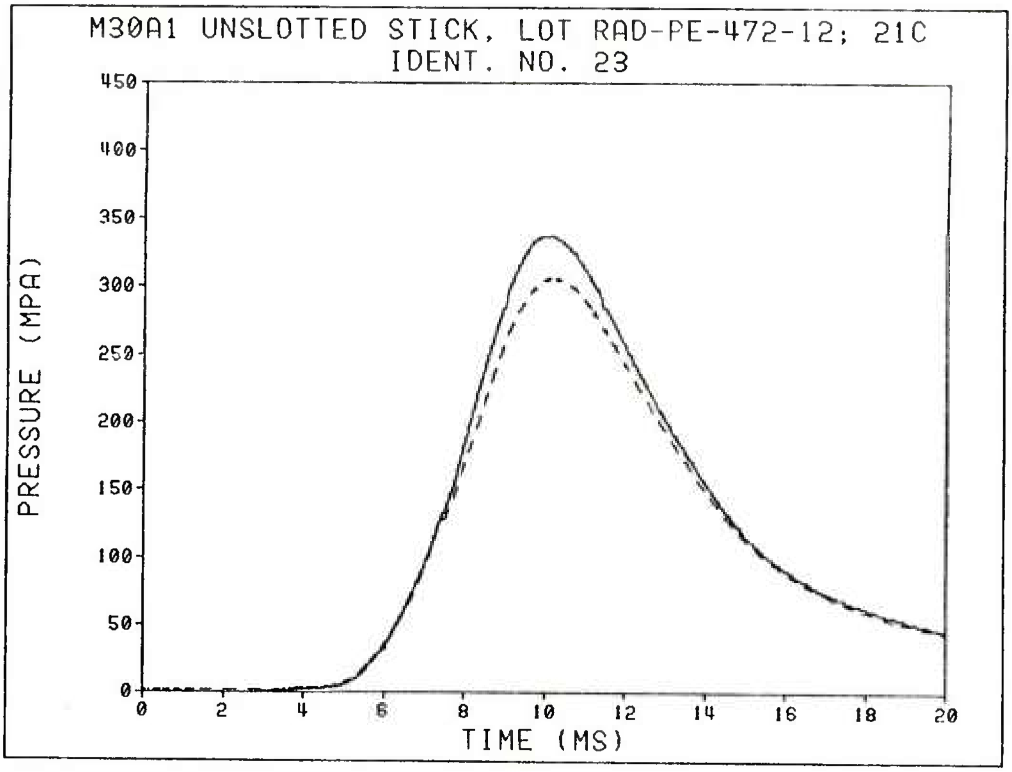
2
4
6
8
10
12
14
16
18
20


M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; 21C
IDENT. NO. 23
PRESSURE (MPA)
450
400
350
300
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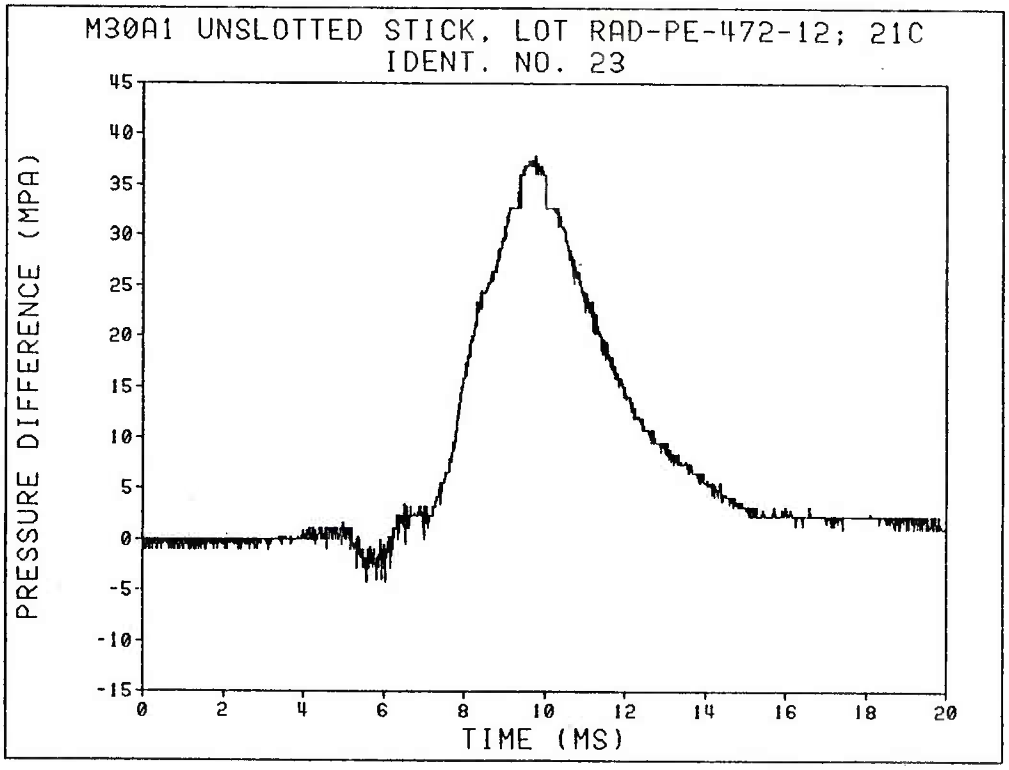
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; 21C
IDENT. NO. 23
PRESSURE DIFFERENCE (MPA)
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35
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25
20
15
10
5
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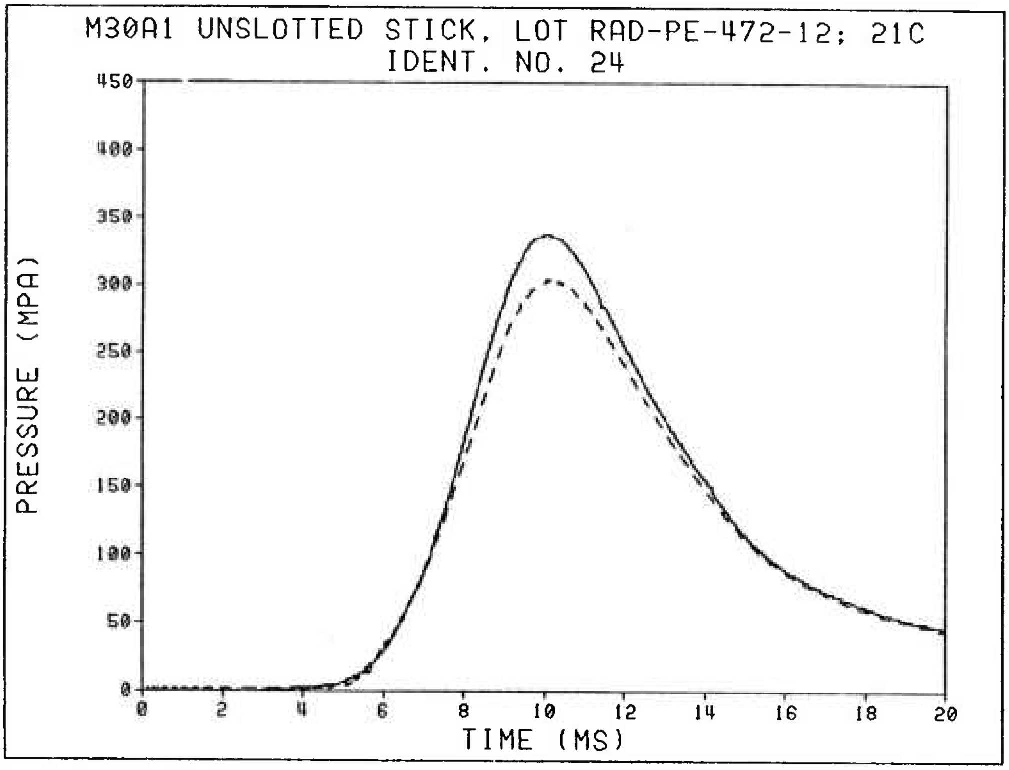
-5
-10
-15
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; 21C
IDENT. NO. 24
PRESSURE (MPA)
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50
100
150
200
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300
350
400
450
TIME (MS)
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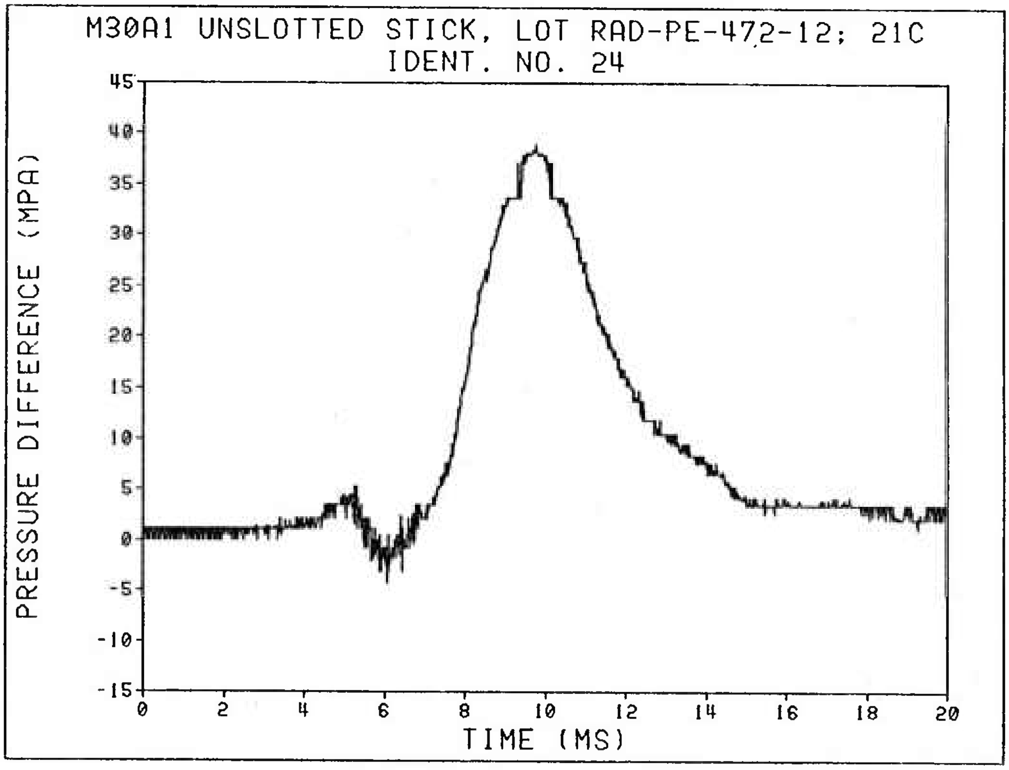
2
4
6
8
10
12
14
16
18
20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IDENT. NO. 24
PRESSURE DIFFERENCE (MPA)
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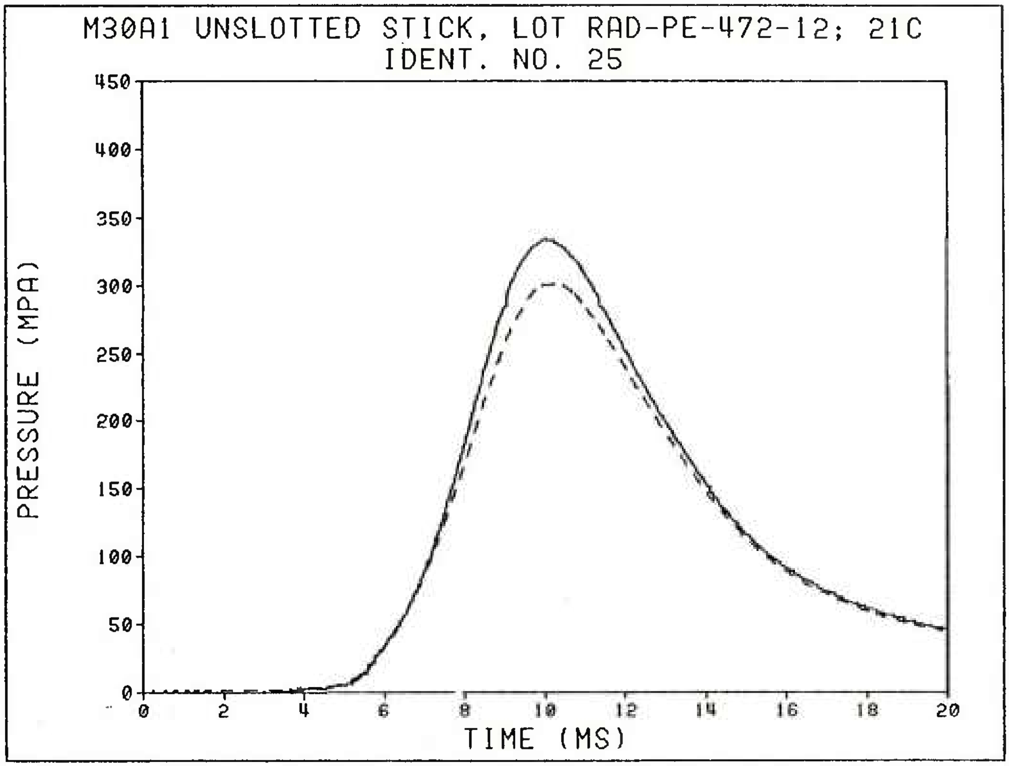
-10
-5
0
5
10
15
20
25
30
35
40
45
TIME (MS)
0
2
4
6
8
10
12
14
16
18
20


M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; 21C
IDENT. NO. 25
PRESSURE (MPA)
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100
150
200
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300
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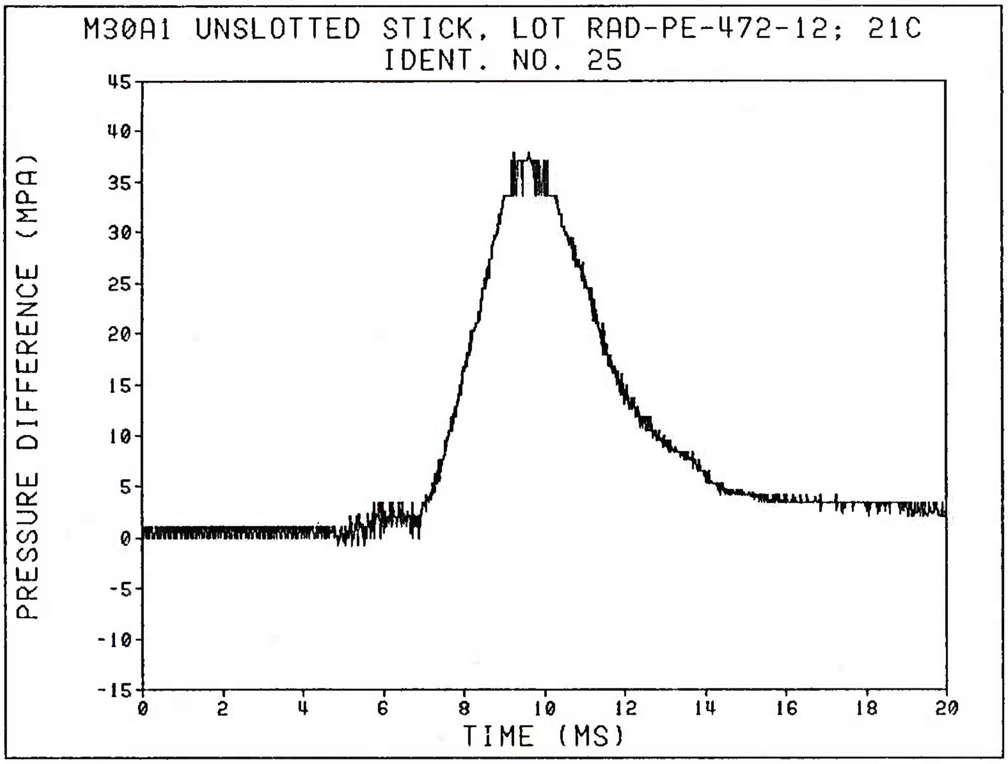
400
450
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)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IDENT. NO. 25
PRESSURE DIFFERENCE (MPA)
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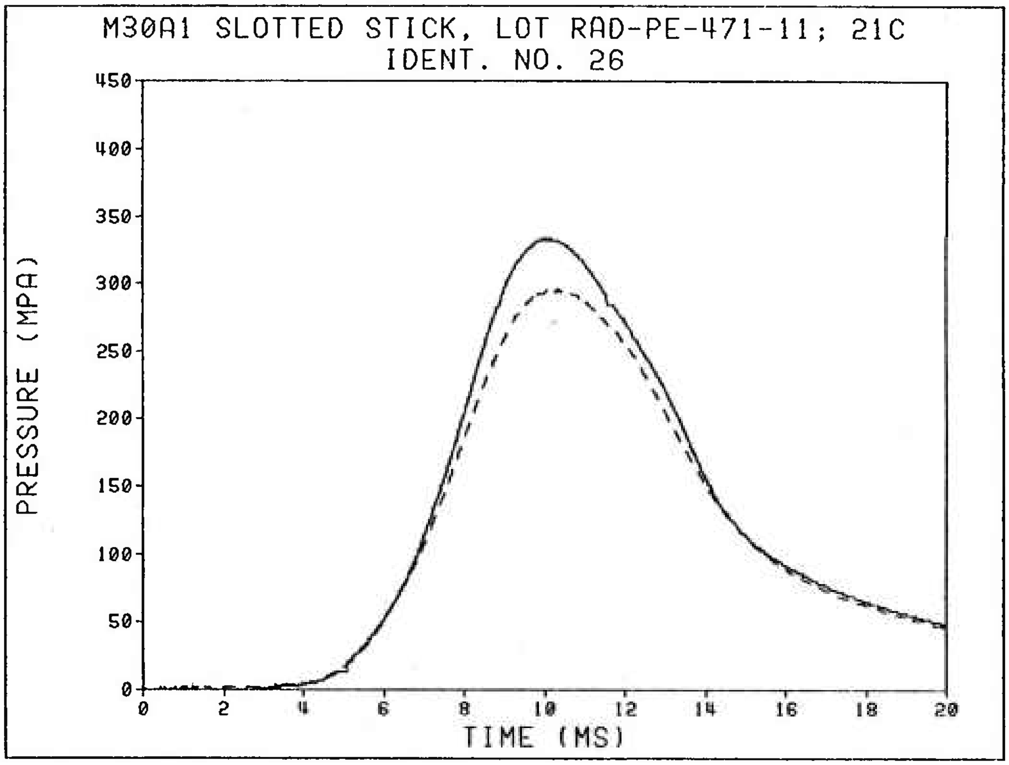
-10
-5
0
5
10
15
20
25
30
35
40
45
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-471-11; 21C
IDENT. NO. 26
PRESSURE (MPA)
TIME (MS)
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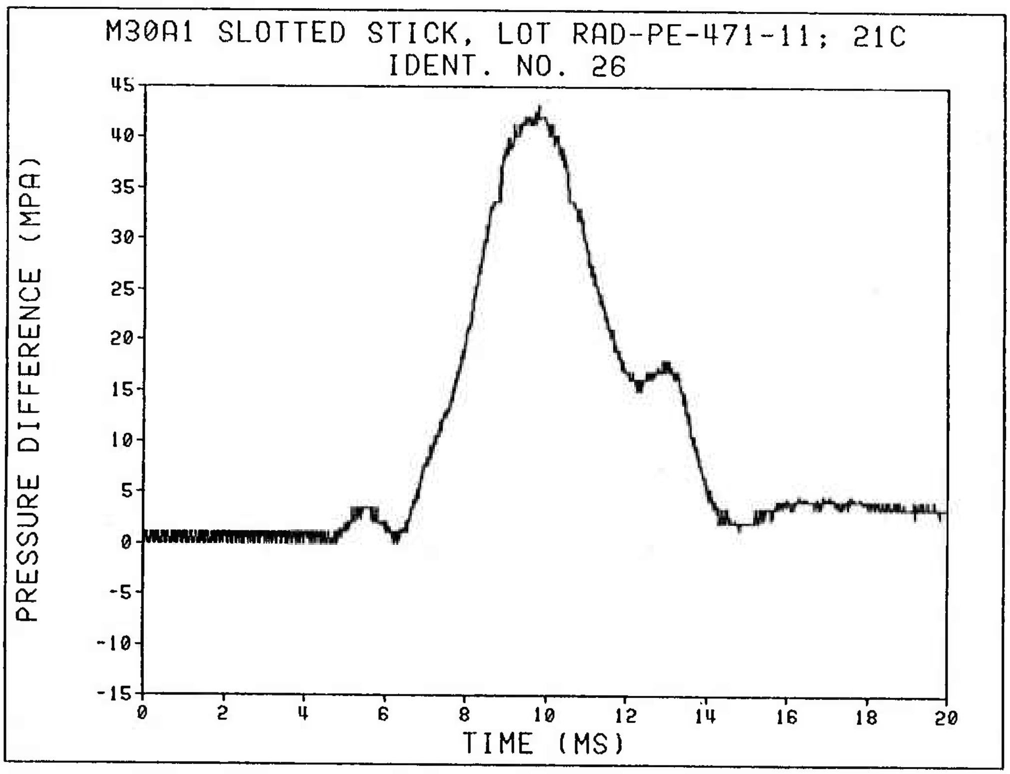
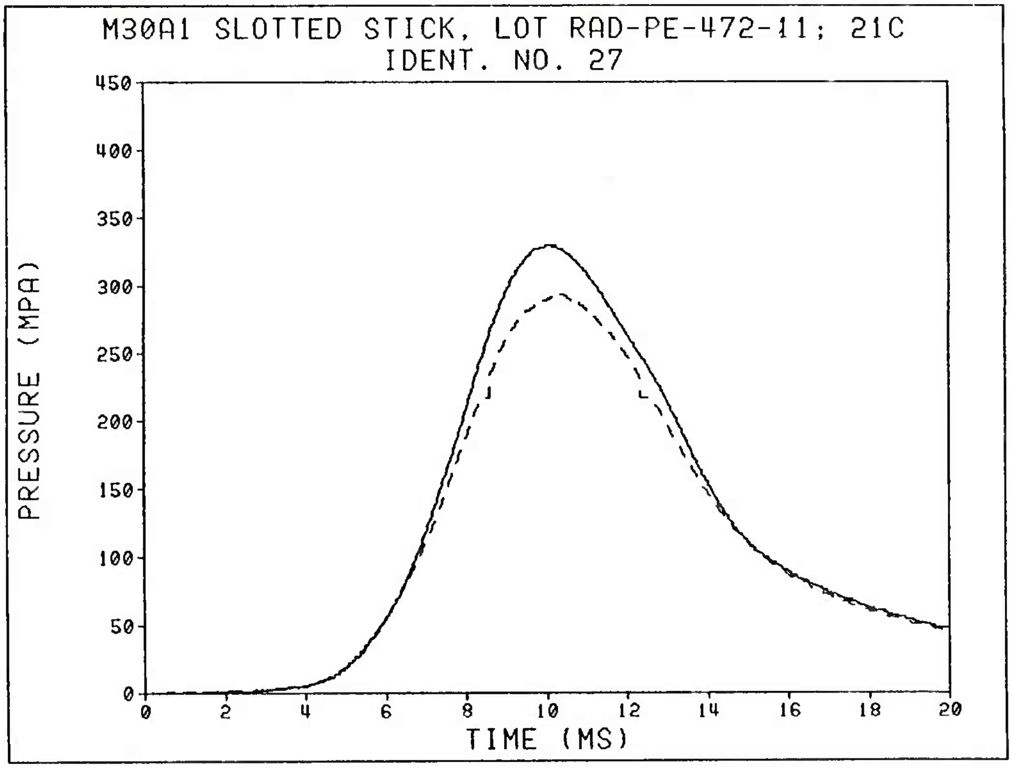
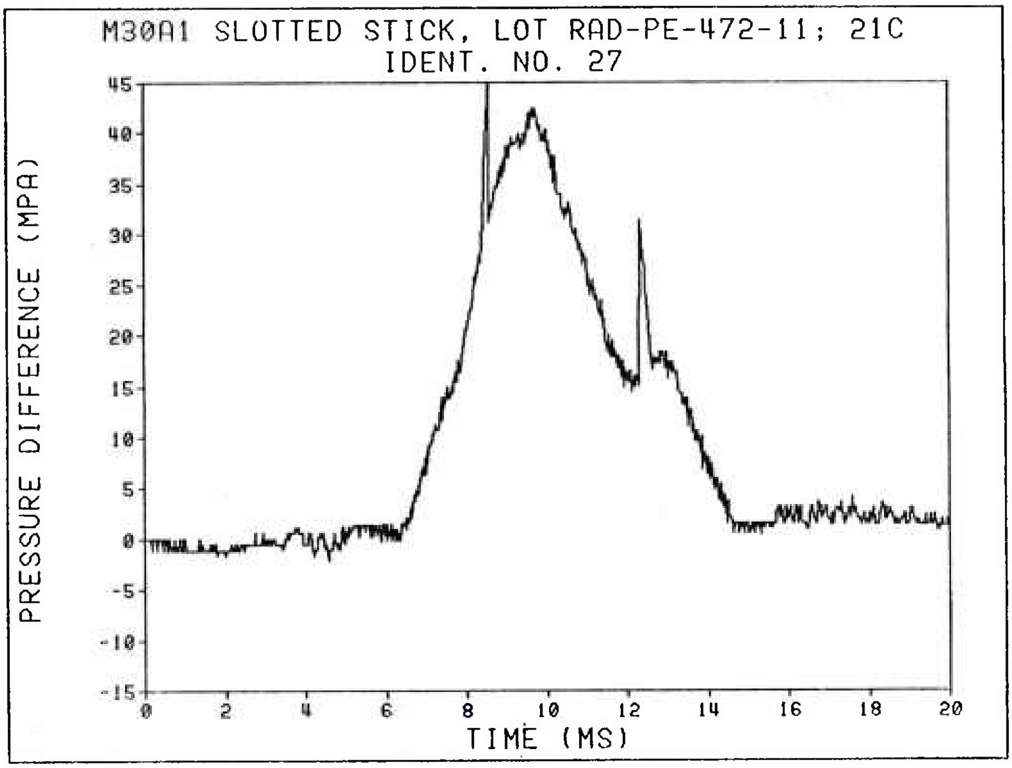
2
4
6
8
10
12
14
16
18
20
0
50
100
150
200
250
300
350
400
450


M30A1 SLOTTED STICK, LOT RAD-PE-471-11; 21C
IDENT. NO. 26
PRESSURE DIFFERENCE (MPA)
TIME (MS)
0
2
4
6
8
10
12
14
16
18
20
-15
-10
-5
0
5
10
15
20
25
30
35
40
45


M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 21C
IDENT. NO. 27
PRESSURE (MPA)
TIME (MS)
0
50
100
150
200
250
300
350
400
450
0
2
4
6
8
10
12
14
16
18
20


M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 21C
IDENT. NO. 27
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
5
10
15
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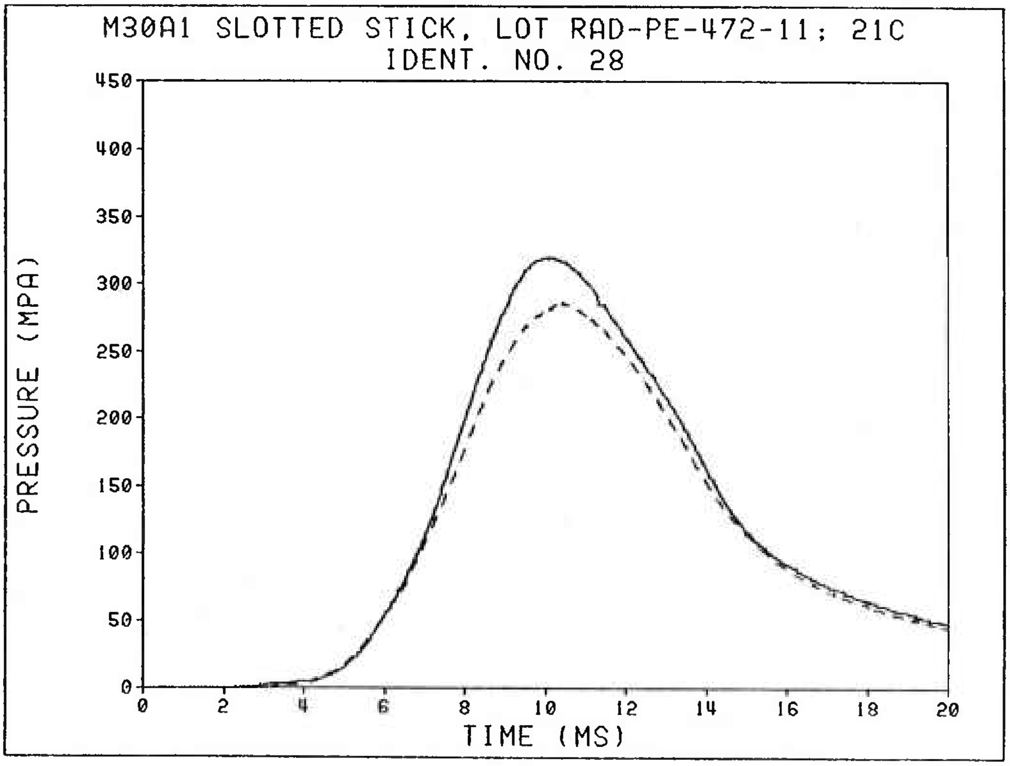
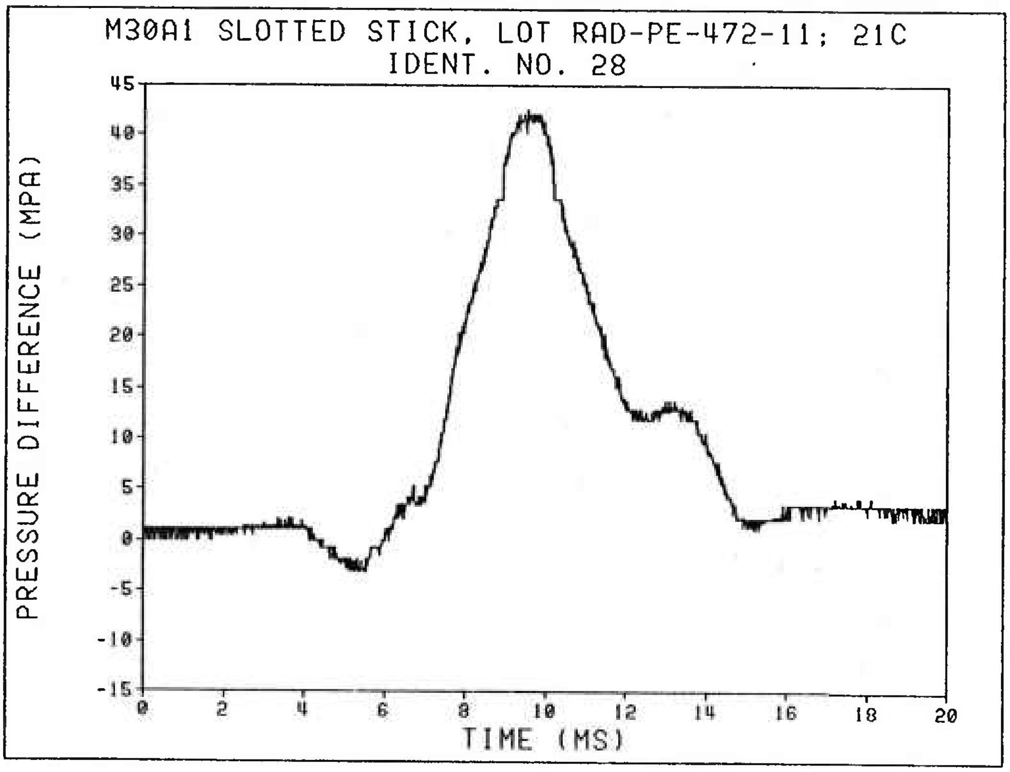
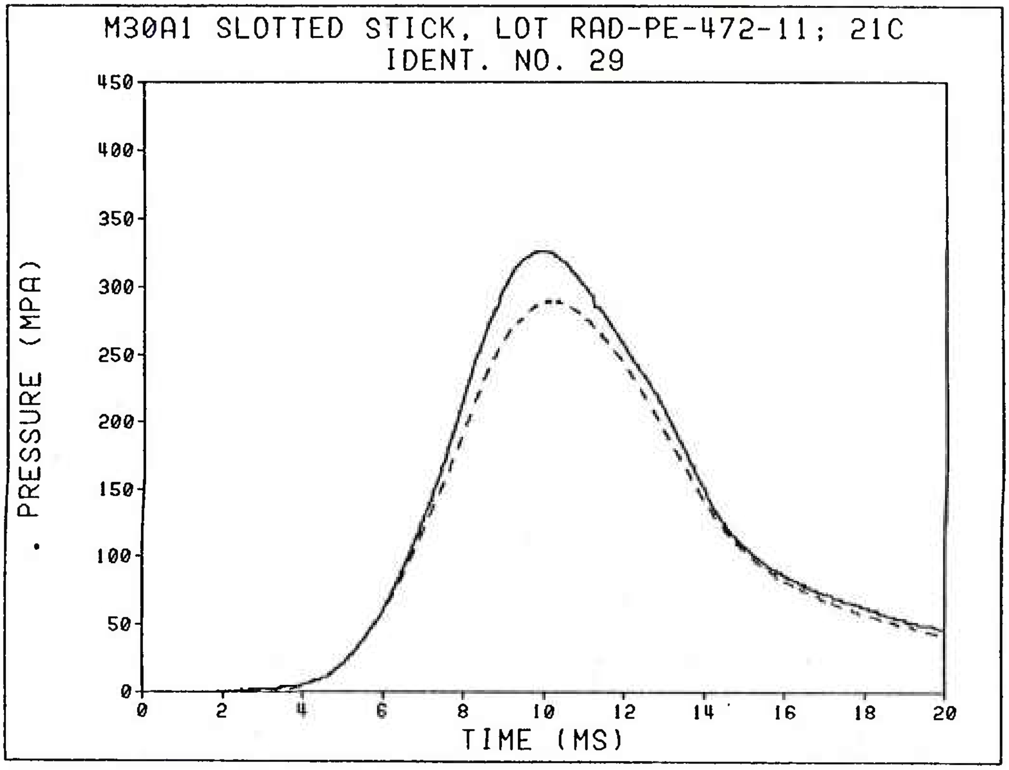
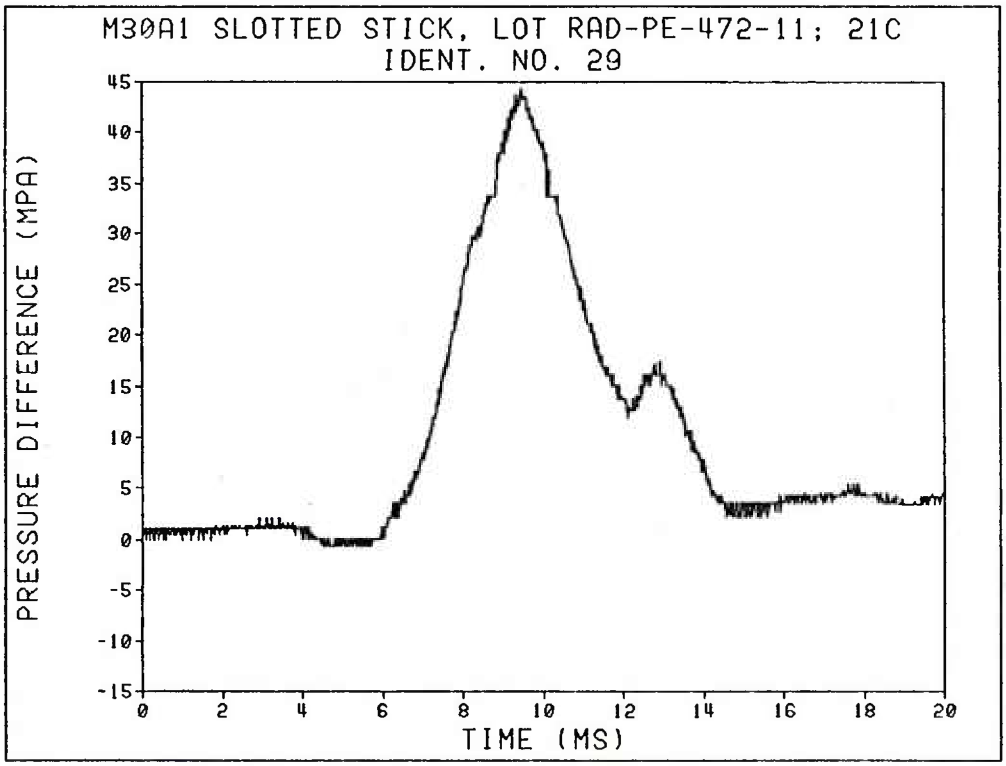
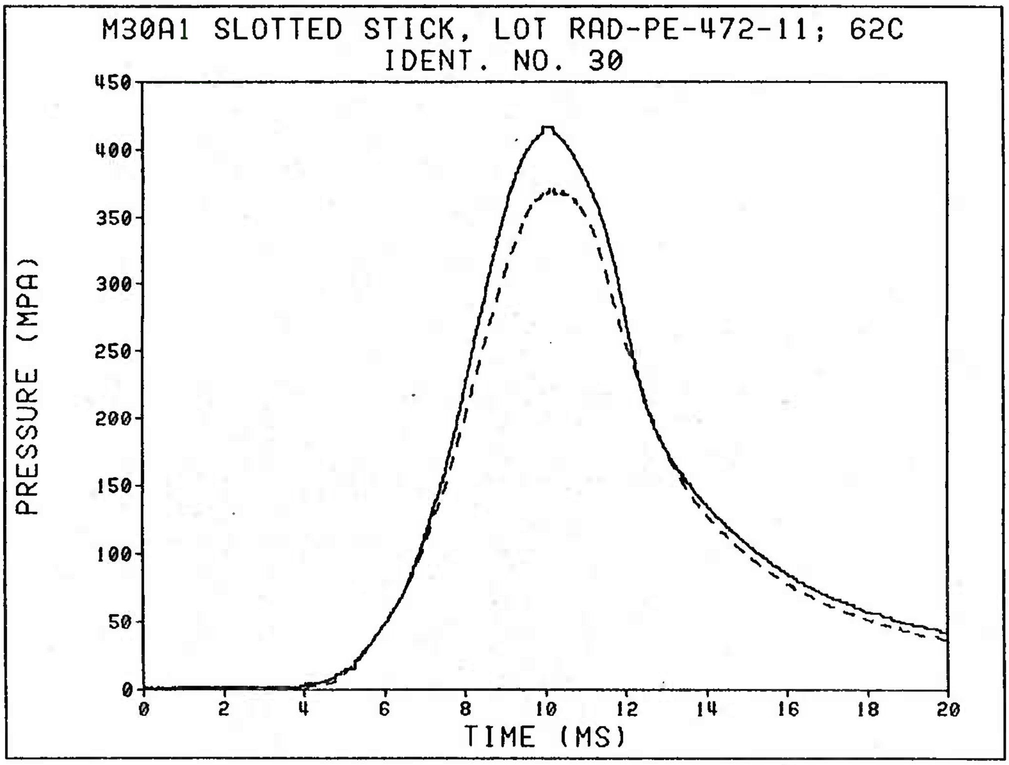
25
30
35
40
45
0
2
4
6
8
10
12
14
16
18
20

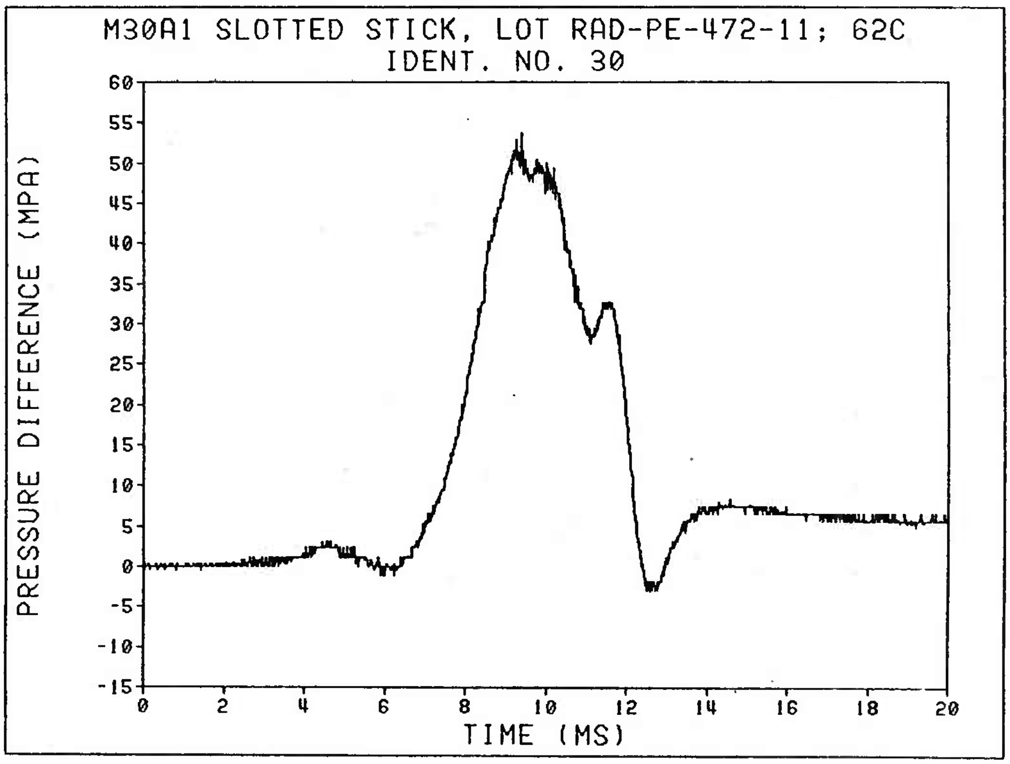

M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 21C
IDENT. NO. 28
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)

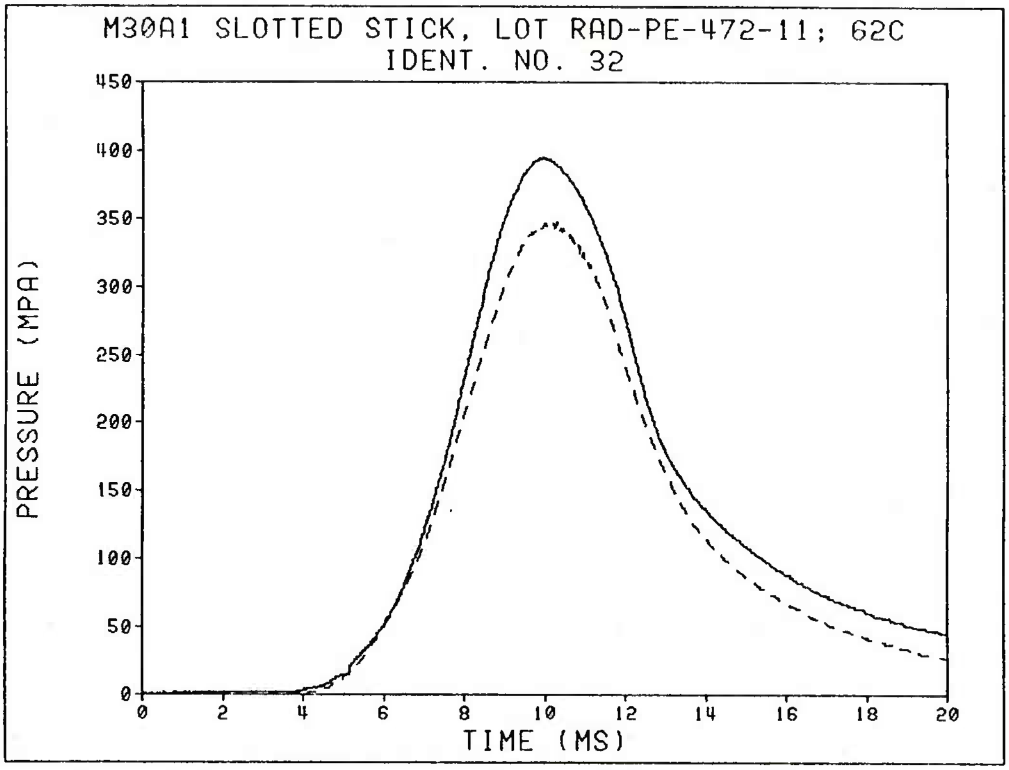

M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 21C
IDENT. NO. 28
PRESSURE DIFFERENCE (MPA)
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 21C
IDENT. NO. 29
PRESSURE (MPA)
TIME (MS)
0
50
100
150
200
250
300
350
400
450
2
4
6
8
10
12
14
16
18
20

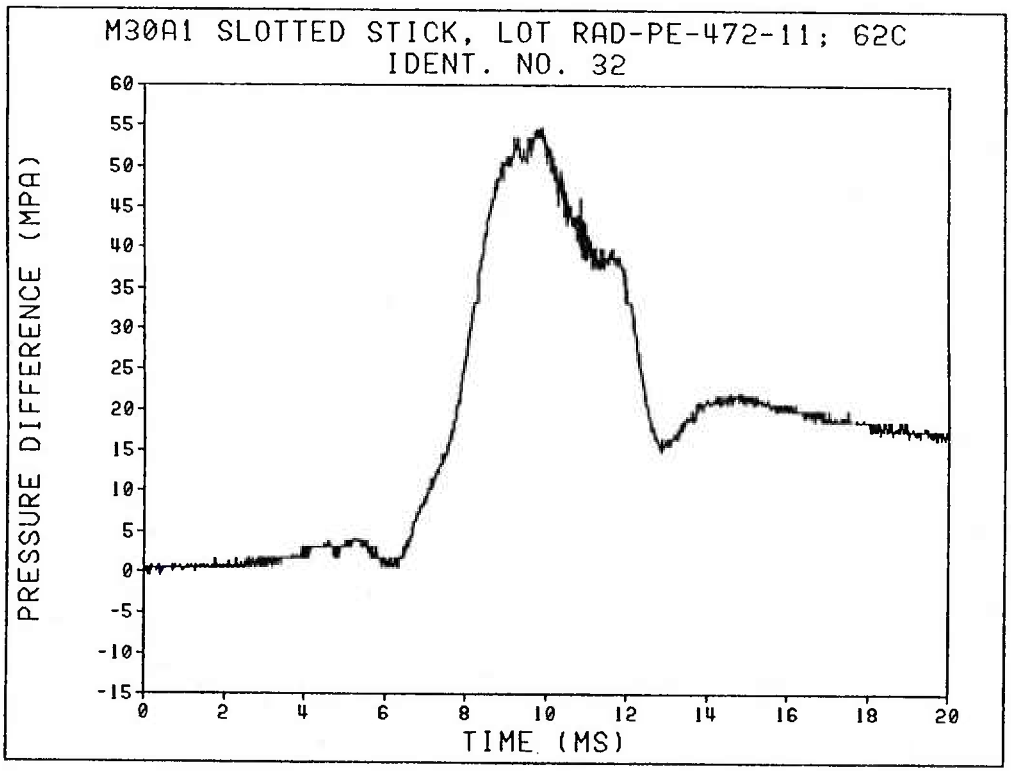

M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 21C
IDENT. NO. 29
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
2
4
6
8
10
12
14
16
18
20


M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 62C
IDENT. NO. 30
PRESSURE (MPA)
TIME (MS)
0
50
100
150
200
250
300
350
400
450
0
2
4
6
8
10
12
14
16
18
20

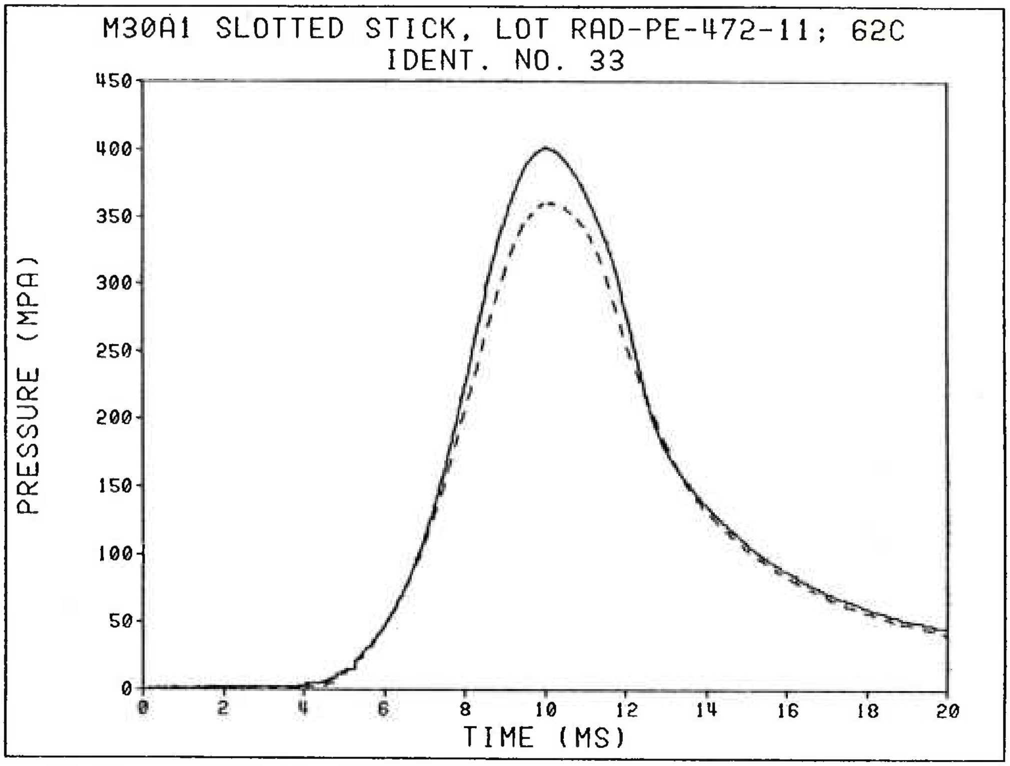

M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 62C
IDENT. NO. 30
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
0
2
4
6
8
10
12
14
16
18
20



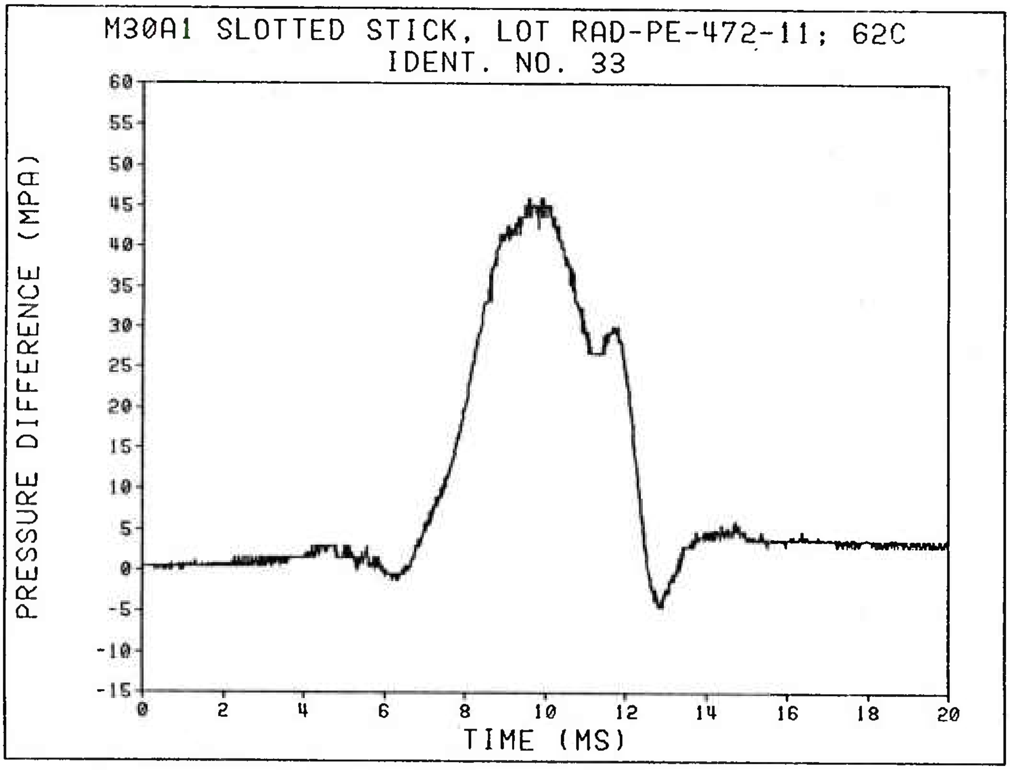
M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 62C
IDENT. NO. 32
PRESSURE (MPA)
TIME (MS)



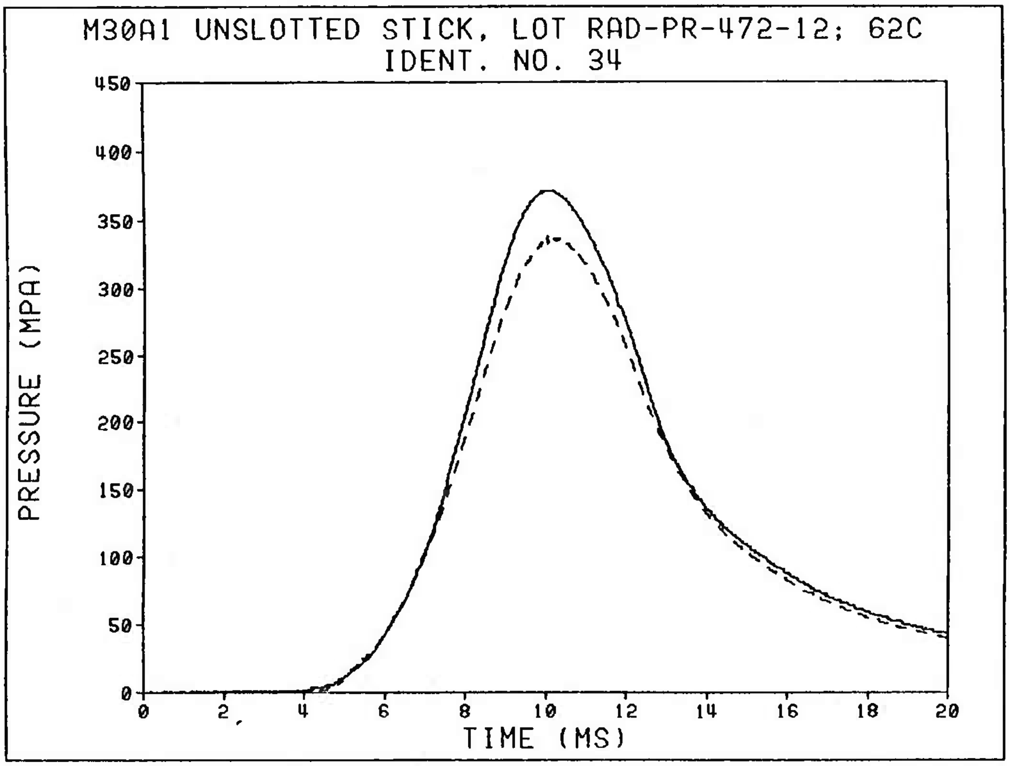
M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 62C
IDENT. NO. 32
PRESSURE DIFFERENCE (MPA)
TIME (MS)

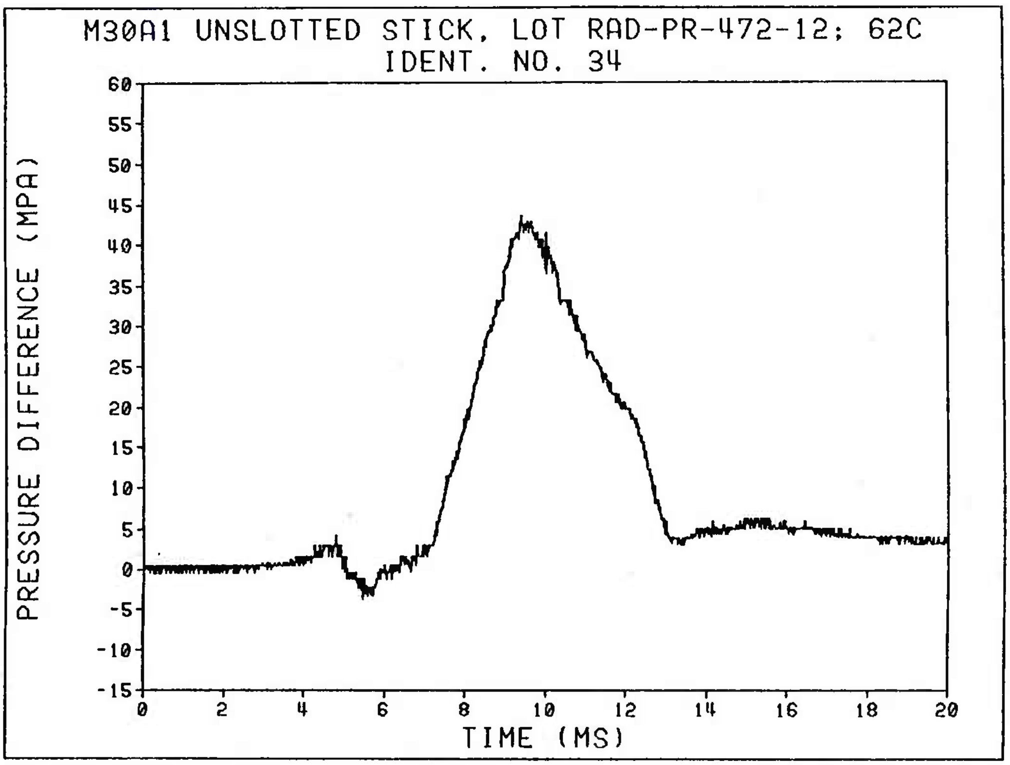


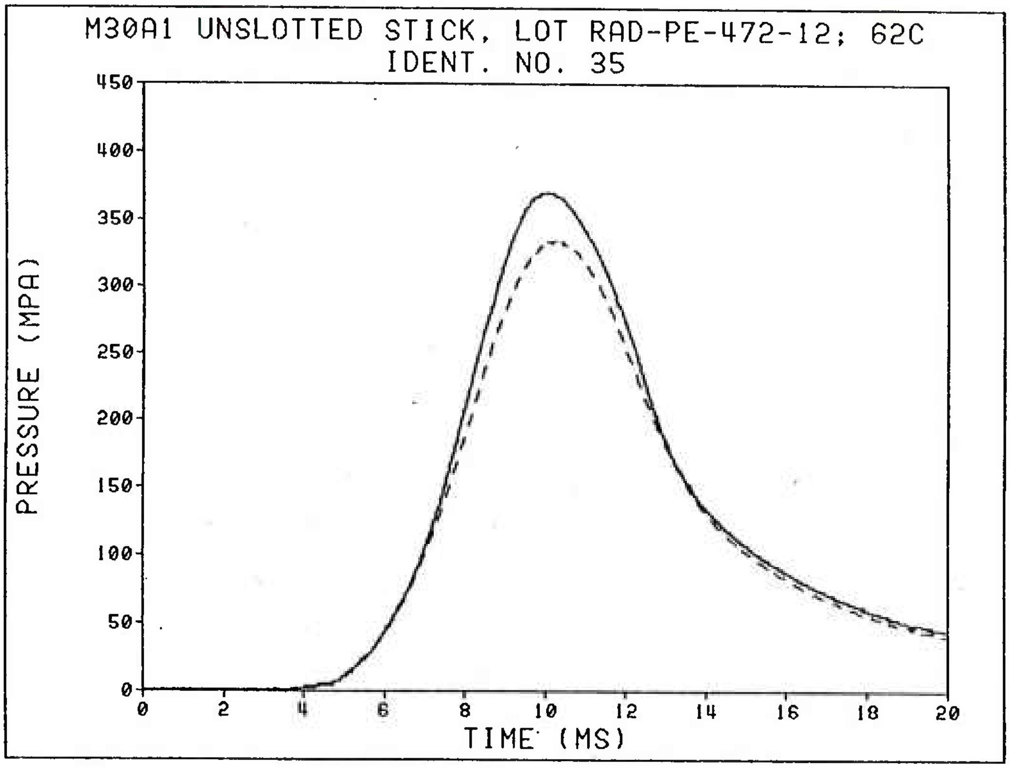
M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 62C
IDENT. NO. 33
PRESSURE (MPA)
TIME (MS)

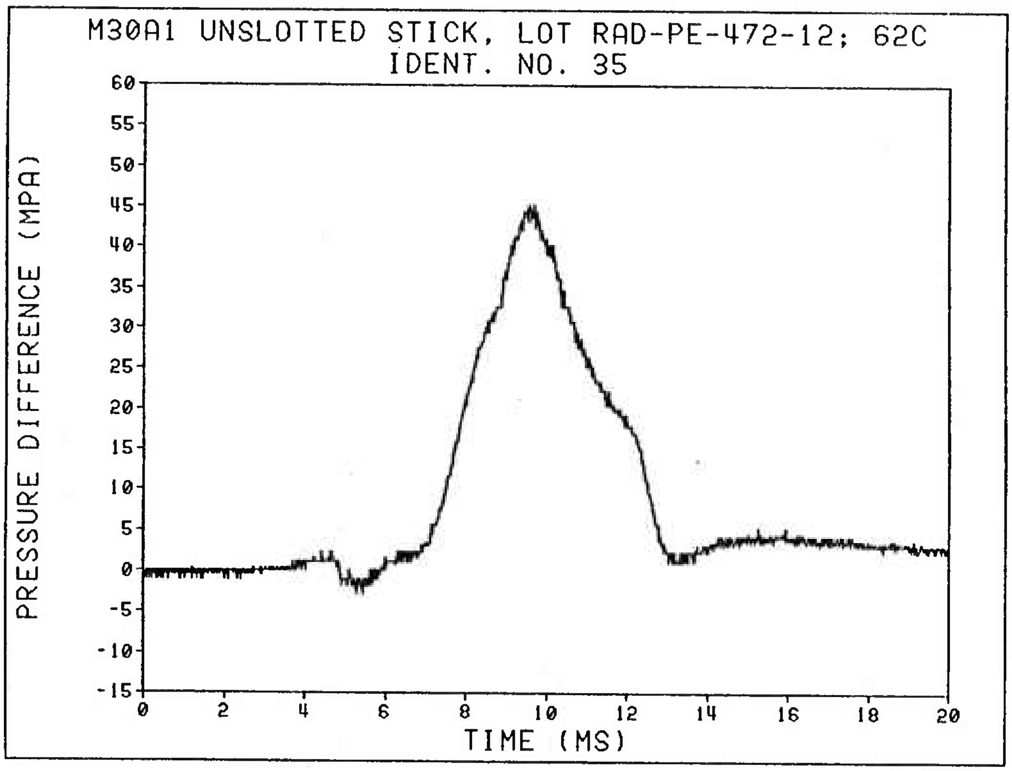


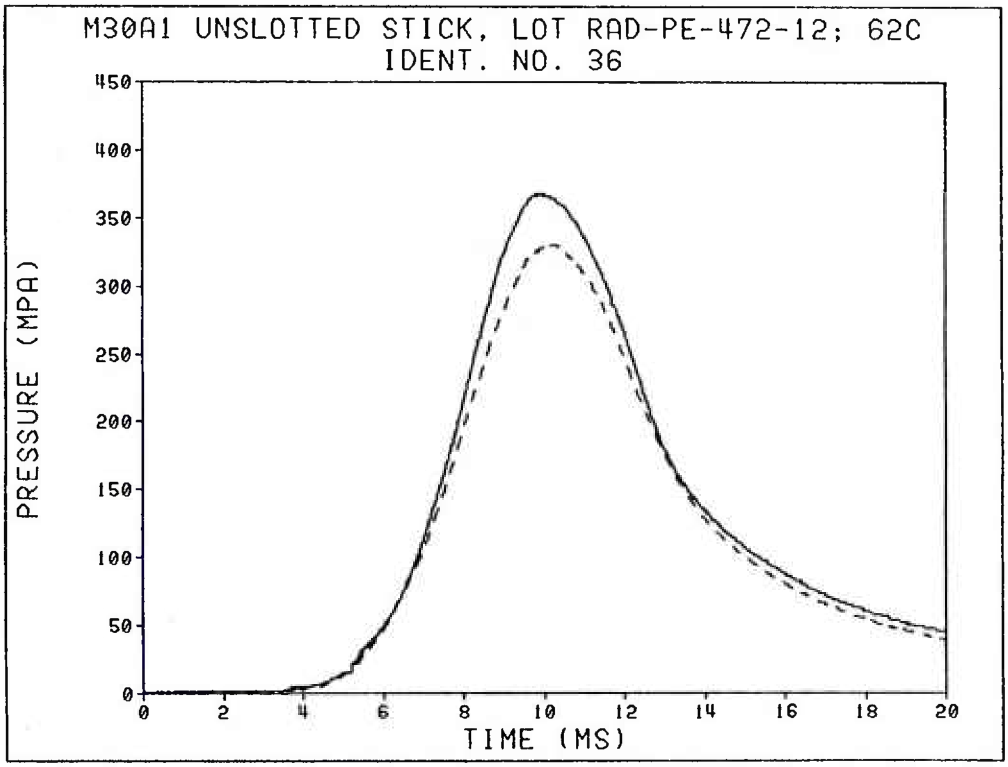
M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 62C
IDENT. NO. 33
PRESSURE DIFFERENCE (MPA)
TIME (MS)

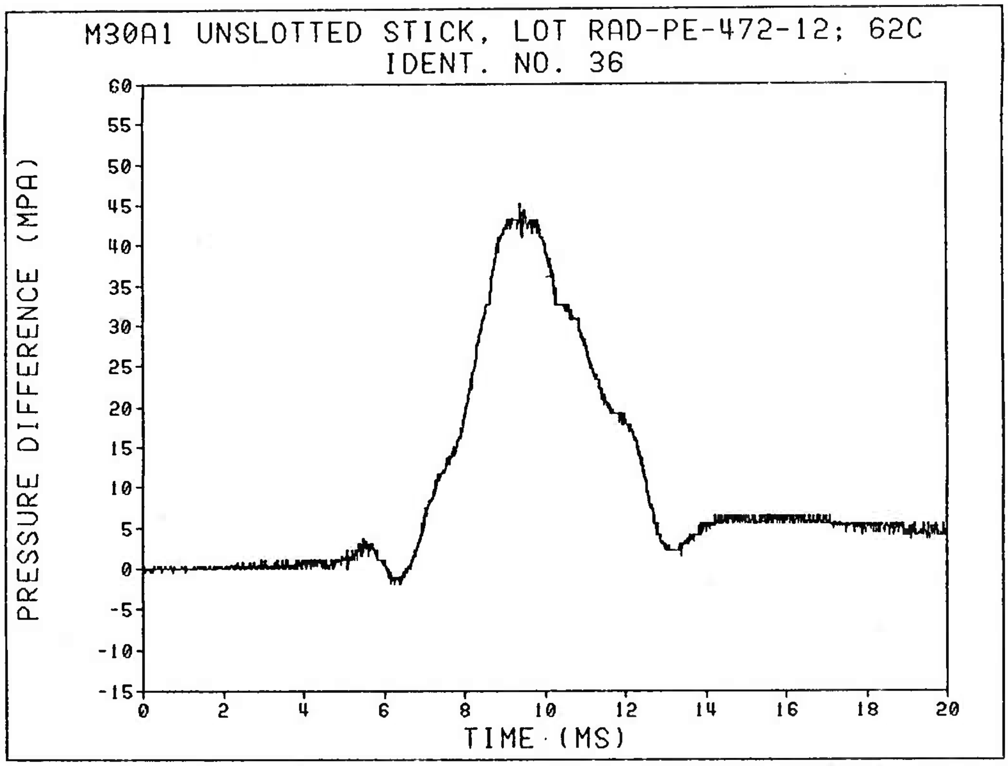

M30A1 UNSLOTTED STICK, LOT RAD-PR-472-12; 62C
IDENT. NO. 34
PRESSURE (MPA)
TIME (MS)
0
50
100
150
200
250
300
350
400
450
0
2
4
6
8
10
12
14
16
18
20

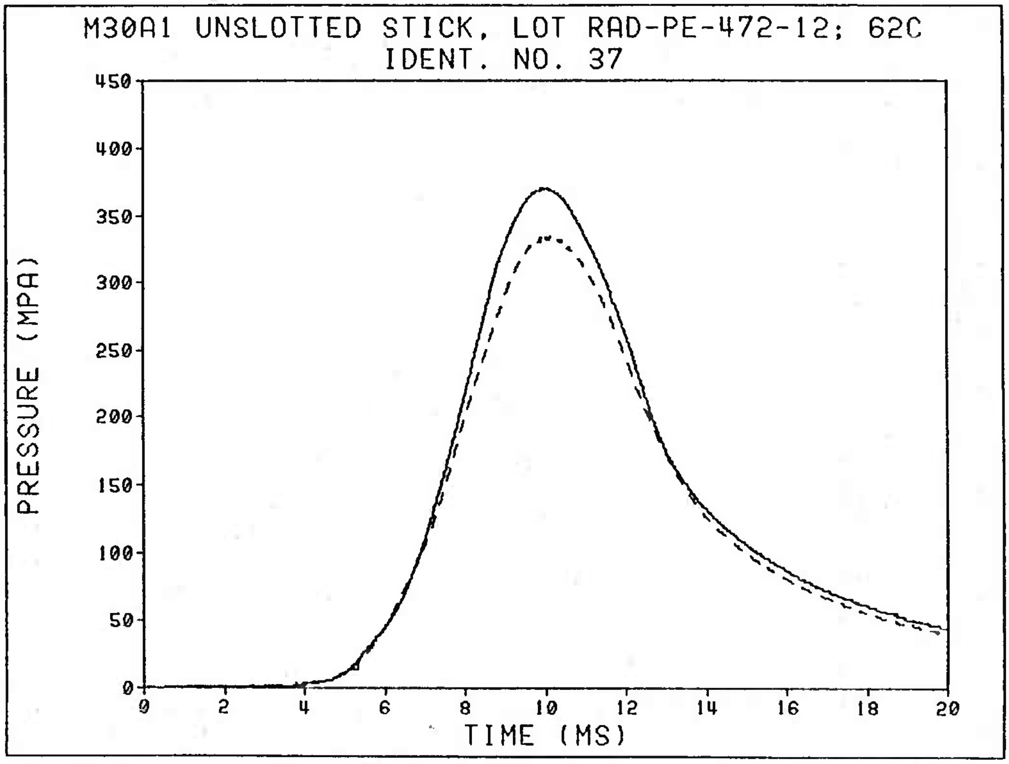

M30A1 UNSLOTTED STICK, LOT RAD-PR-472-12; 62C
IDENT. NO. 34
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
0
2
4
6
8
10
12
14
16
18
20

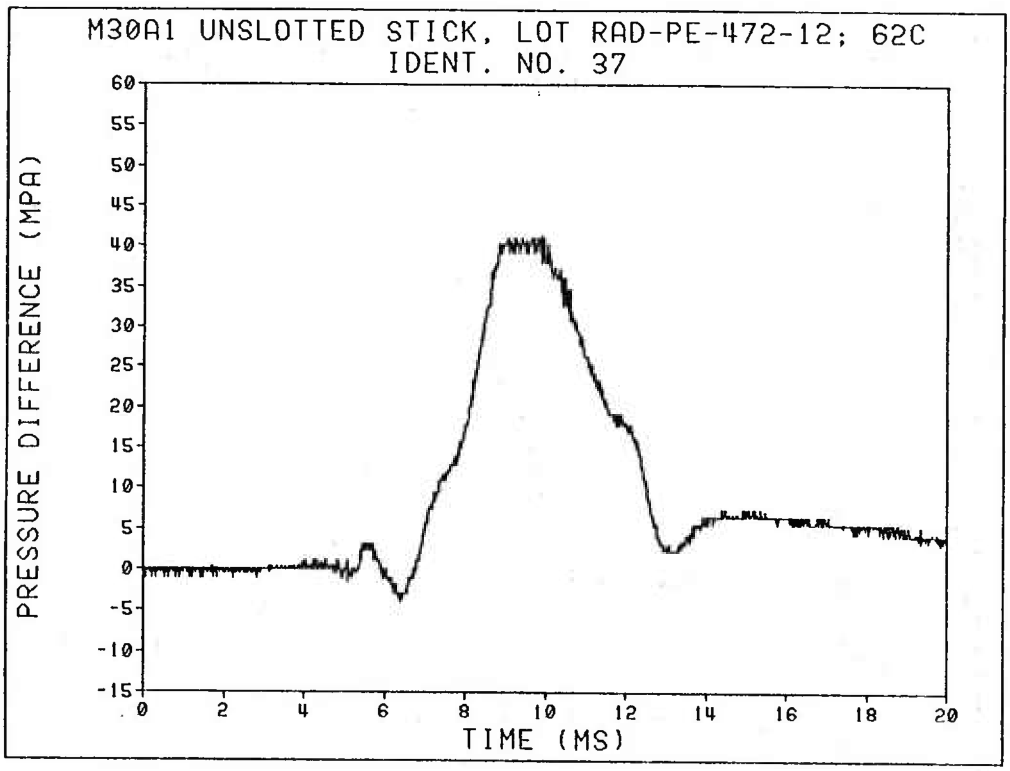

M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; 62C
IDENT. NO. 35
PRESSURE (MPA)
TIME (MS)
0
50
100
150
200
250
300
350
400
450
0
2
4
6
8
10
12
14
16
18
20

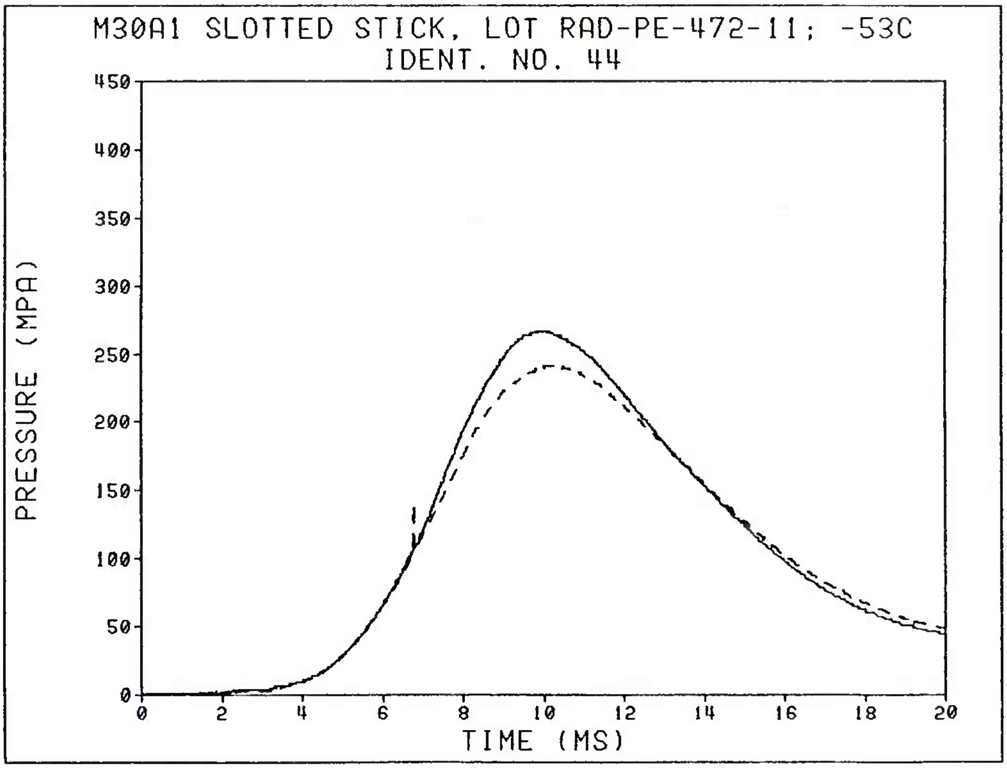

M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; 62C
IDENT. NO. 35
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
0
2
4
6
8
10
12
14
16
18
20

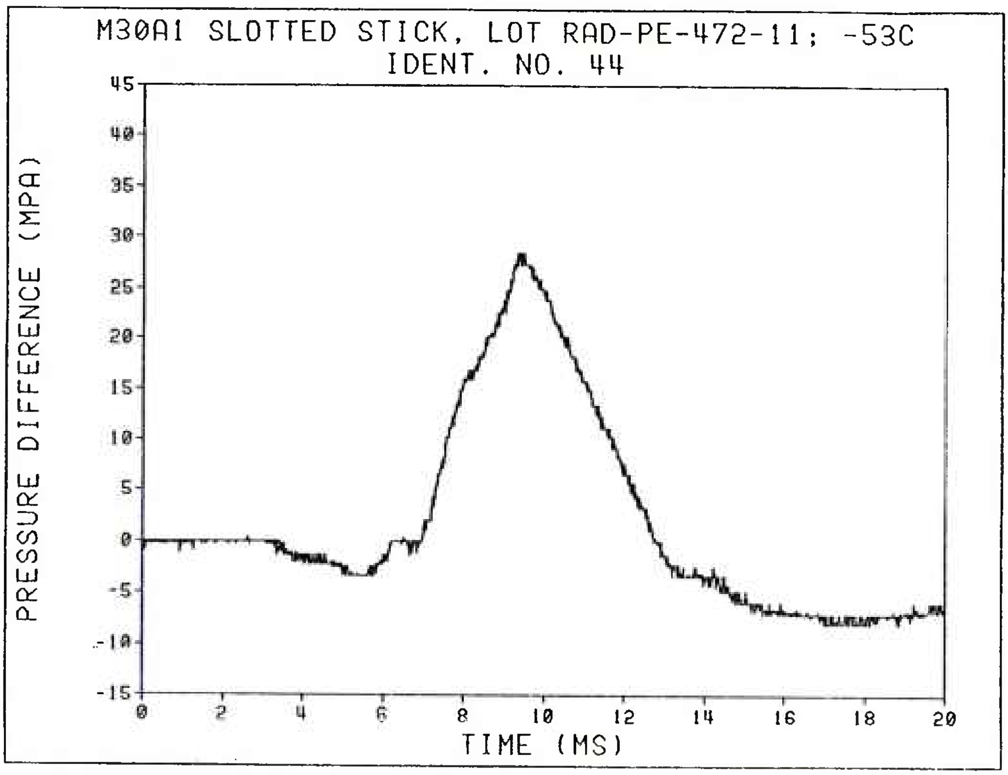

M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; 62C
IDENT. NO. 36
PRESSURE (MPA)
TIME (MS)
0
50
100
150
200
250
300
350
400
450
0
2
4
6
8
10
12
14
16
18
20

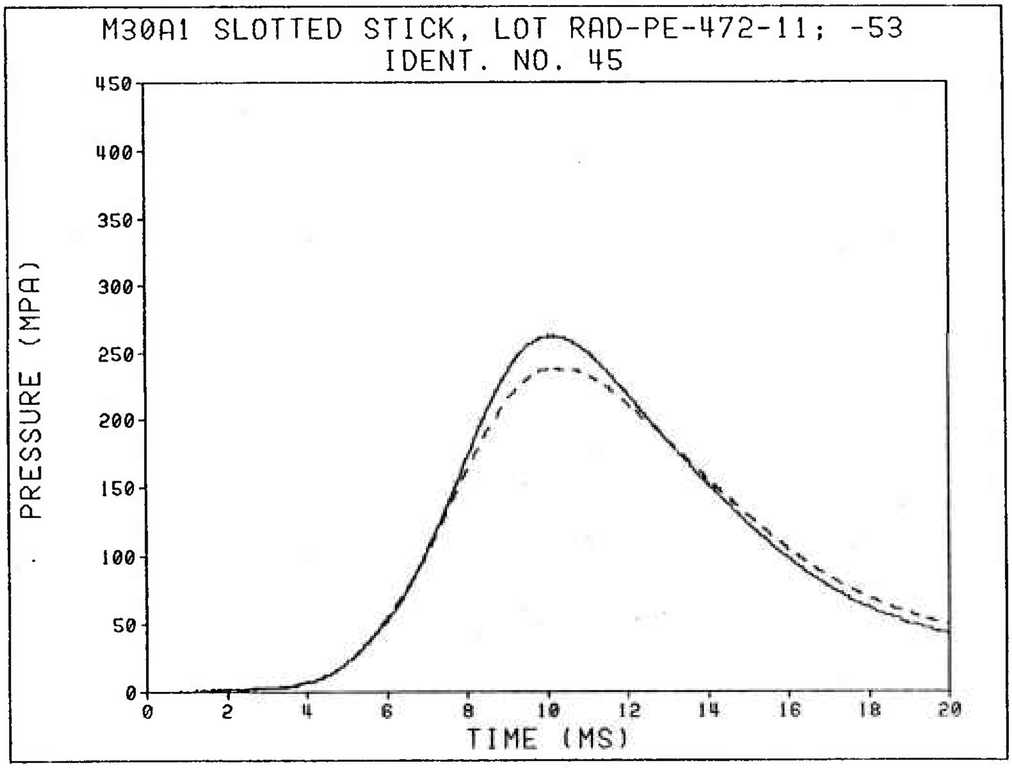

M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; 62C
IDENT. NO. 36
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
0
2
4
6
8
10
12
14
16
18
20

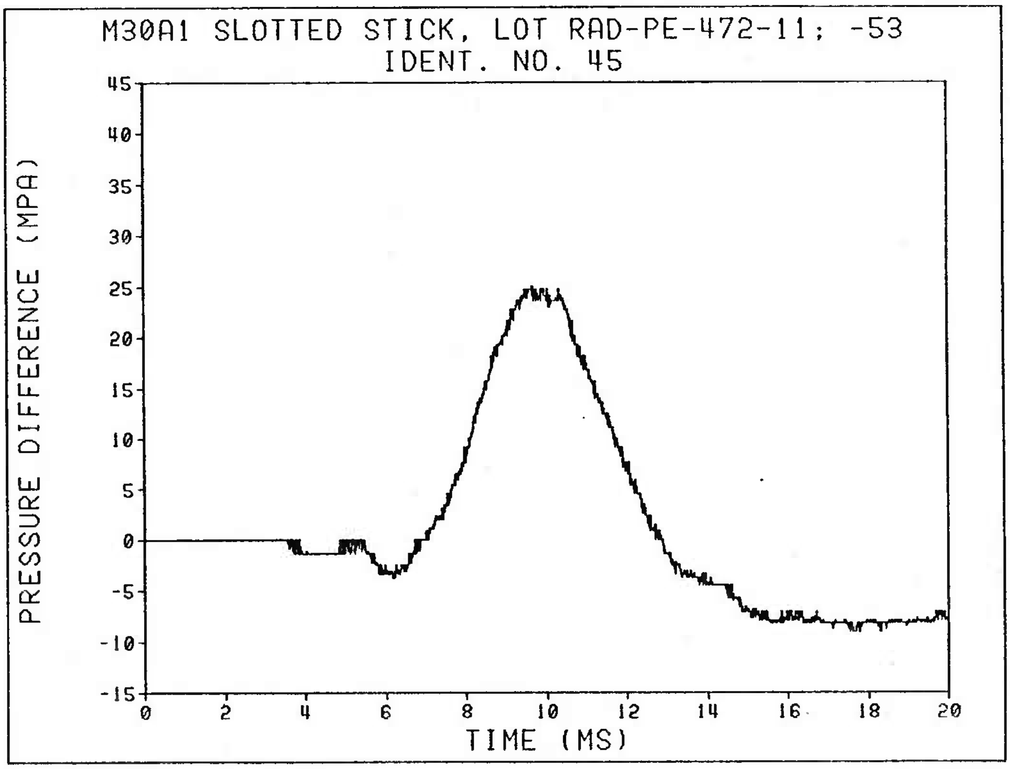

M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; 62C
IDENT. NO. 37
PRESSURE (MPA)
TIME (MS)
0
50
100
150
200
250
300
350
400
450
2
4
6
8
10
12
14
16
18
20

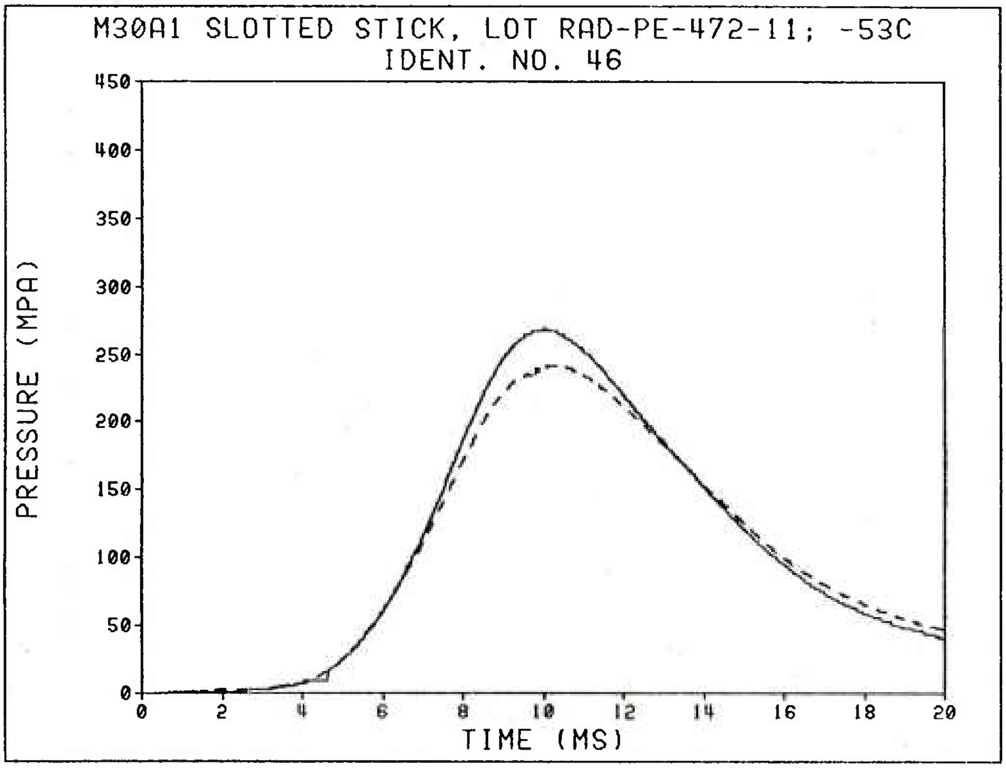

M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; 62C
IDENT. NO. 37
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
2
4
6
8
10
12
14
16
18
20


M30A1 SLOTTED STICK, LOT RAD-PE-472-11; -53C
IDENT. NO. 44
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)

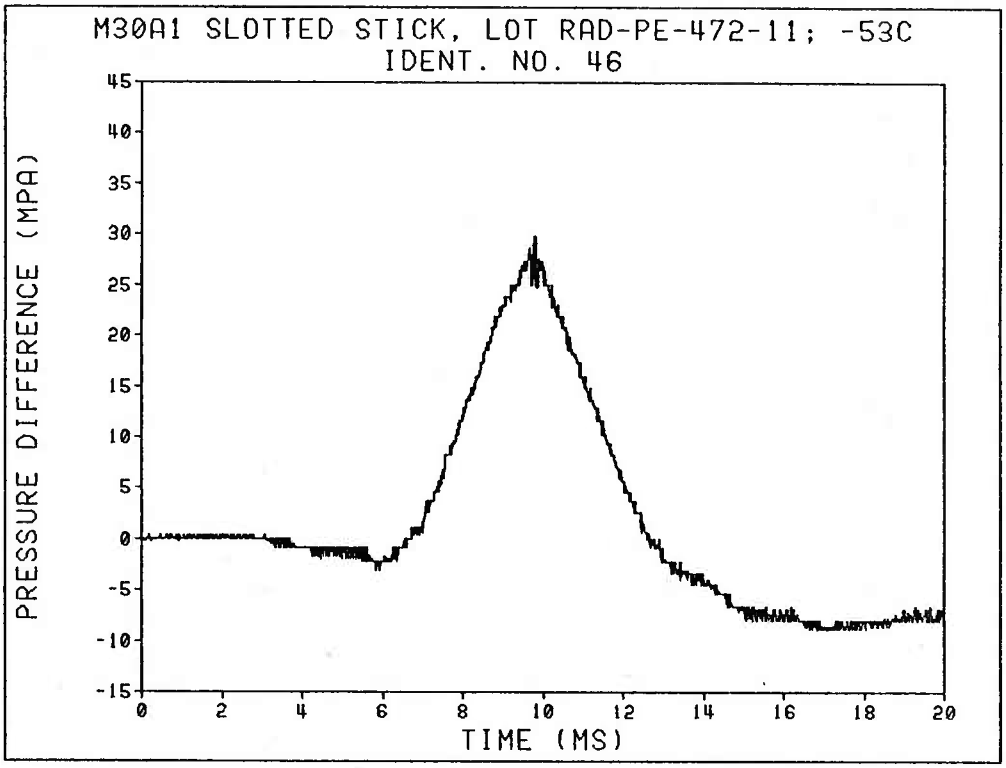

M30A1 SLOTTED STICK, LOT RAD-PE-472-11; -53C
IDENT. NO. 44
PRESSURE DIFFERENCE (MPA)
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-472-11; -53
IDENT. NO. 45
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)

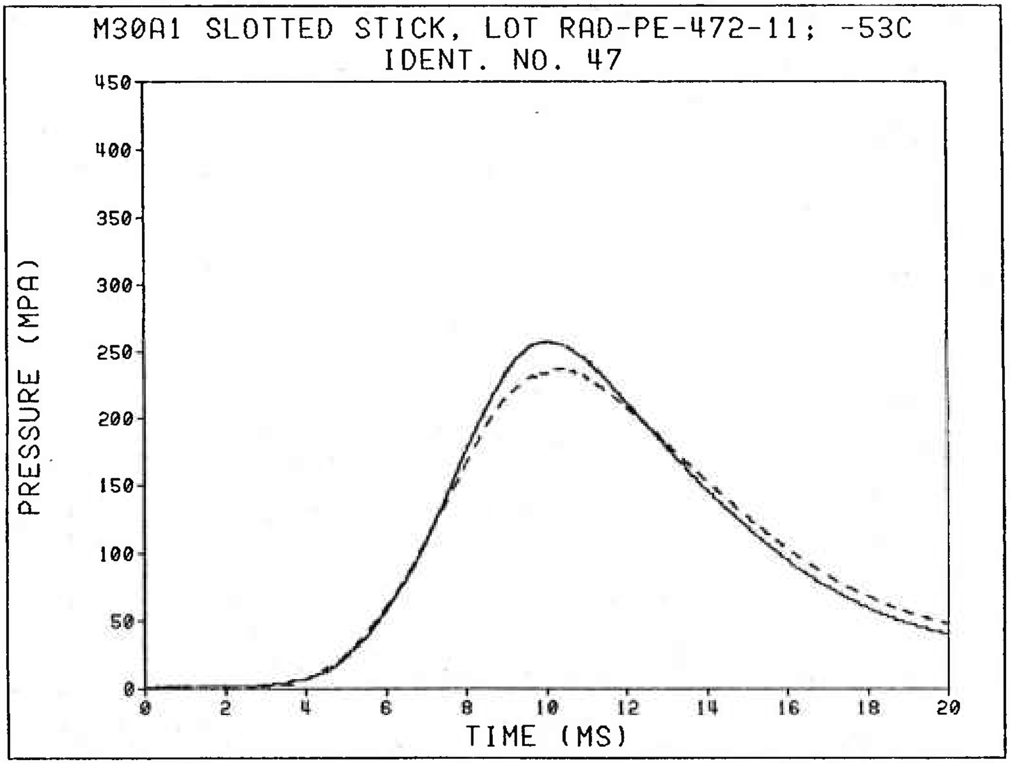

M30A1 SLOTTED STICK, LOT RAD-PE-472-11; -53
IDENT. NO. 45
PRESSURE DIFFERENCE (MPA)
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)

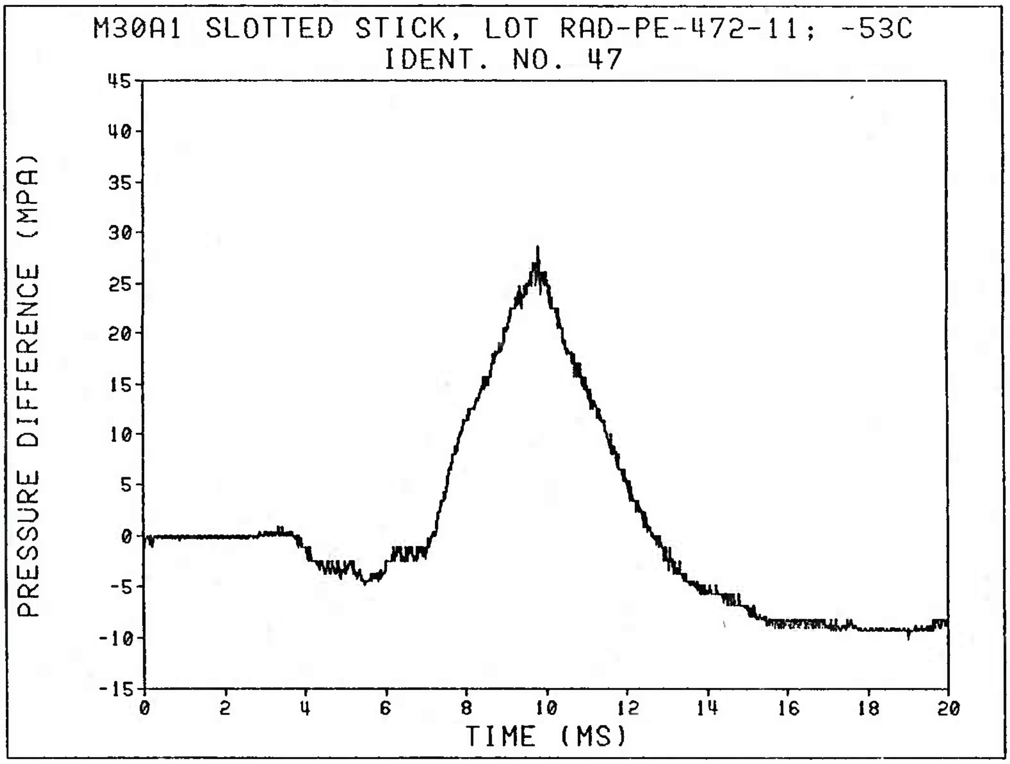


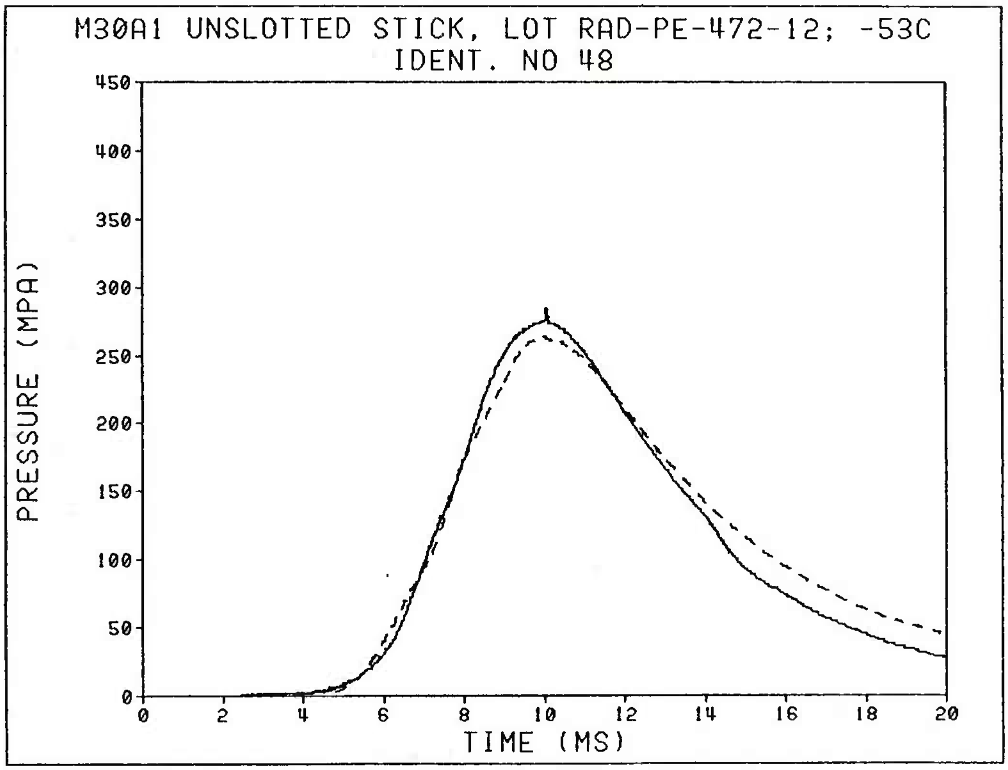
M30A1 SLOTTED STICK, LOT RAD-PE-472-11; -53C
IDENT. NO. 46
PRESSURE (MPA)
TIME (MS)
0
50
100
150
200
250
300
350
400
450
0
2
4
6
8
10
12
14
16
18
20

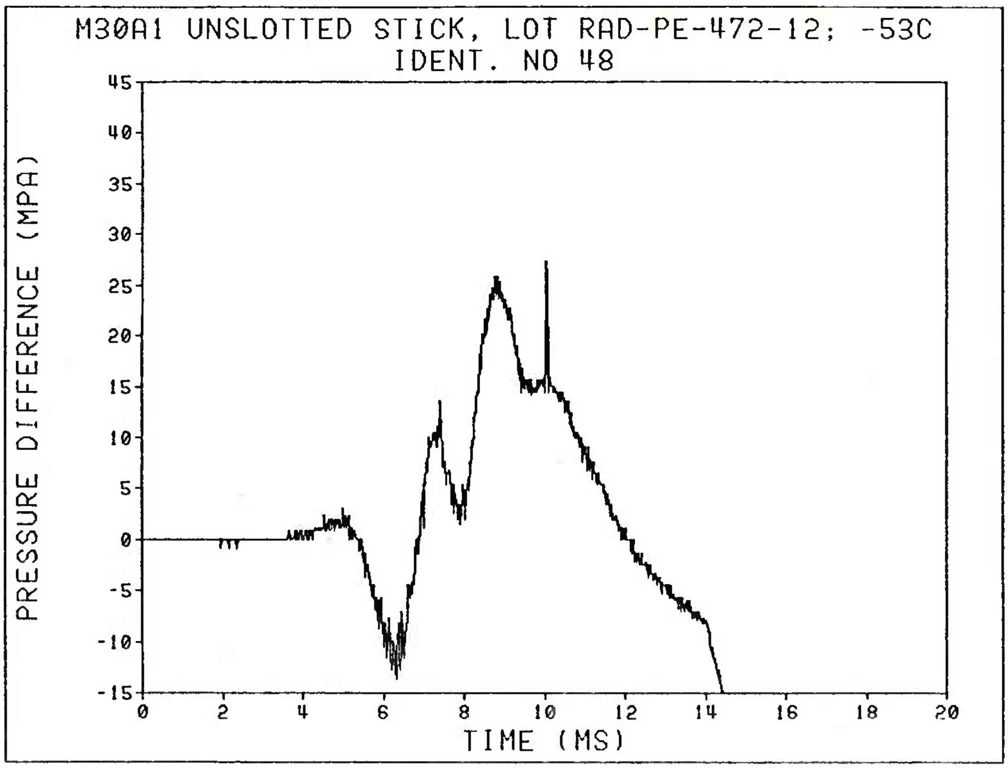


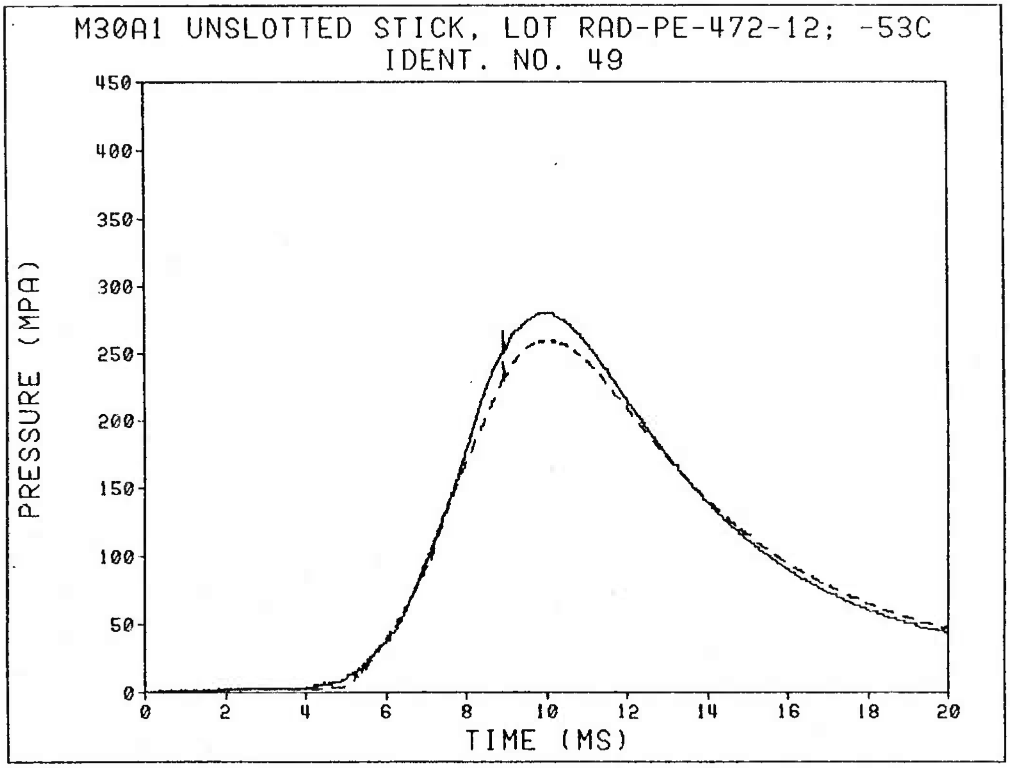
M30A1 SLOTTED STICK, LOT RAD-PE-472-11; -53C
IDENT. NO. 46
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
0
2
4
6
8
10
12
14
16
18
20

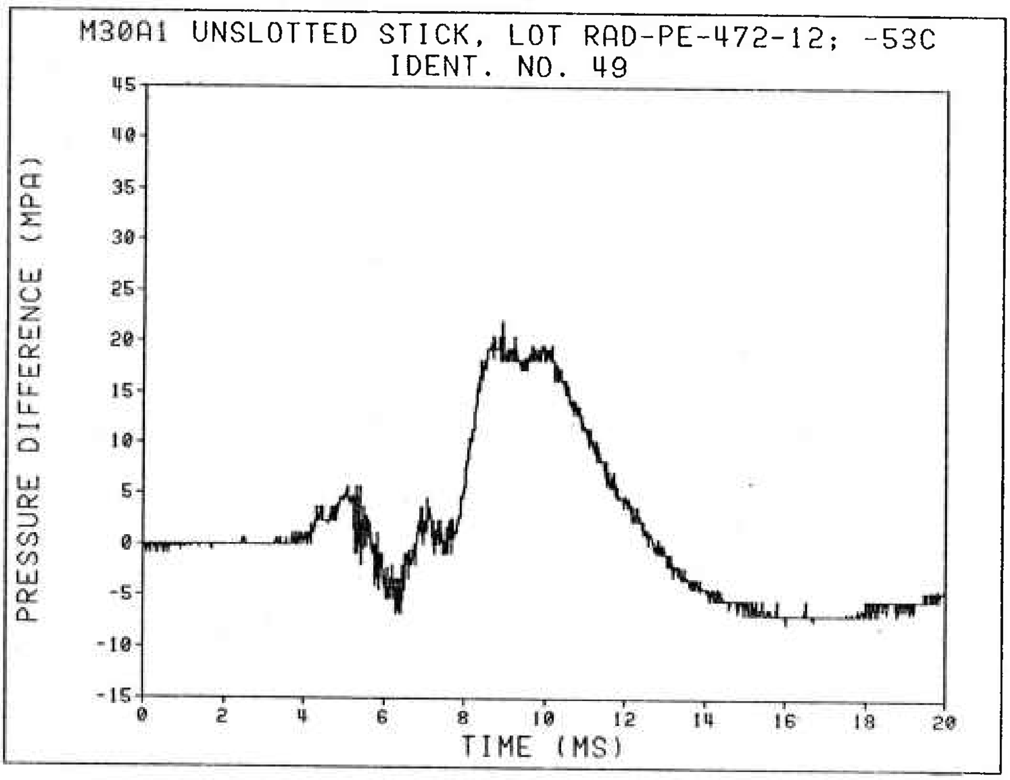

M30A1 SLOTTED STICK, LOT RAD-PE-472-11; -53C
IDENT. NO. 47
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)

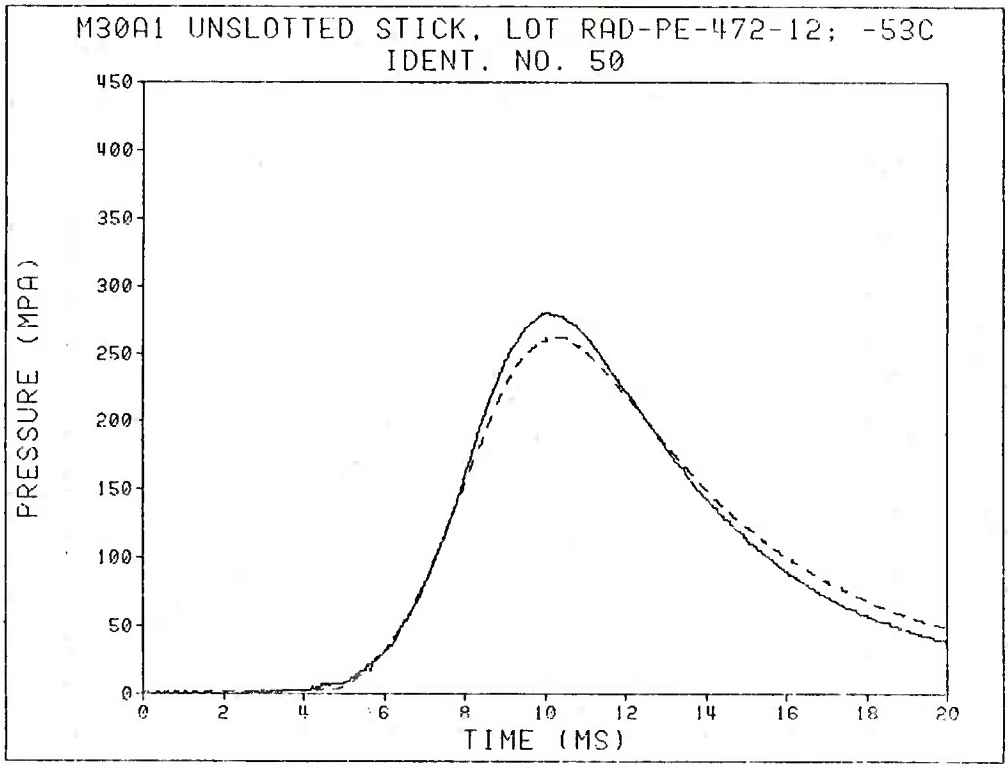

M30A1 SLOTTED STICK, LOT RAD-PE-472-11; -53C
IDENT. NO. 47
PRESSURE DIFFERENCE (MPA)
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)

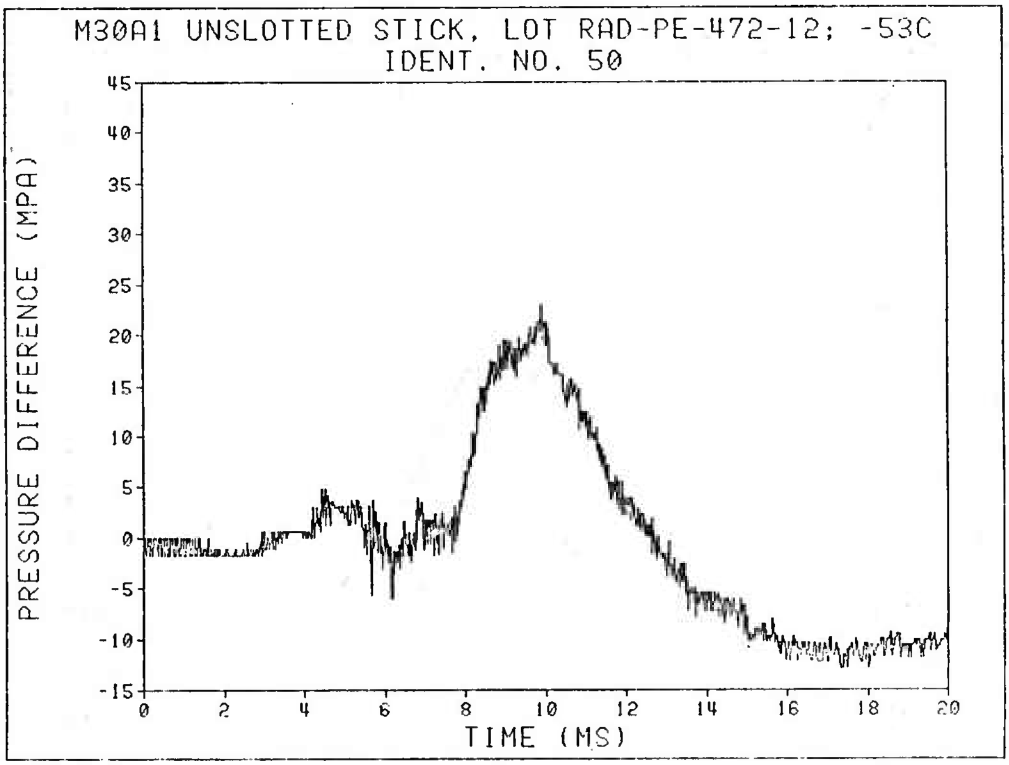

M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; -53C
IDENT. NO 48
PRESSURE (MPA)
TIME (MS)
0
50
100
150
200
250
300
350
400
450
0
2
4
6
8
10
12
14
16
18
20

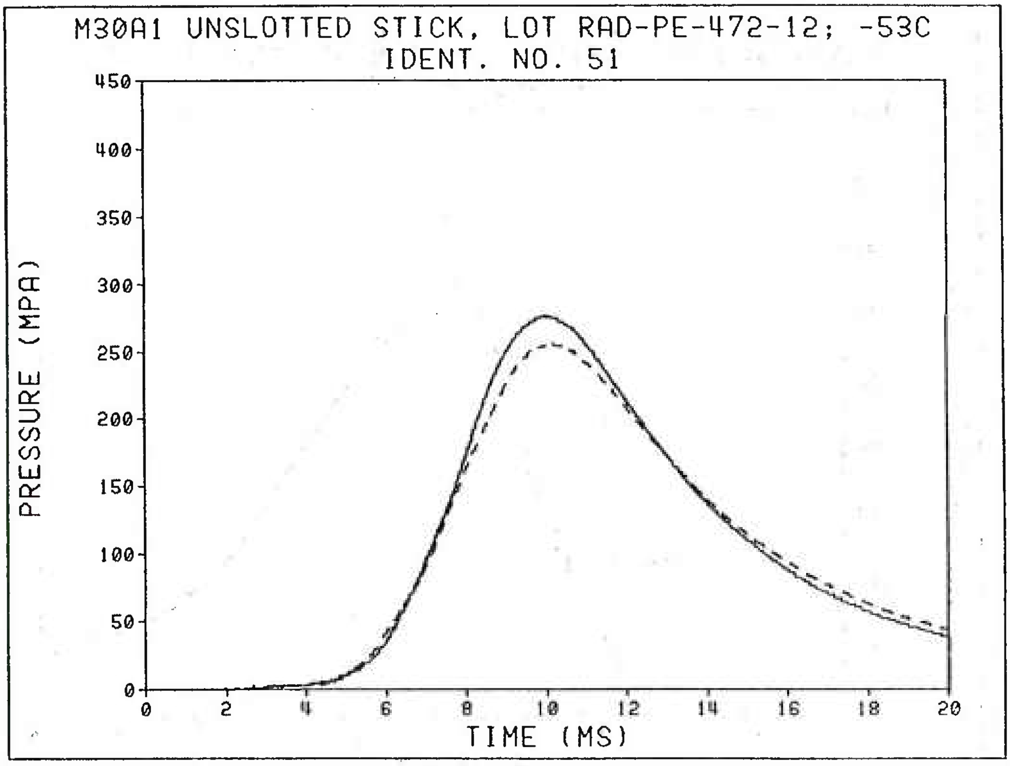

M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; -53C
IDENT. NO 48
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
0
2
4
6
8
10
12
14
16
18
20


M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; -53C
IDENT. NO. 49
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
0 2 4 6 8 10 12 14 16 18 20
TIME (MS)

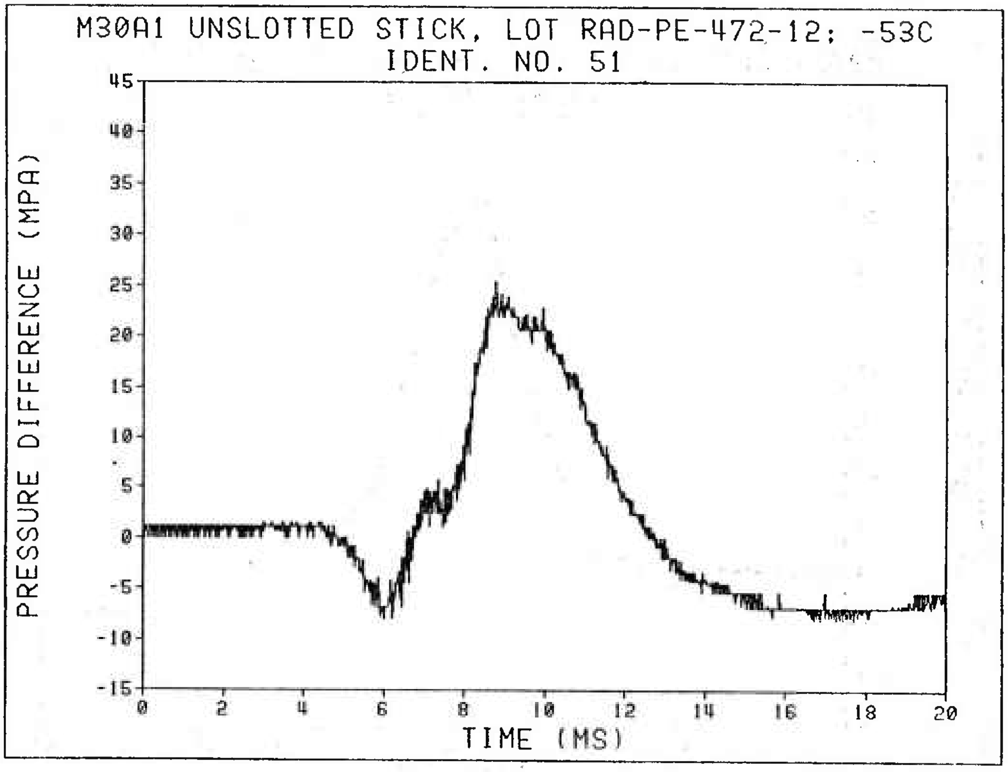

M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; -53C
IDENT. NO. 49
PRESSURE DIFFERENCE (MPA)
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
0 2 4 6 8 10 12 14 16 18 20
TIME (MS)


M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; -53C
IDENT. NO. 50
PRESSURE (MPA)
TIME (MS)
0
50
100
150
200
250
300
350
400
450
2
4
6
8
10
12
14
16
18
20

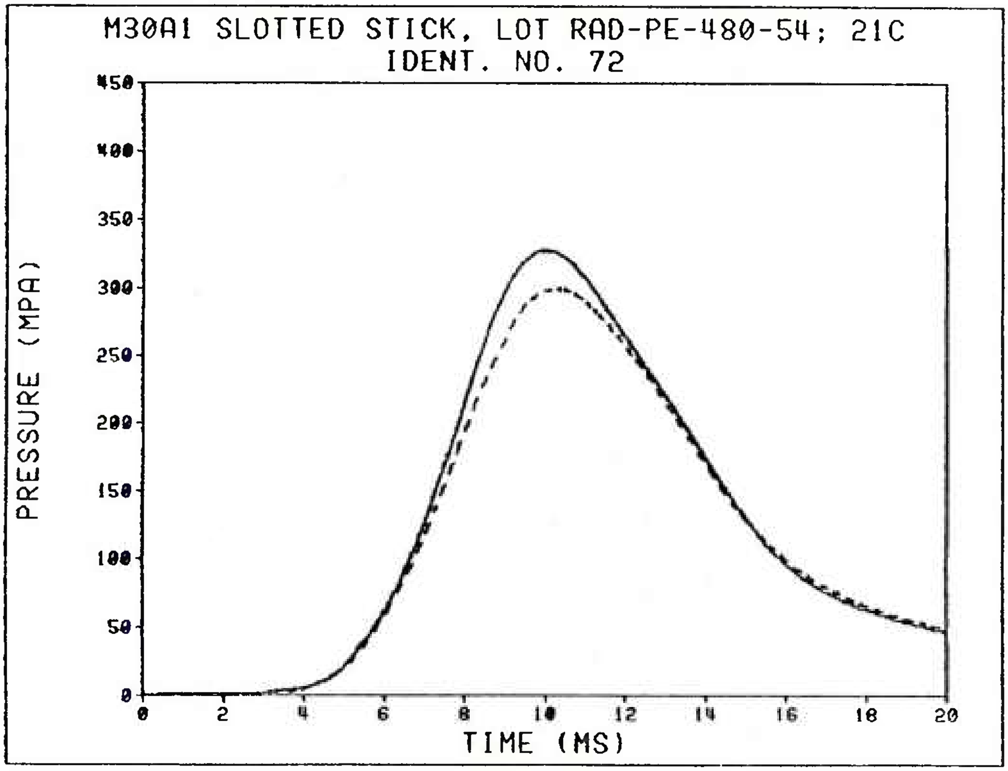

M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; -53C
IDENT. NO. 50
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
2
4
6
8
10
12
14
16
18
20

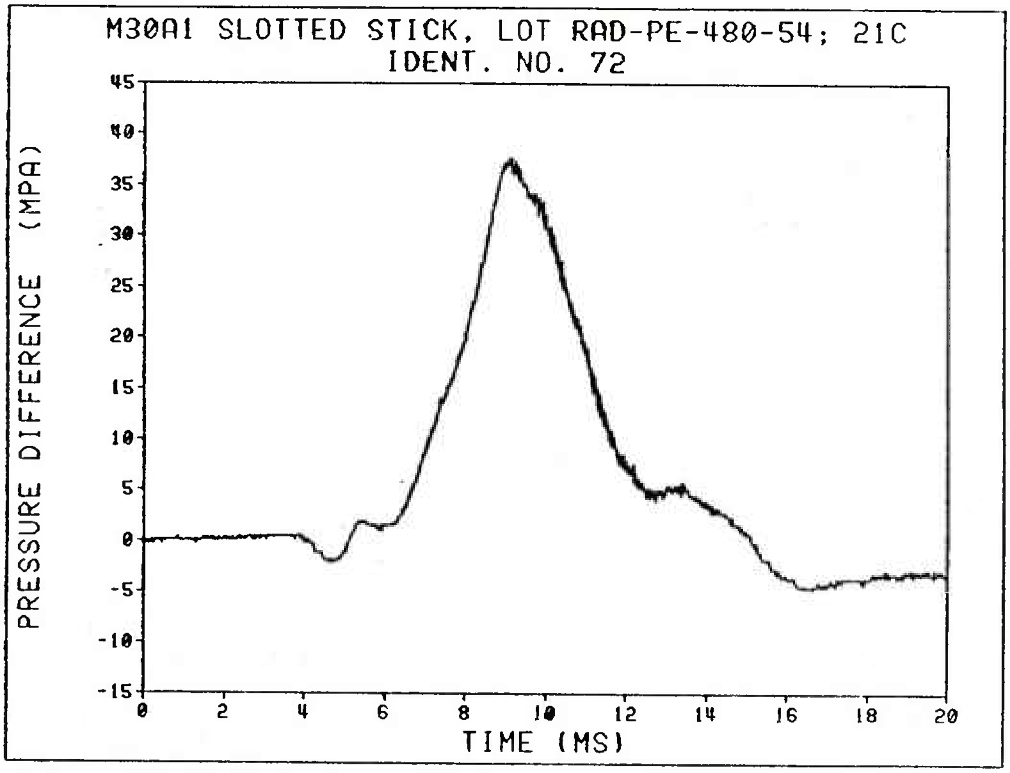


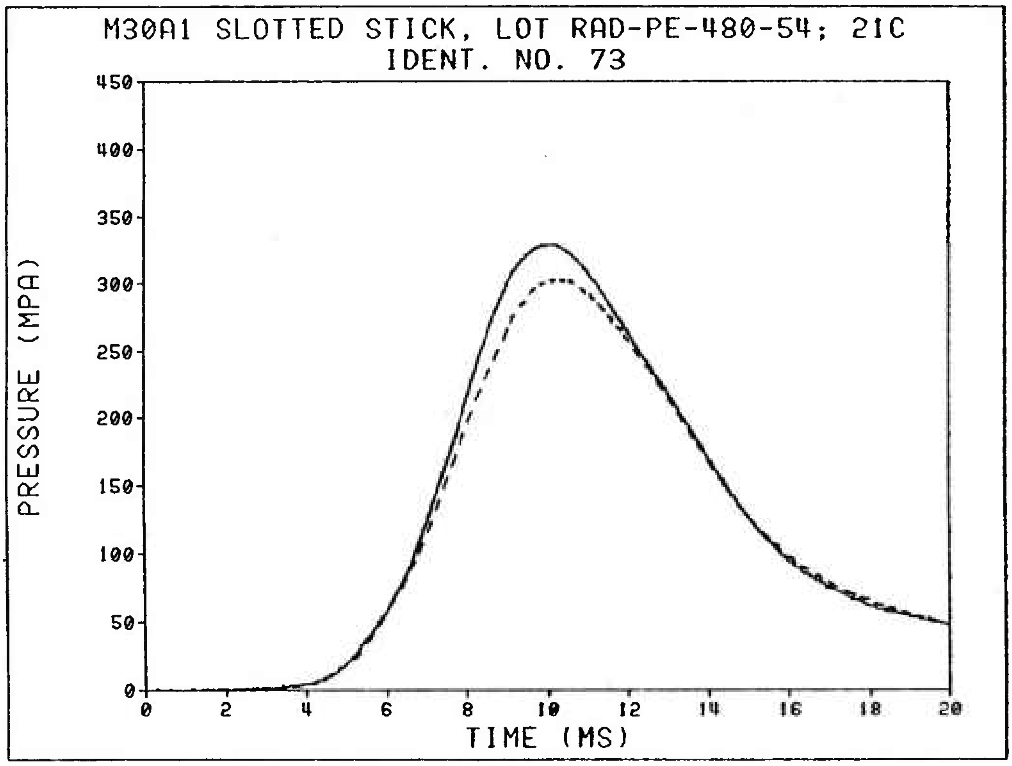
M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; -53C
IDENT. NO. 51
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)



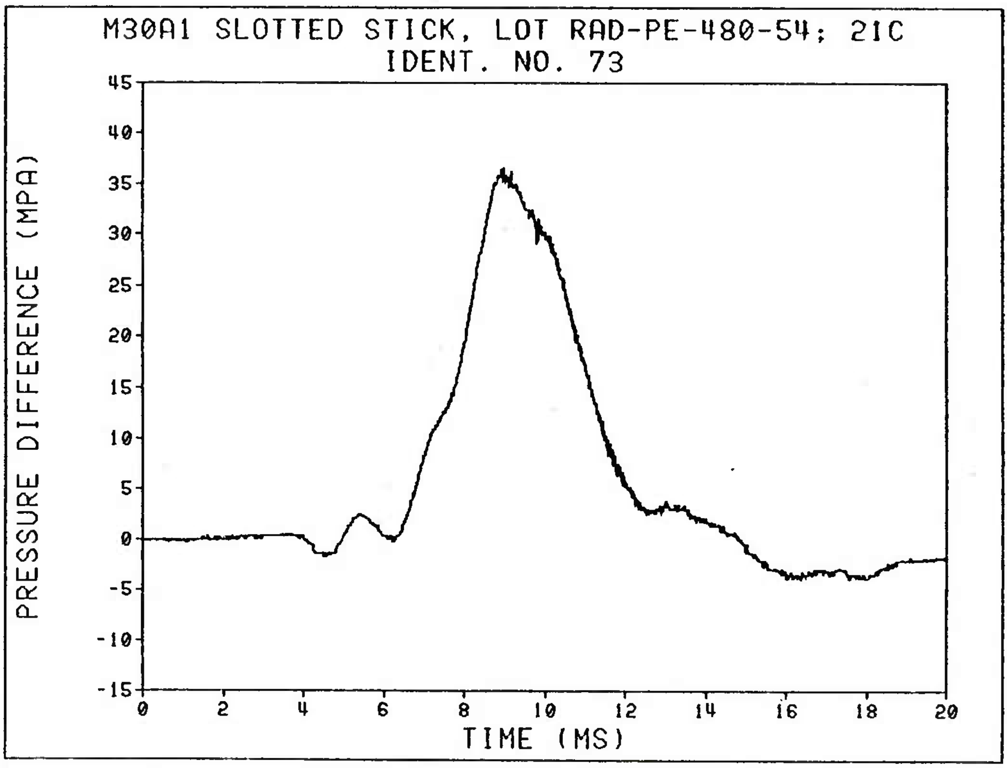
M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; -53C
IDENT. NO. 51
PRESSURE DIFFERENCE (MPA)
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-480-54; 21C
IDENT. NO. 72
PRESSURE (MPA)
TIME (MS)

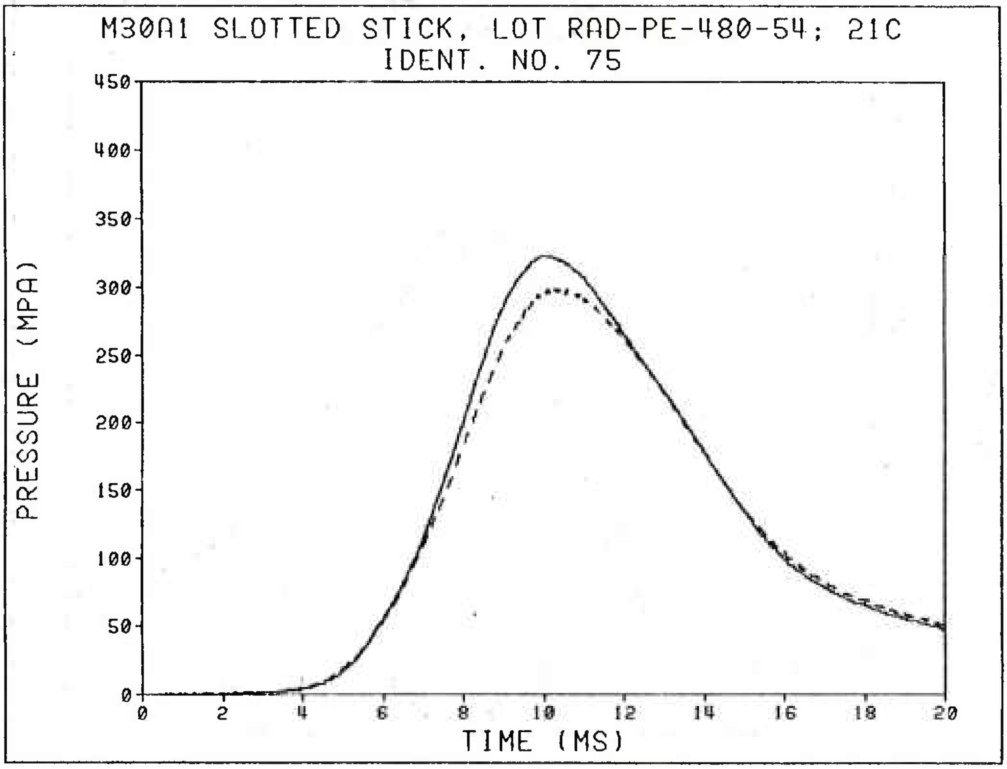

M30A1 SLOTTED STICK, LOT RAD-PE-480-54; 21C
IDENT. NO. 72
PRESSURE DIFFERENCE (MPA)
TIME (MS)

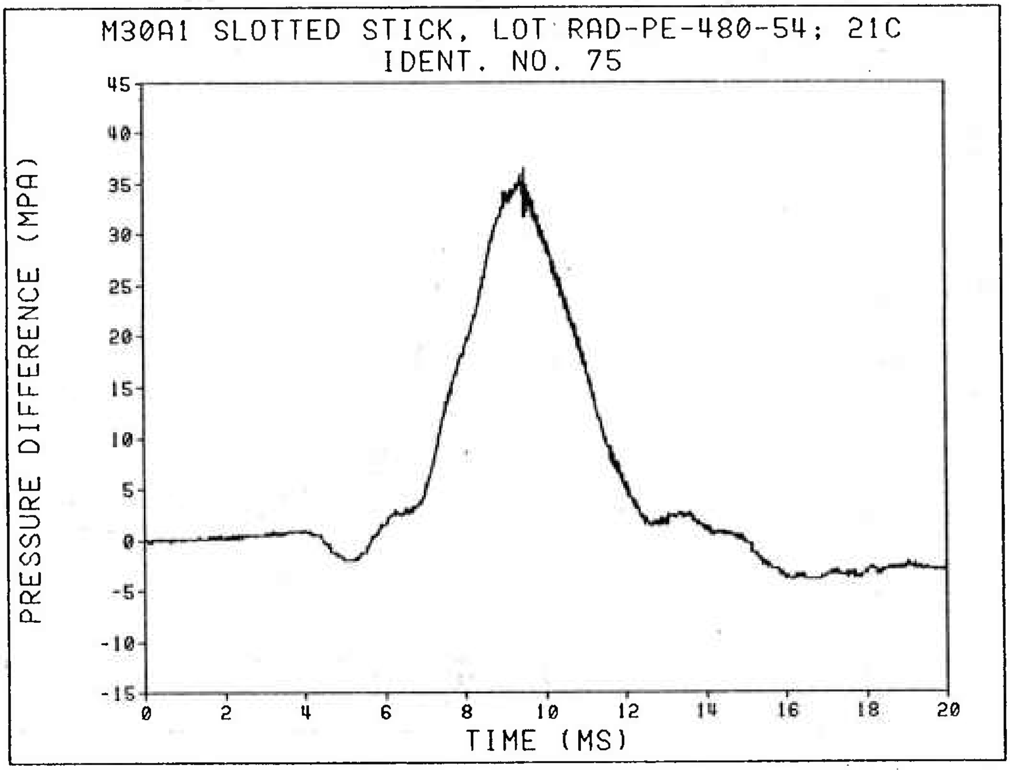


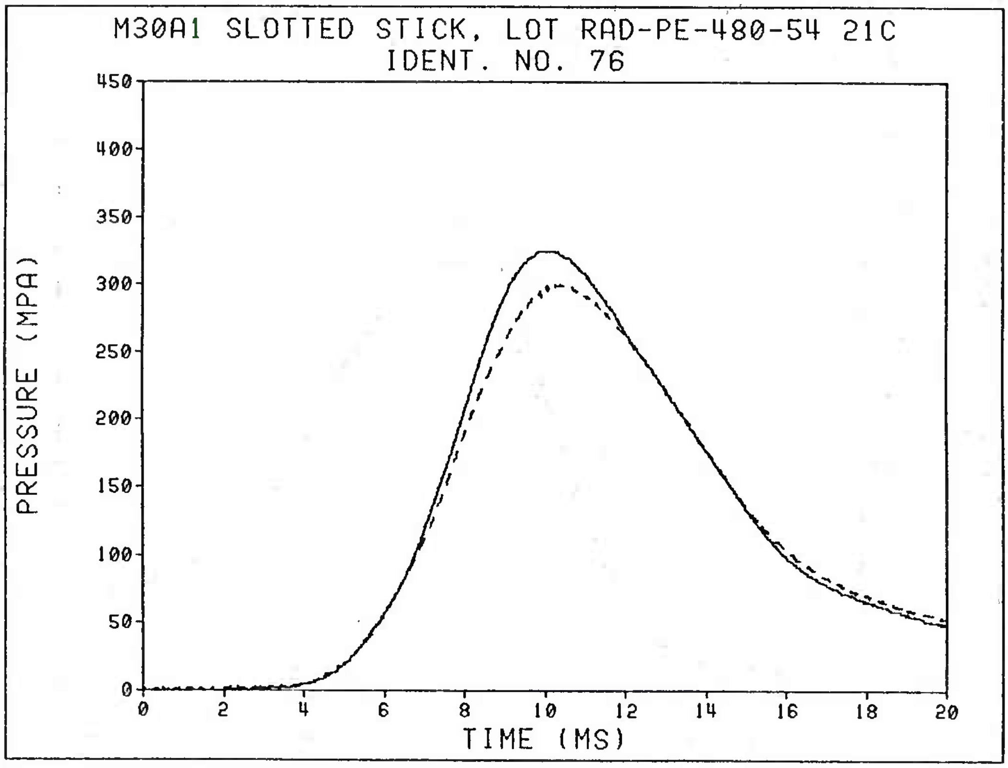
M30A1 SLOTTED STICK, LOT RAD-PE-480-54; 21C
IDENT. NO. 73
PRESSURE (MPA)
TIME (MS)



M30A1 SLOTTED STICK, LOT RAD-PE-480-54; 21C
IDENT. NO. 73
PRESSURE DIFFERENCE (MPA)
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-480-54; 21C
IDENT. NO. 75
PRESSURE (MPA)
TIME (MS)
0
50
100
150
200
250
300
350
400
450
0
2
4
6
8
10
12
14
16
18
20


M30A1 SLOTTED STICK, LOT RAD-PE-480-54; 21C
IDENT. NO. 75
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
0
2
4
6
8
10
12
14
16
18
20


M30A1 SLOTTED STICK, LOT RAD-PE-480-54 21C
IDENT. NO. 76
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
0
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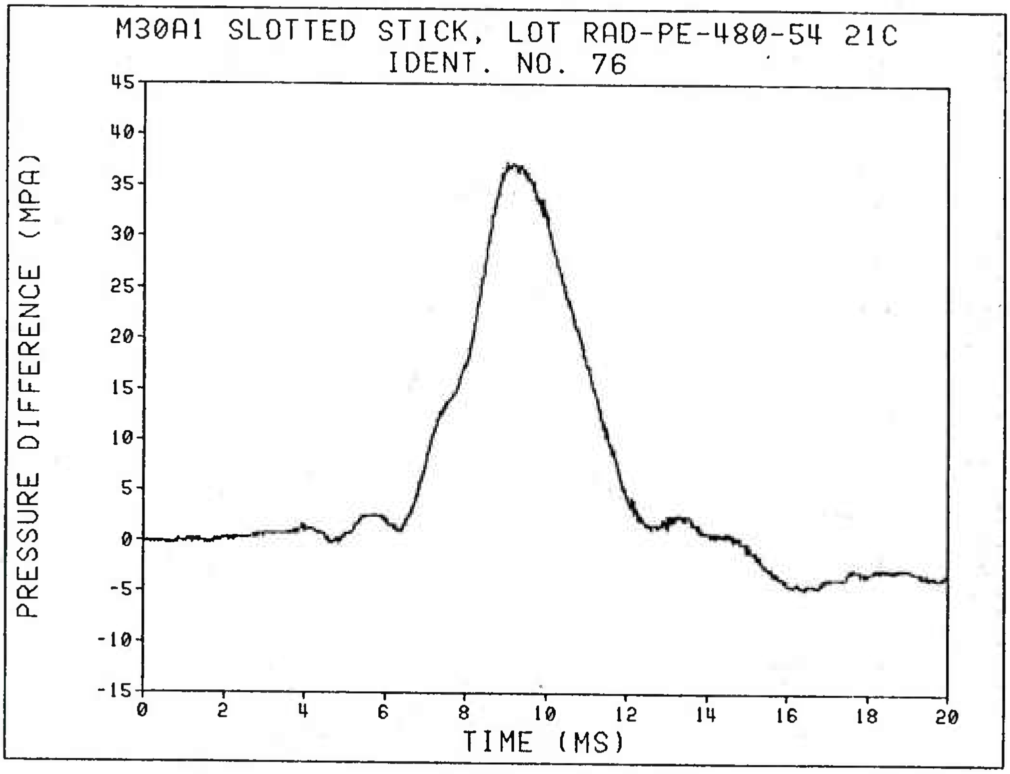
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-480-54 21C
IDENT. NO. 76
PRESSURE DIFFERENCE (MPA)
45
40
35
30
25
20
15
10
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-10
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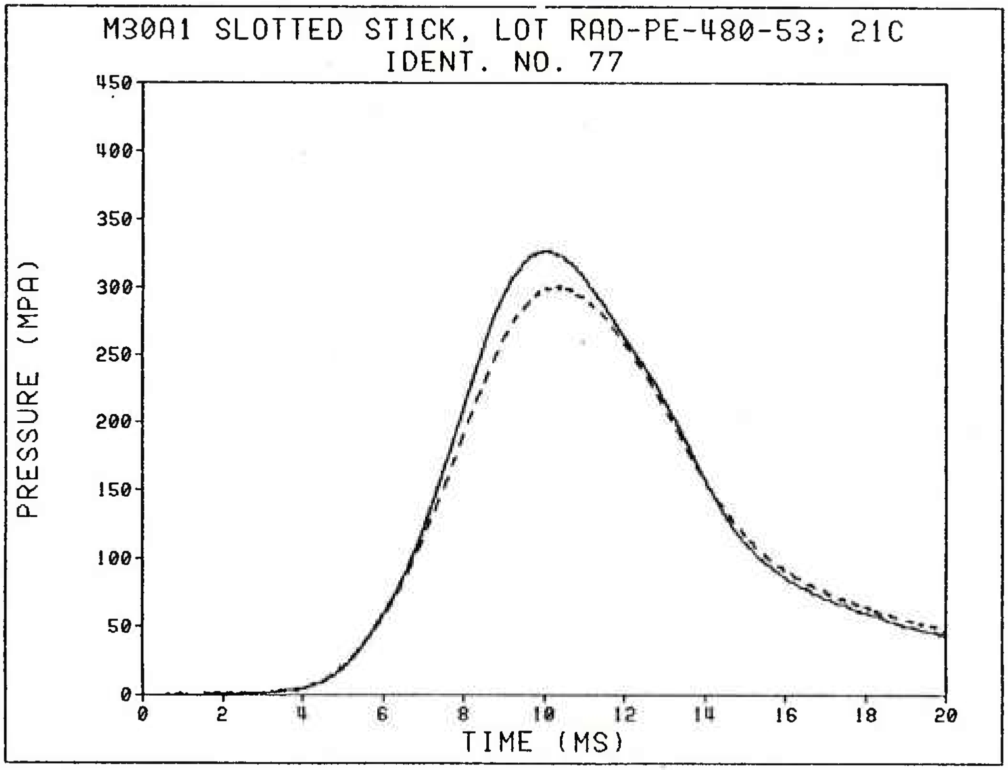
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-480-53; 21C
IDENT. NO. 77
PRESSURE (MPA)
450
400
350
300
250
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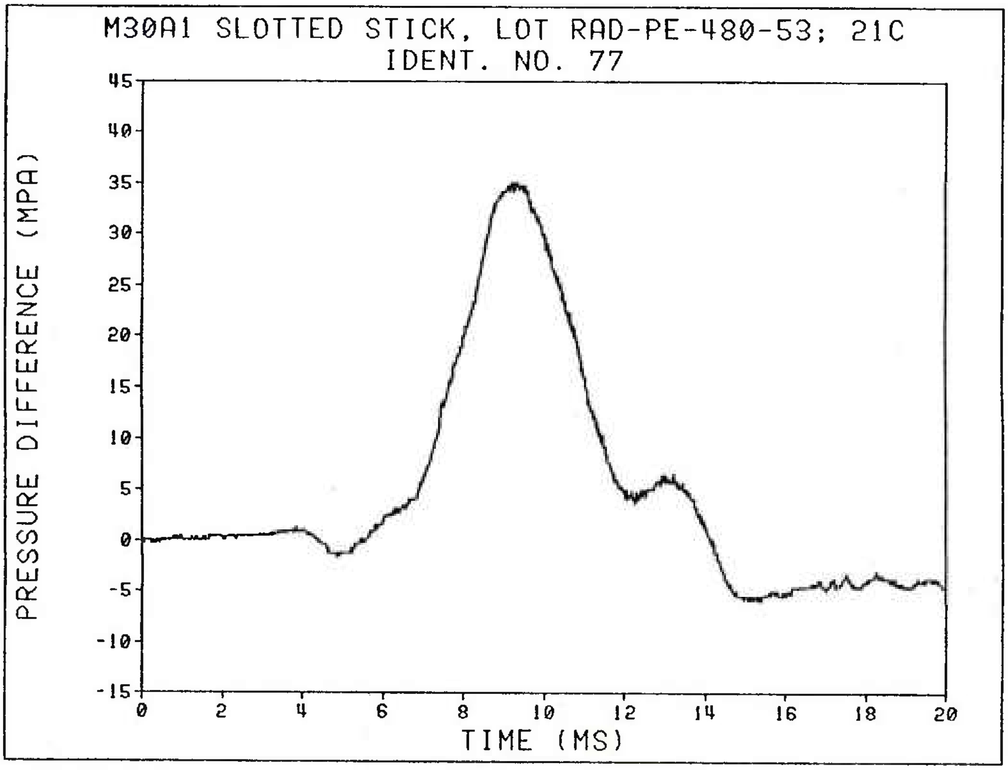
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-480-53; 21C
IDENT. NO. 77
PRESSURE DIFFERENCE (MPA)
45
40
35
30
25
20
15
10
5
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-10
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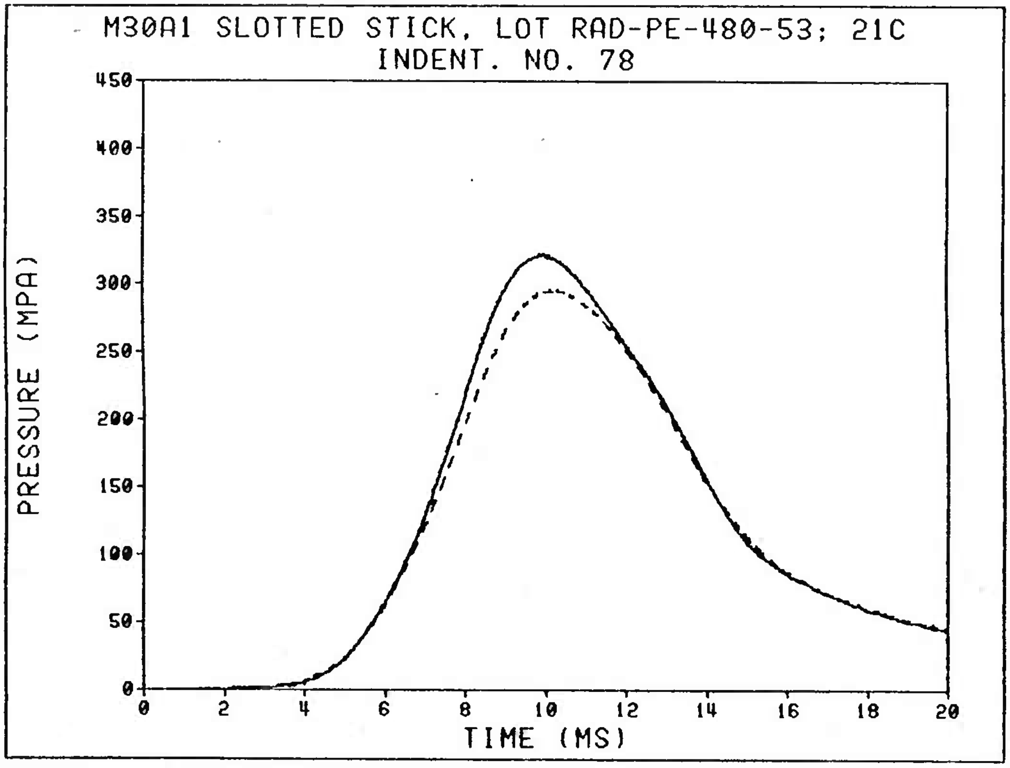
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-480-53; 21C
INDENT. NO. 78
PRESSURE (MPA)
450
400
350
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200
150
100
50
0
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2
4
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8
10
12
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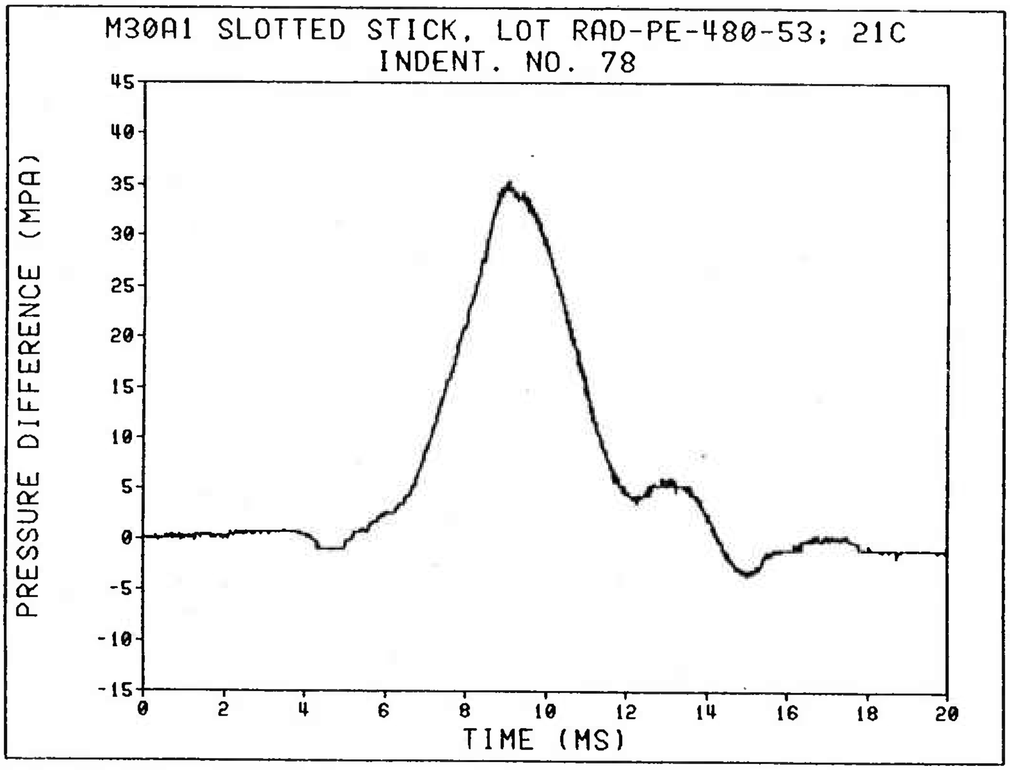
16
18
20
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-480-53; 21C
INDENT. NO. 78
PRESSURE DIFFERENCE (MPA)
45
40
35
30
25
20
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-10
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12
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18
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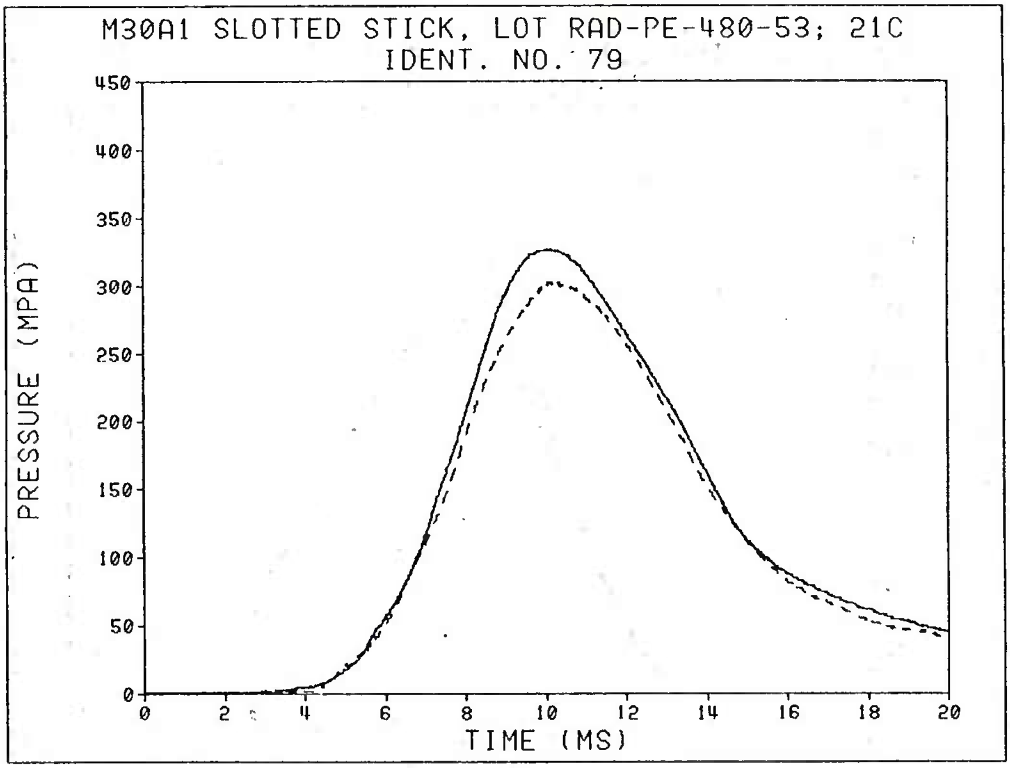
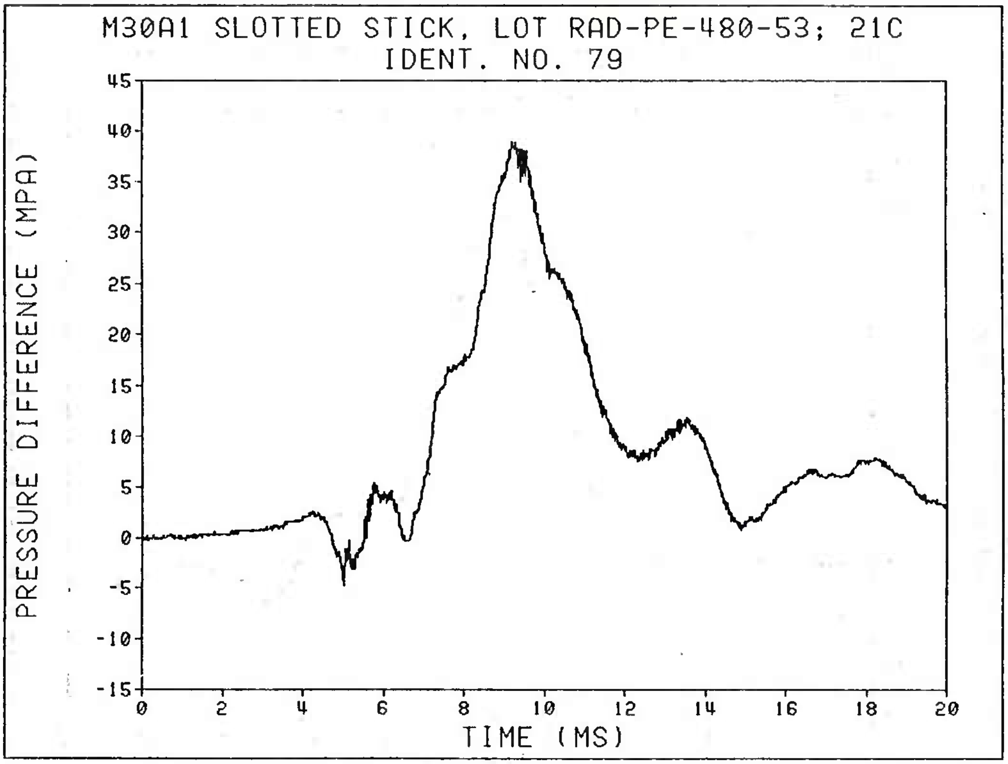
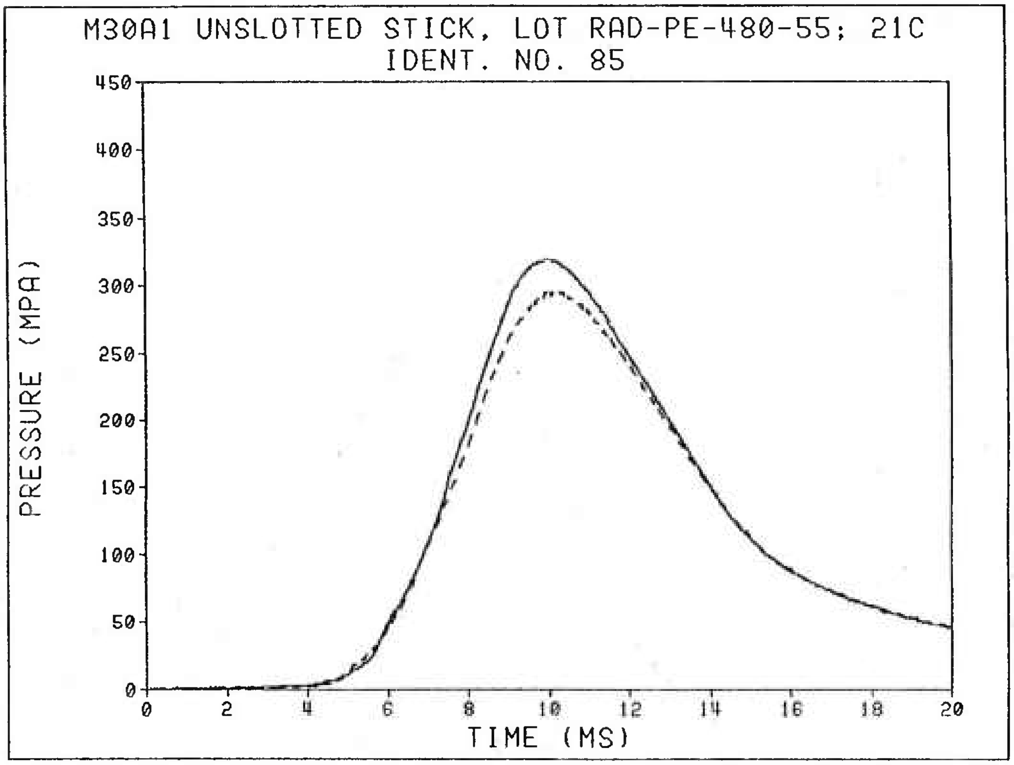
TIME (MS)



M30A1 SLOTTED STICK, LOT RAD-PE-480-53; 21C
IDENT. NO. 79
PRESSURE (MPA)
TIME (MS)



M30A1 SLOTTED STICK, LOT RAD-PE-480-53; 21C
IDENT. NO. 79
PRESSURE DIFFERENCE (MPA)
TIME (MS)


M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; 21C
IDENT. NO. 85
PRESSURE (MPA)
450
400
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200
150
100
50
0
0
2
4
6
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10
12
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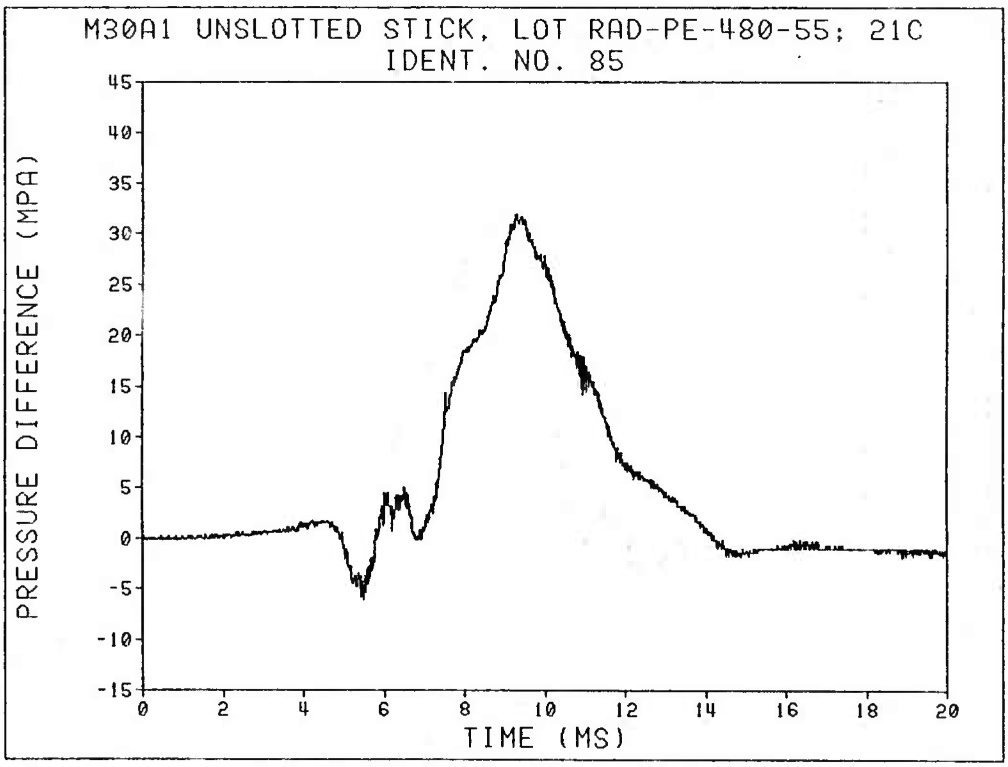
16
18
20
TIME (MS)


M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; 21C
IDENT. NO. 85
PRESSURE DIFFERENCE (MPA)
45
40
35
30
25
20
15
10
5
0
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-10
-15
0
2
4
6
8
10
12
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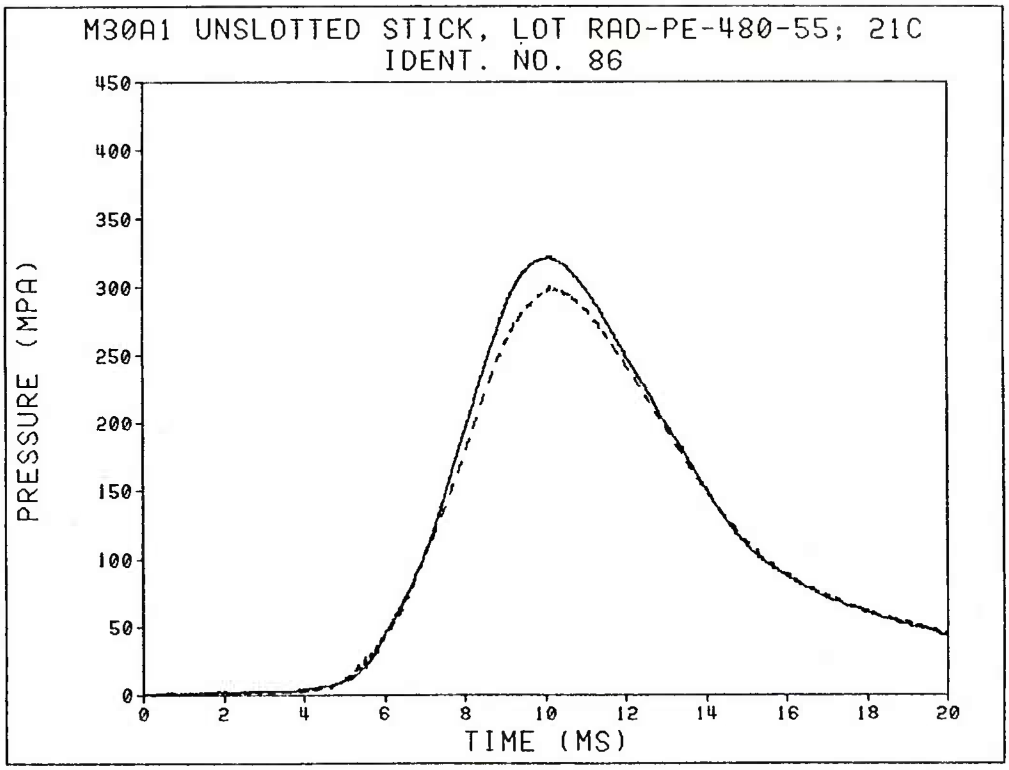
18
20
TIME (MS)


M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; 21C
IDENT. NO. 86
PRESSURE (MPA)
TIME (MS)
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250
300
350
400
450
0
2
4
6
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14
16
18
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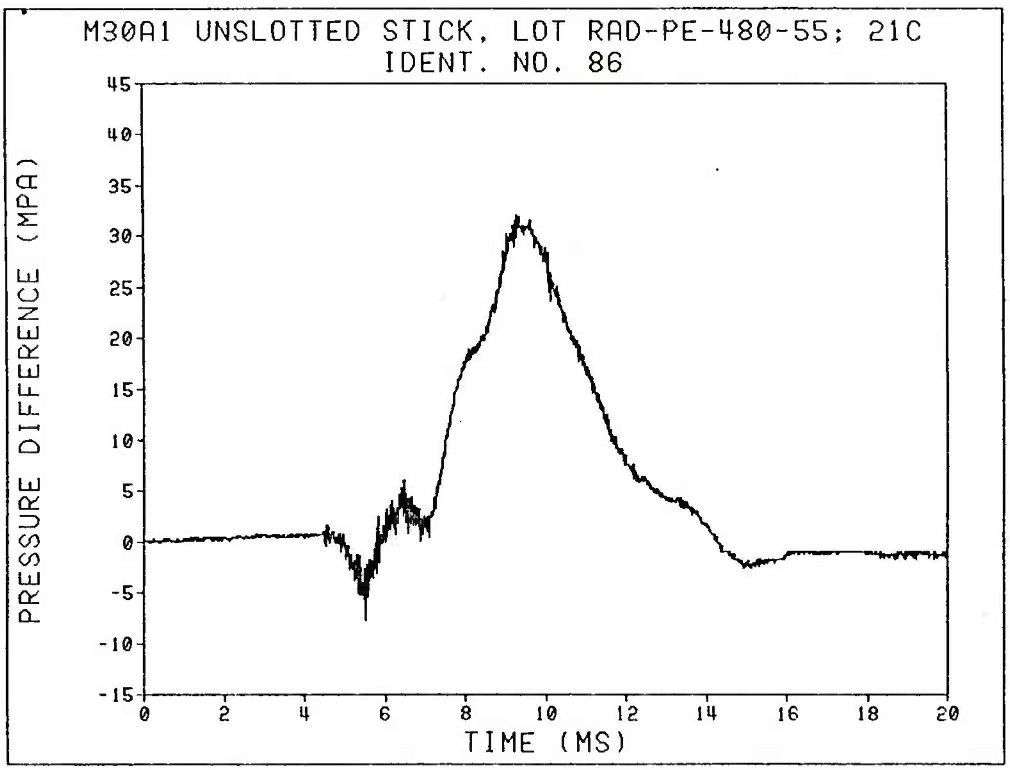
M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; 21C
IDENT. NO. 86
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
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10
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25
30
35
40
45
0
2
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6
8
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14
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18
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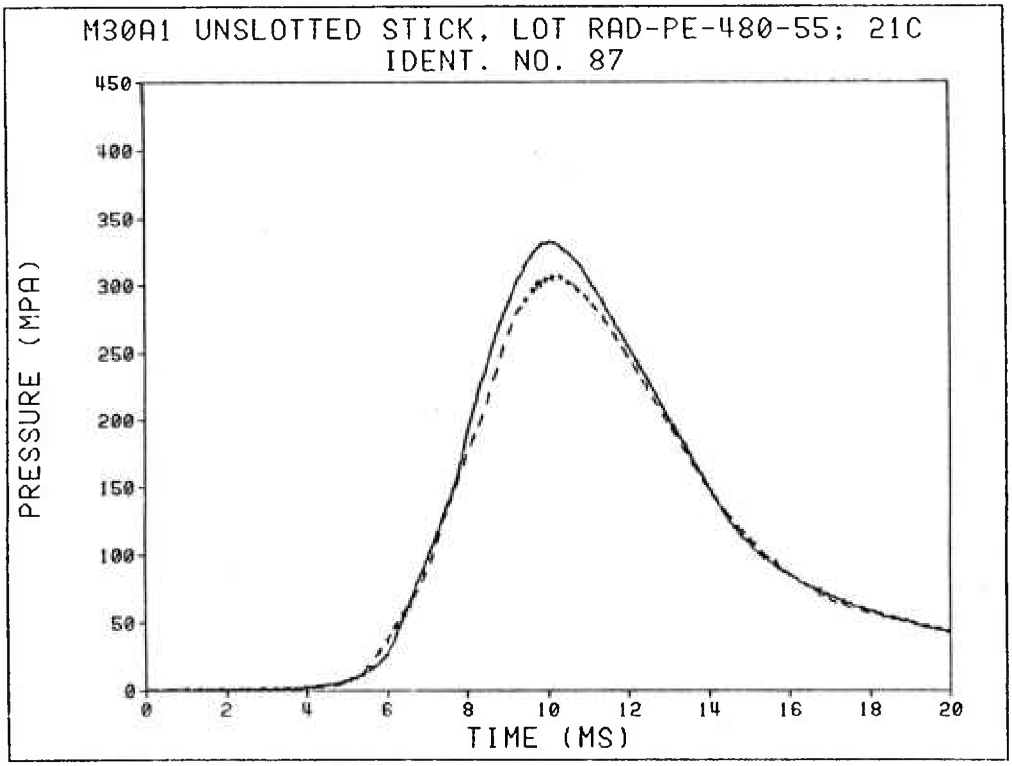
M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; 21C
IDENT. NO. 87
PRESSURE (MPA)
0
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100
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300
350
400
450
TIME (MS)
0
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4
6
8
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12
14
16
18
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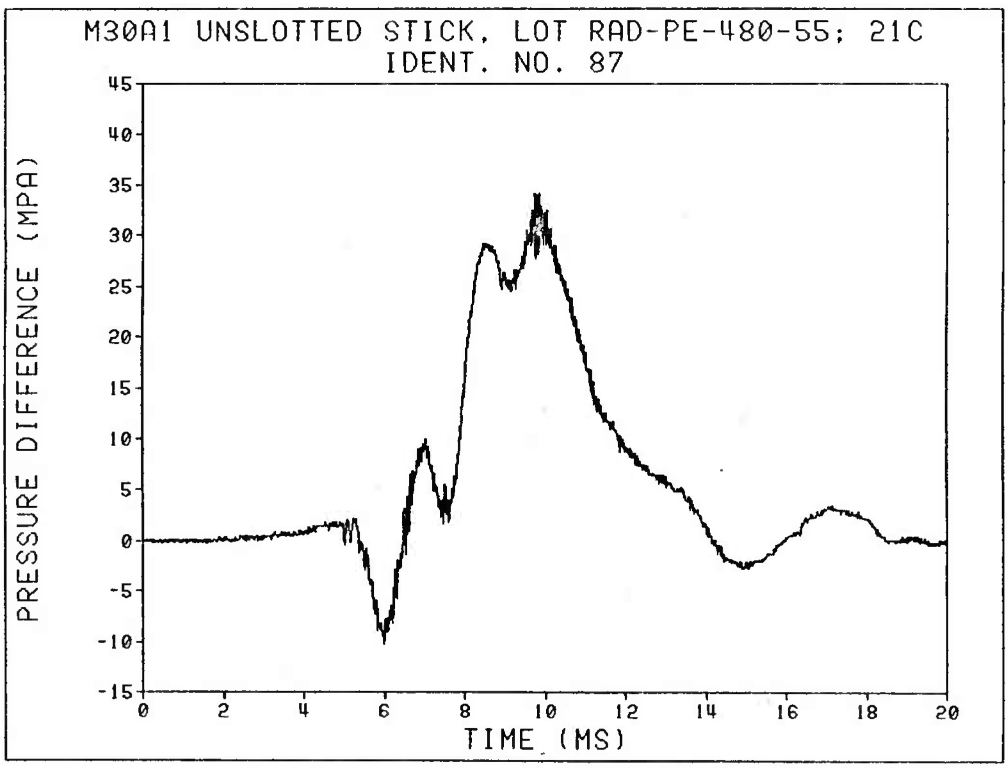
M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; 21C
IDENT. NO. 87
PRESSURE DIFFERENCE (MPA)
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
TIME (MS)
0
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4
6
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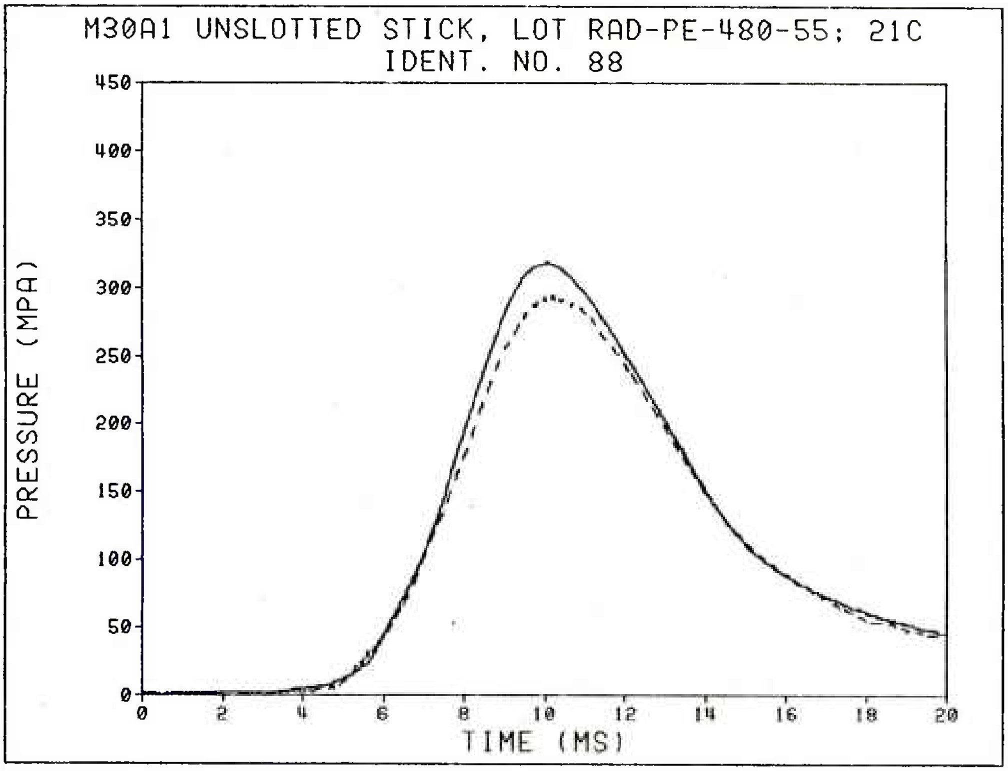
M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; 21C
IDENT. NO. 88
PRESSURE (MPA)
450
400
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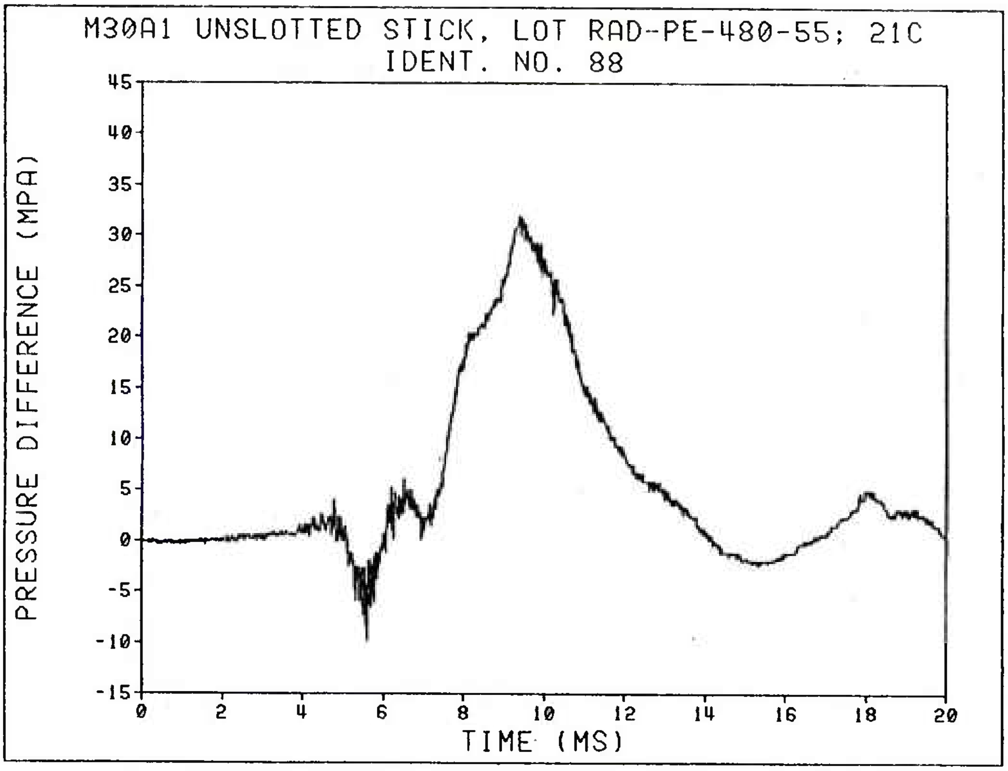
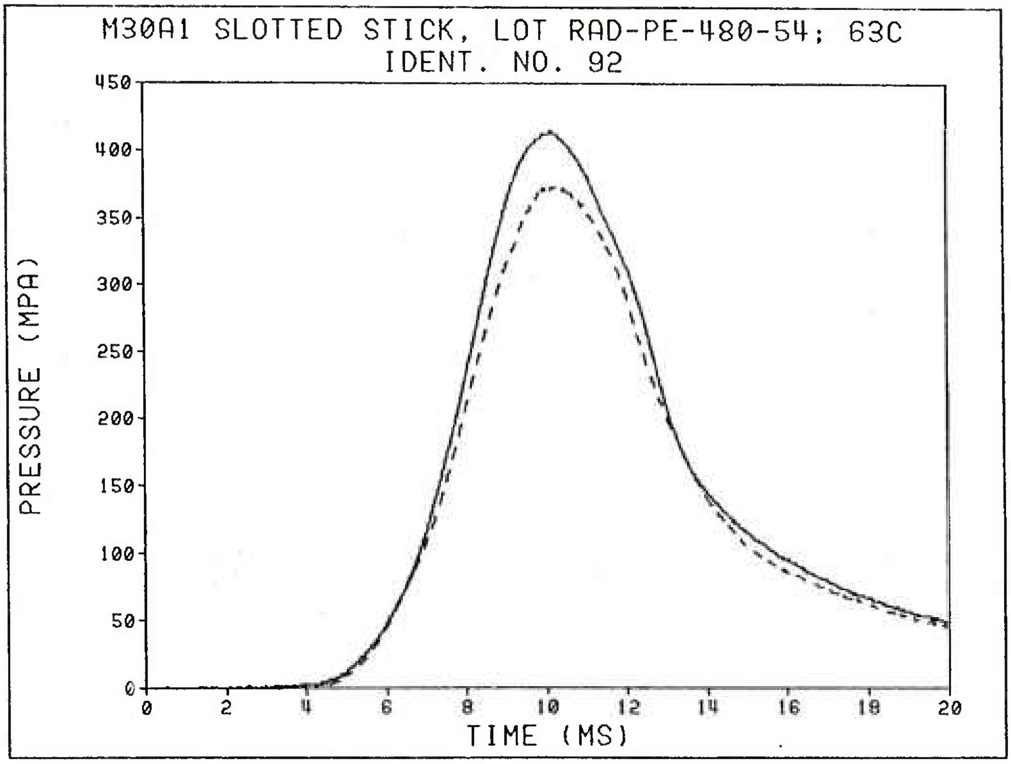
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; 21C
IDENT. NO. 88
PRESSURE DIFFERENCE (MPA)
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-480-54; 63C
IDENT. NO. 92
PRESSURE (MPA)
450
400
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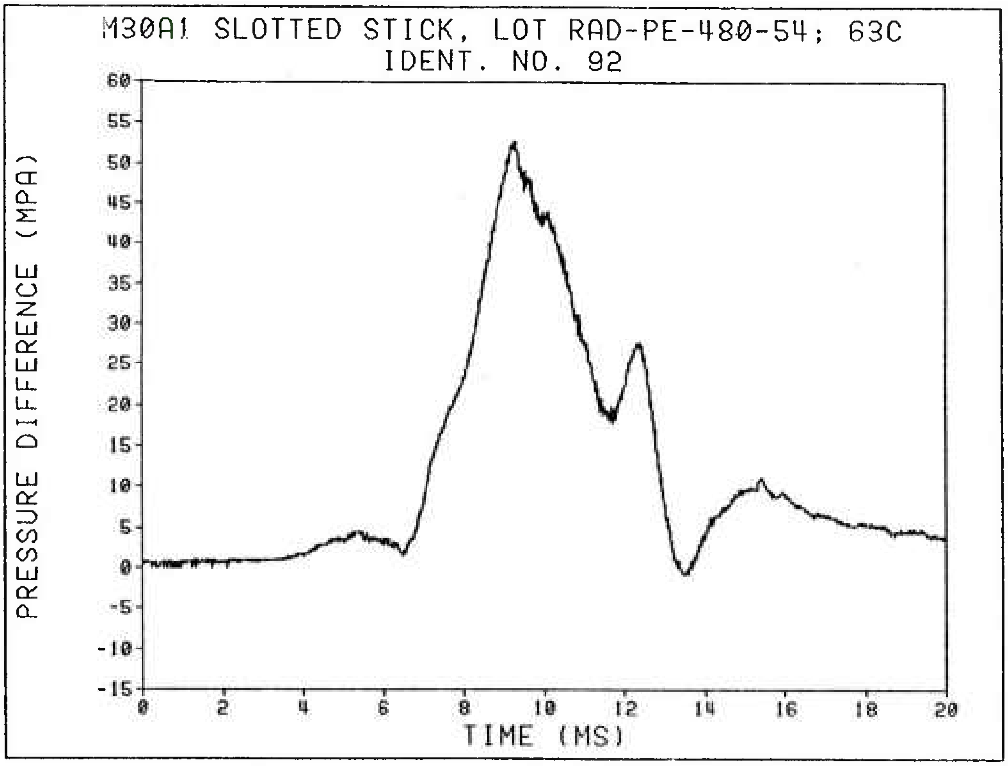
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-480-54; 63C
IDENT. NO. 92
PRESSURE DIFFERENCE (MPA)
60
55
50
45
40
35
30
25
20
15
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-15
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2
4
6
8
10
12
14
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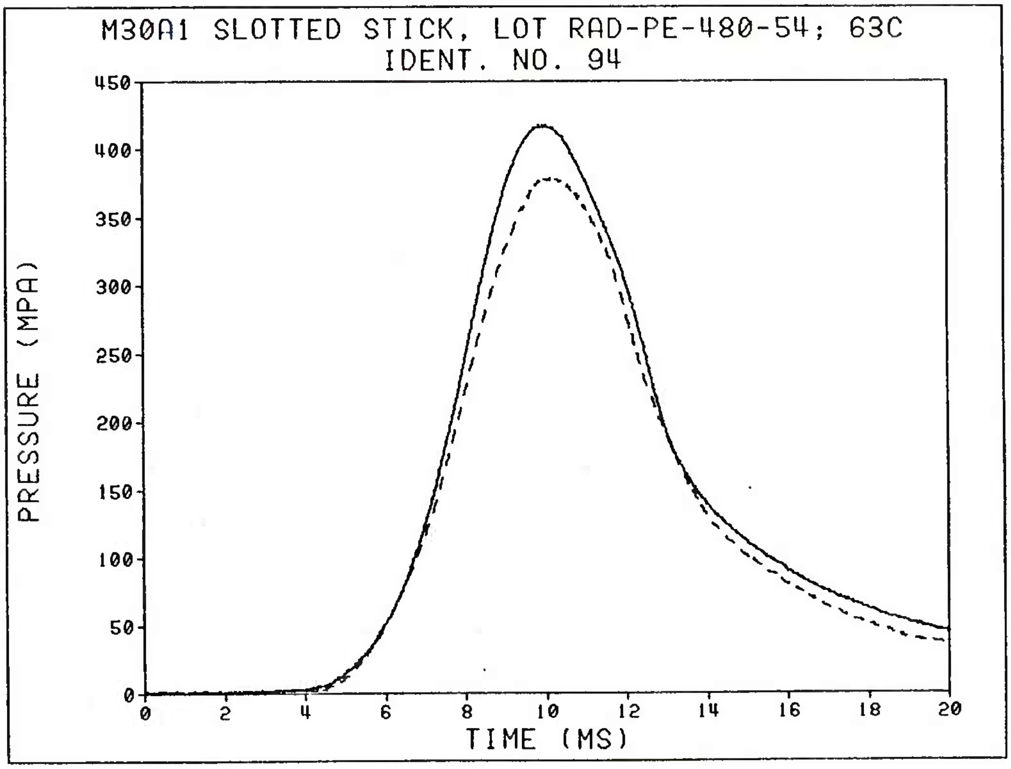
18
20
TIME (MS)



M30A1 SLOTTED STICK, LOT RAD-PE-480-54; 63C
IDENT. NO. 94
PRESSURE (MPA)
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400
450
0
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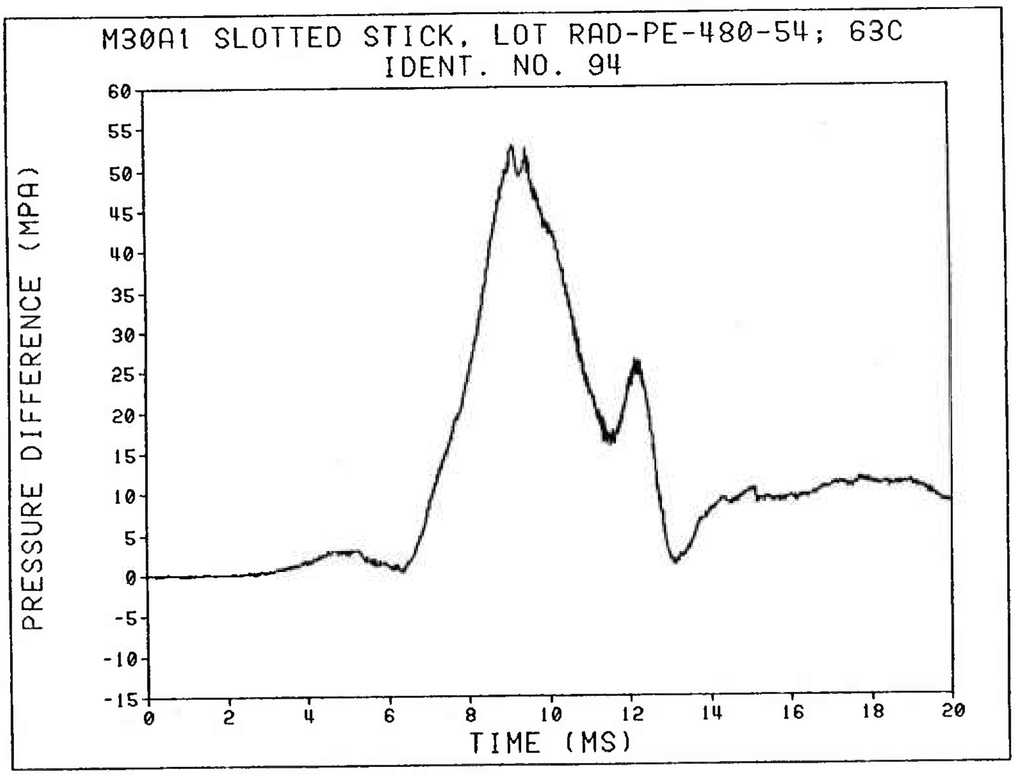
16
18
20
TIME (MS)



M30A1 SLOTTED STICK, LOT RAD-PE-480-54; 63C
IDENT. NO. 94
PRESSURE DIFFERENCE (MPA)
-15
-10
-5
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5
10
15
20
25
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4
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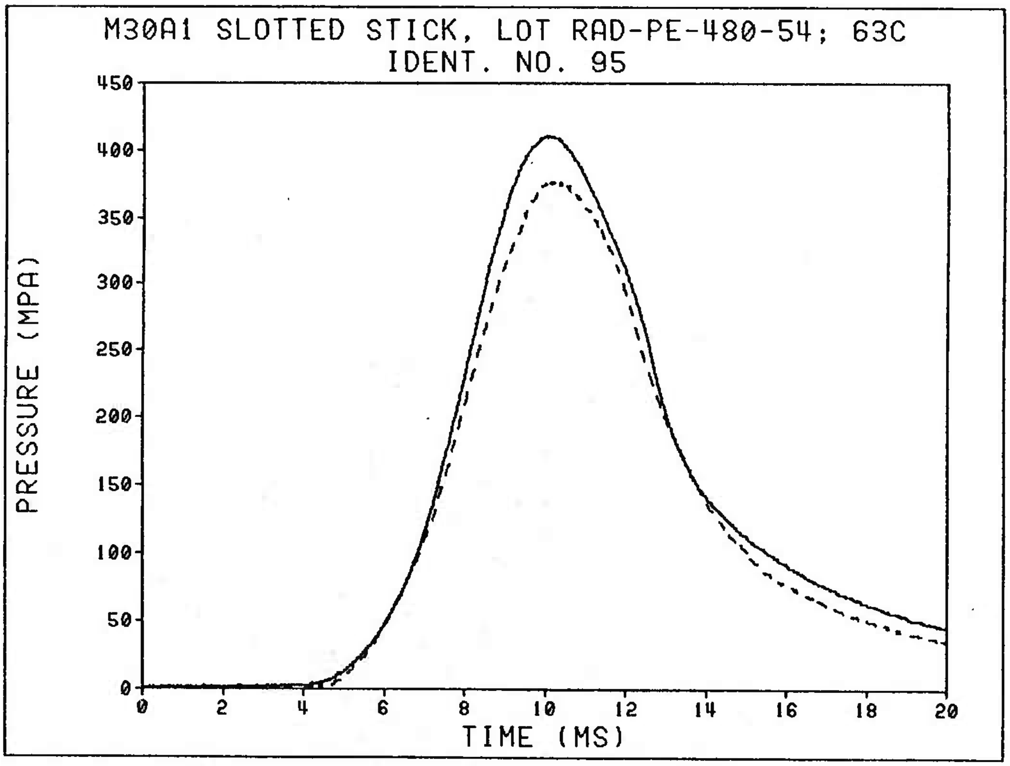
18
20
TIME (MS)



M30A1 SLOTTED STICK, LOT RAD-PE-480-54; 63C
IDENT. NO. 95
PRESSURE (MPA)
TIME (MS)
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300
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400
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14
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18
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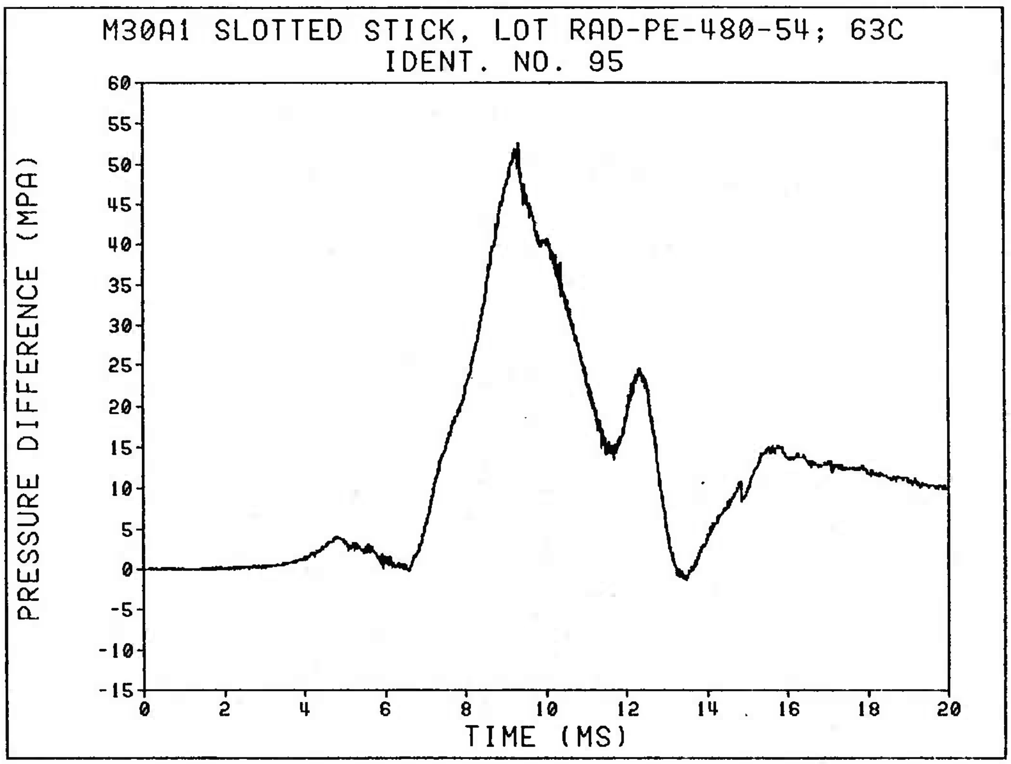

M30A1 SLOTTED STICK, LOT RAD-PE-480-54; 63C
IDENT. NO. 95
PRESSURE DIFFERENCE (MPA)
TIME (MS)
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5
10
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60
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6
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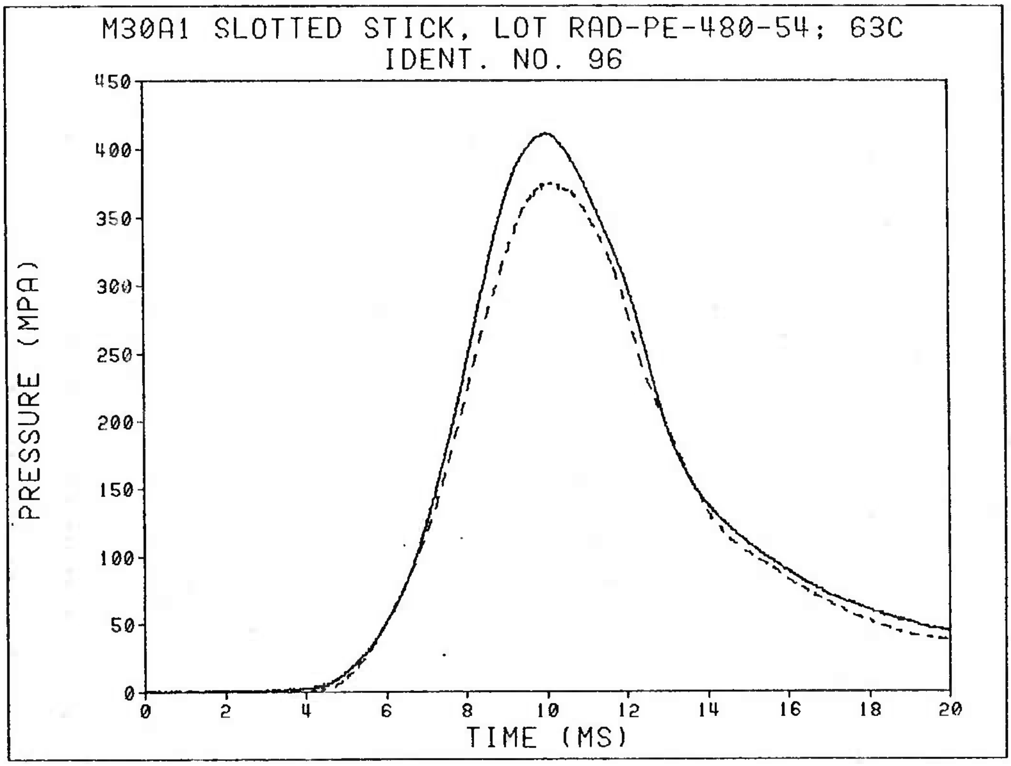
M30A1 SLOTTED STICK, LOT RAD-PE-480-54; 63C
IDENT. NO. 96
PRESSURE (MPA)
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18
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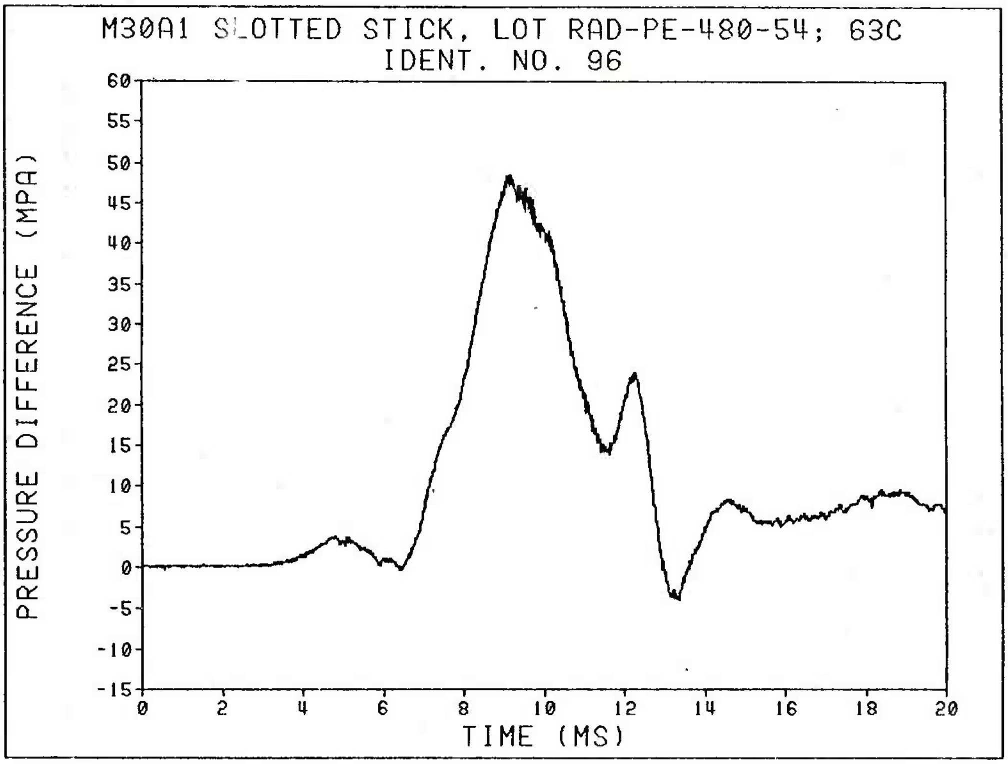
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-480-54; 63C
IDENT. NO. 96
PRESSURE DIFFERENCE (MPA)
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-10
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10
15
20
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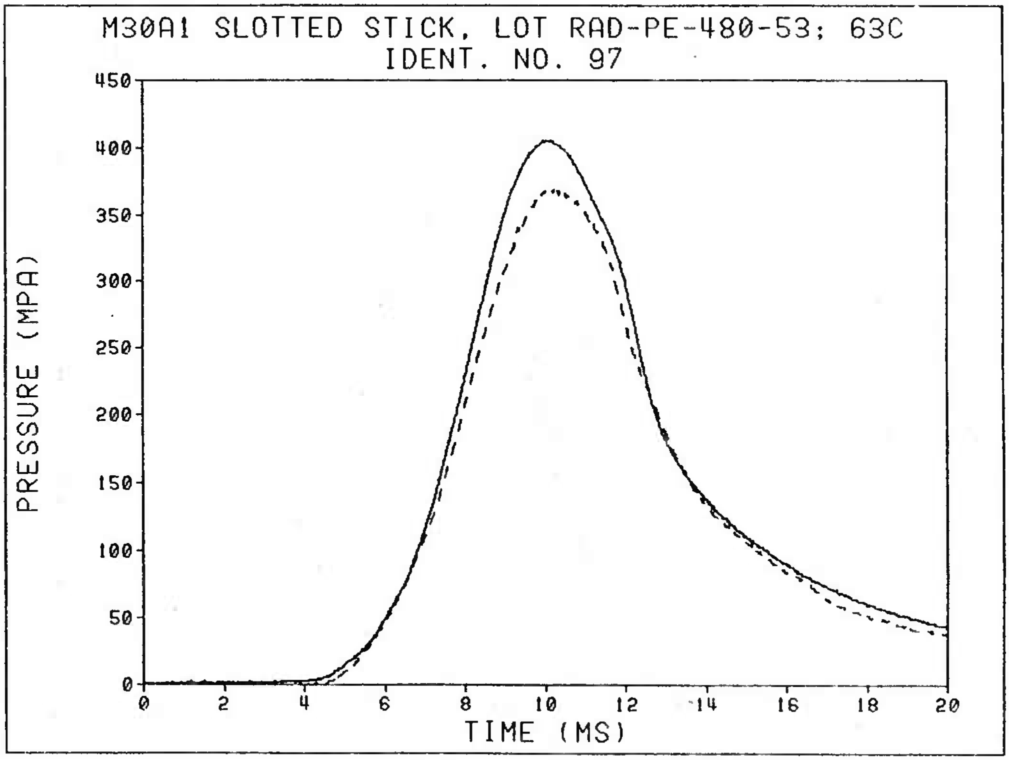
TIME (MS)



M30A1 SLOTTED STICK, LOT RAD-PE-480-53; 63C
IDENT. NO. 97
PRESSURE (MPA)
TIME (MS)
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400
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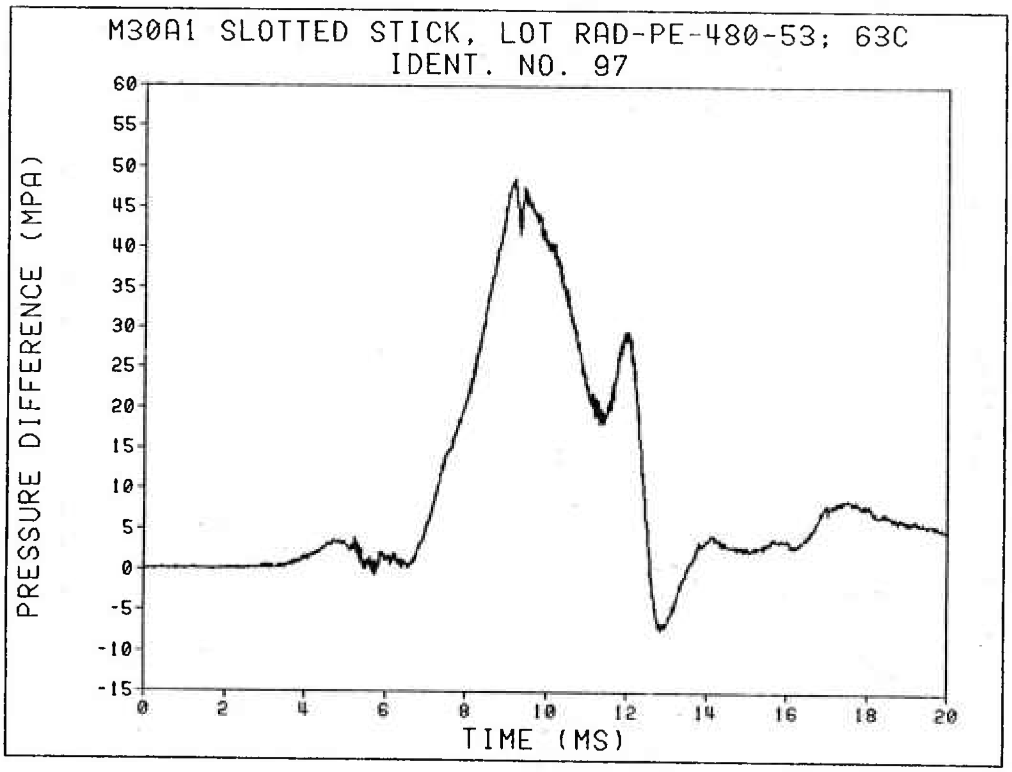

M30A1 SLOTTED STICK, LOT RAD-PE-480-53; 63C
IDENT. NO. 97
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
5
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55
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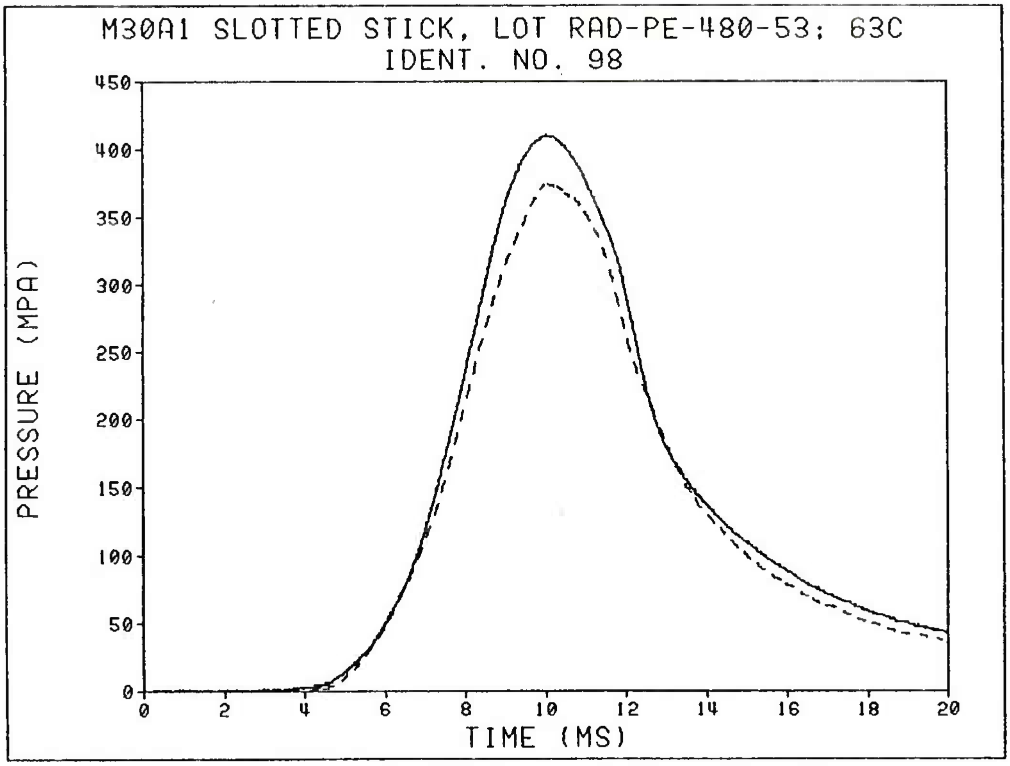
M30A1 SLOTTED STICK, LOT RAD-PE-480-53; 63C
IDENT. NO. 98
PRESSURE (MPA)
TIME (MS)
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200
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100
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2
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6
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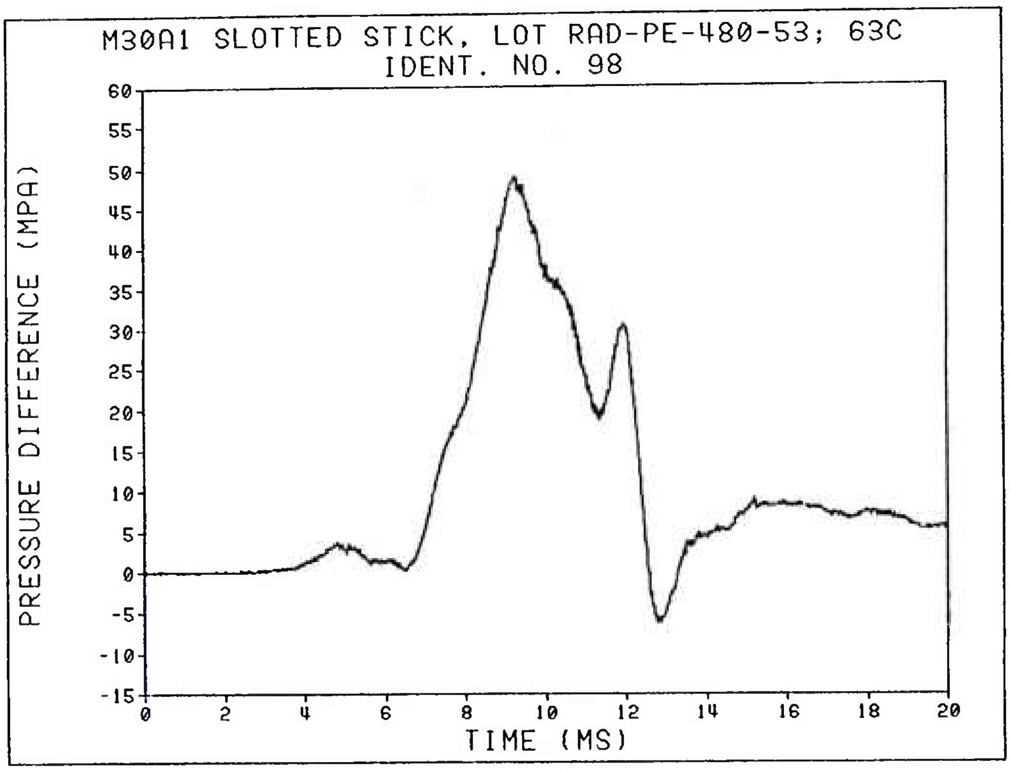
M30A1 SLOTTED STICK, LOT RAD-PE-480-53; 63C
IDENT. NO. 98
PRESSURE DIFFERENCE (MPA)
TIME (MS)
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40
35
30
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-15
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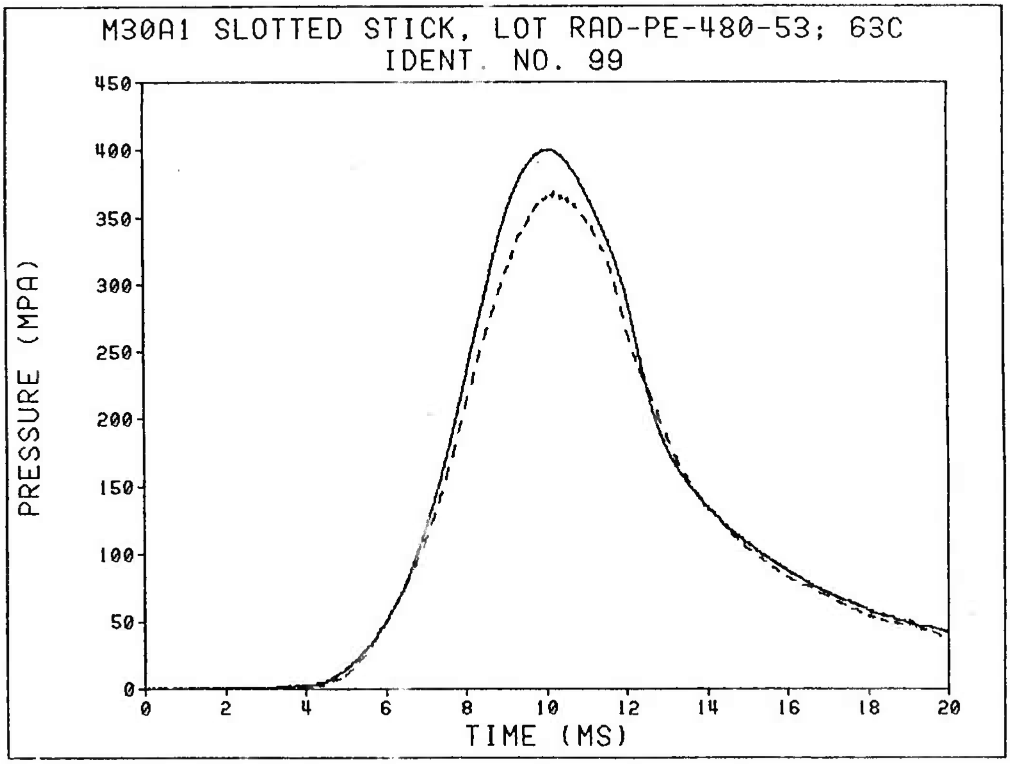
M30A1 SLOTTED STICK, LOT RAD-PE-480-53; 63C
IDENT. NO. 99
PRESSURE (MPA)
TIME (MS)
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100
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200
250
300
350
400
450
0
2
4
6
8
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18
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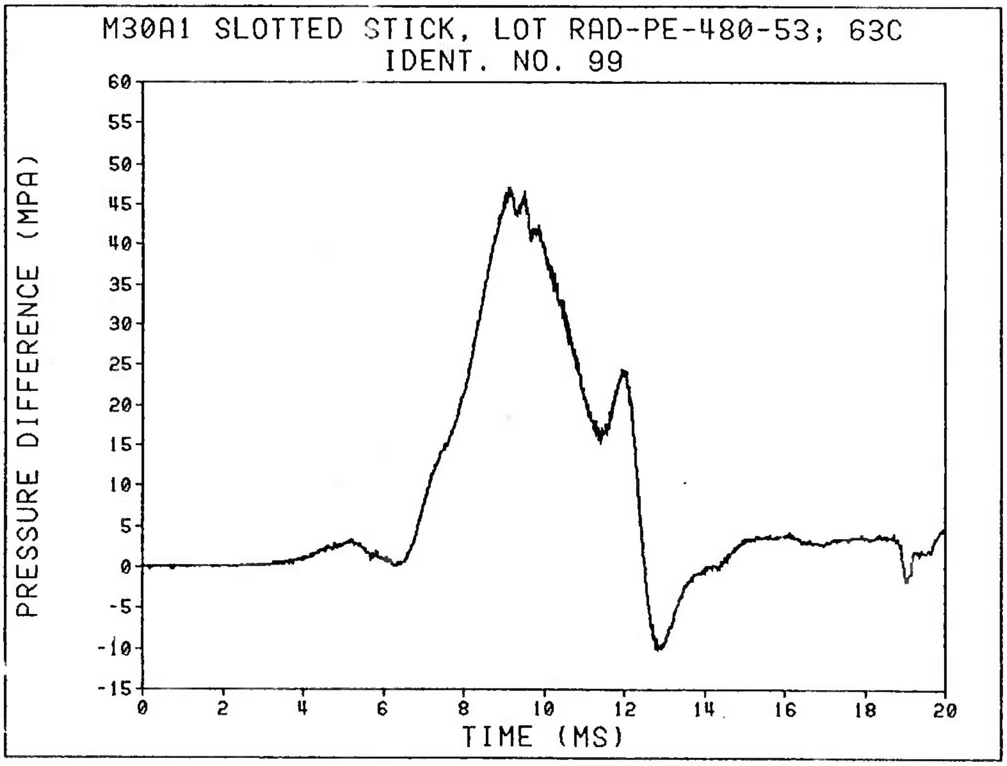
M30A1 SLOTTED STICK, LOT RAD-PE-480-53; 63C
IDENT. NO. 99
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
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10
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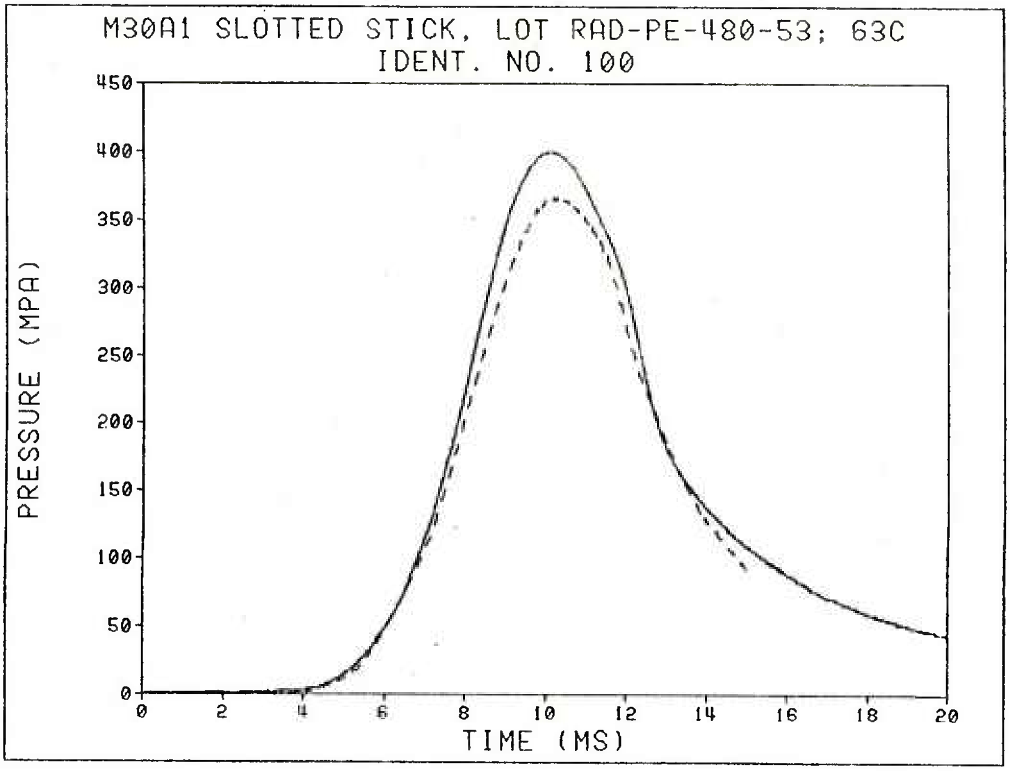
M30A1 SLOTTED STICK, LOT RAD-PE-480-53; 63C
IDENT. NO. 100
PRESSURE (MPA)
TIME (MS)
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250
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450
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6
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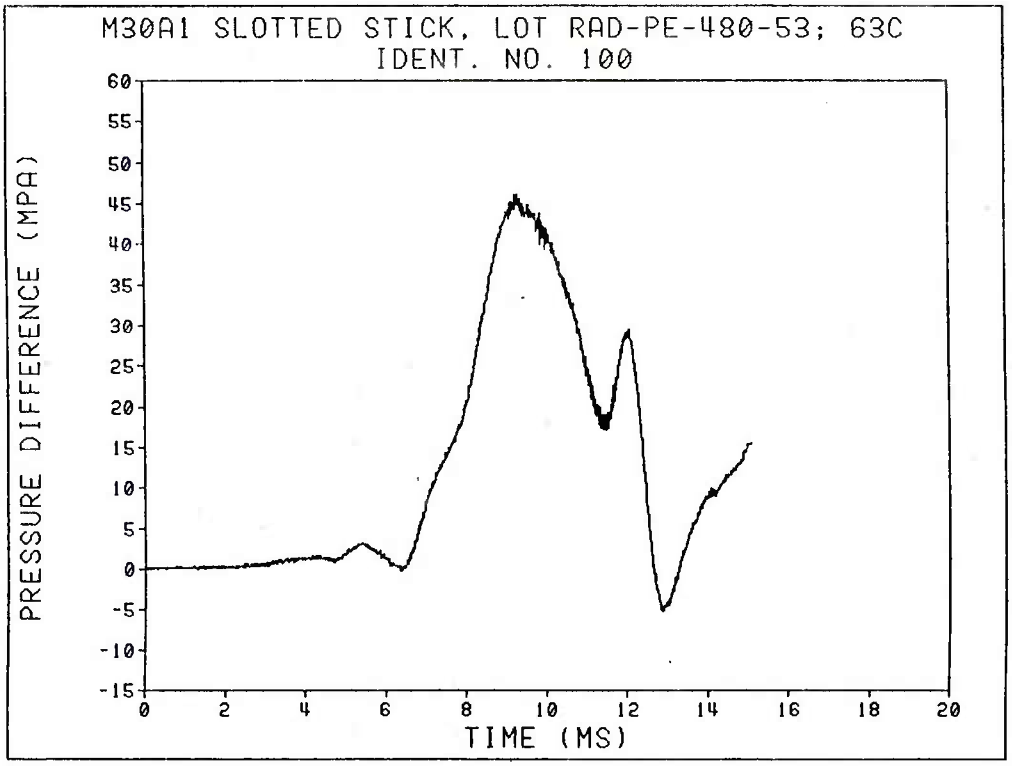
M30A1 SLOTTED STICK, LOT RAD-PE-480-53; 63C
IDENT. NO. 100
PRESSURE DIFFERENCE (MPA)
TIME (MS)
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-10
-5
0
5
10
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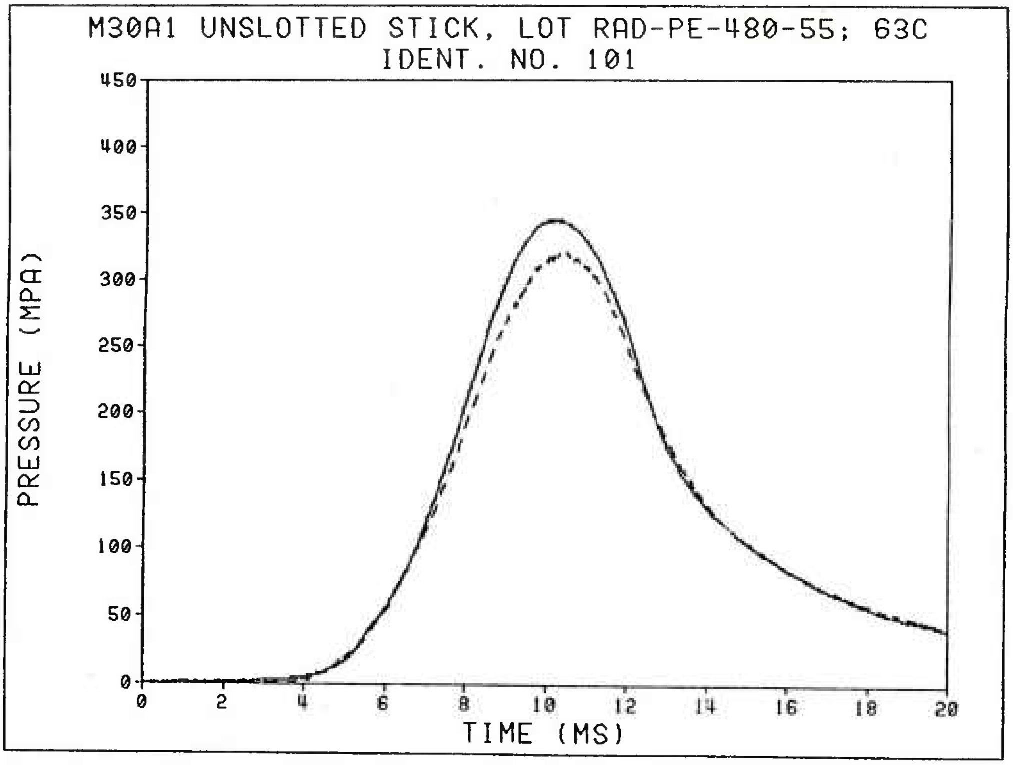
M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; 63C
IDENT. NO. 101
PRESSURE (MPA)
TIME (MS)
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200
150
100
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0
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2
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6
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18
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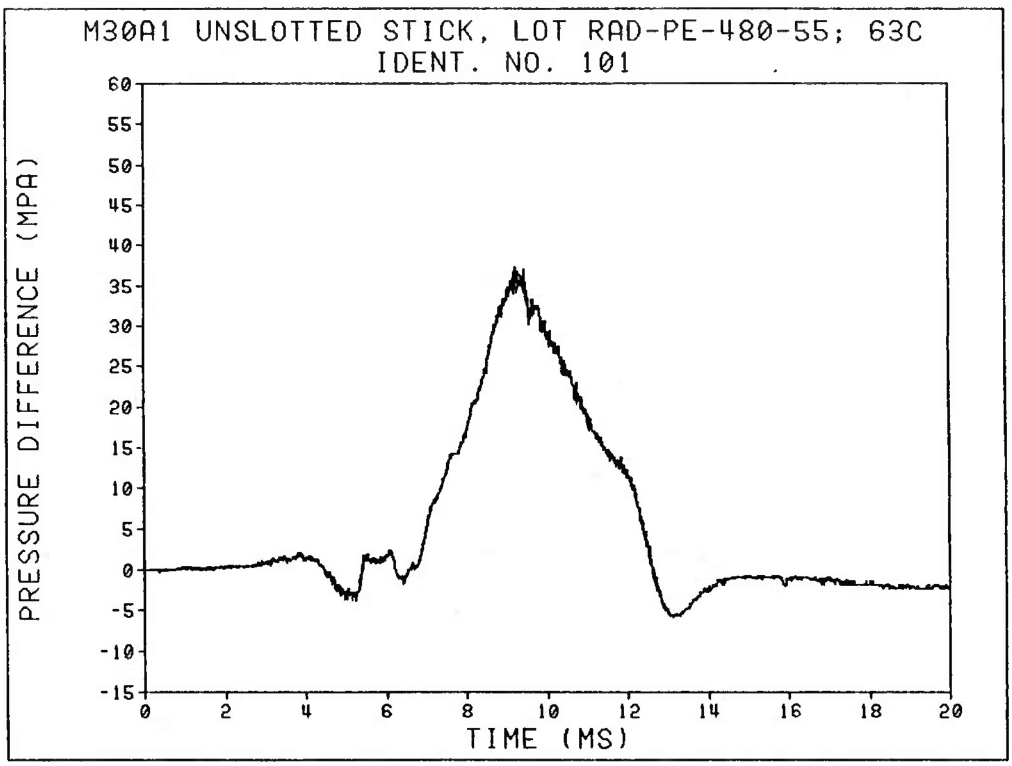
M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; 63C
IDENT. NO. 101
PRESSURE DIFFERENCE (MPA)
TIME (MS)
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55
50
45
40
35
30
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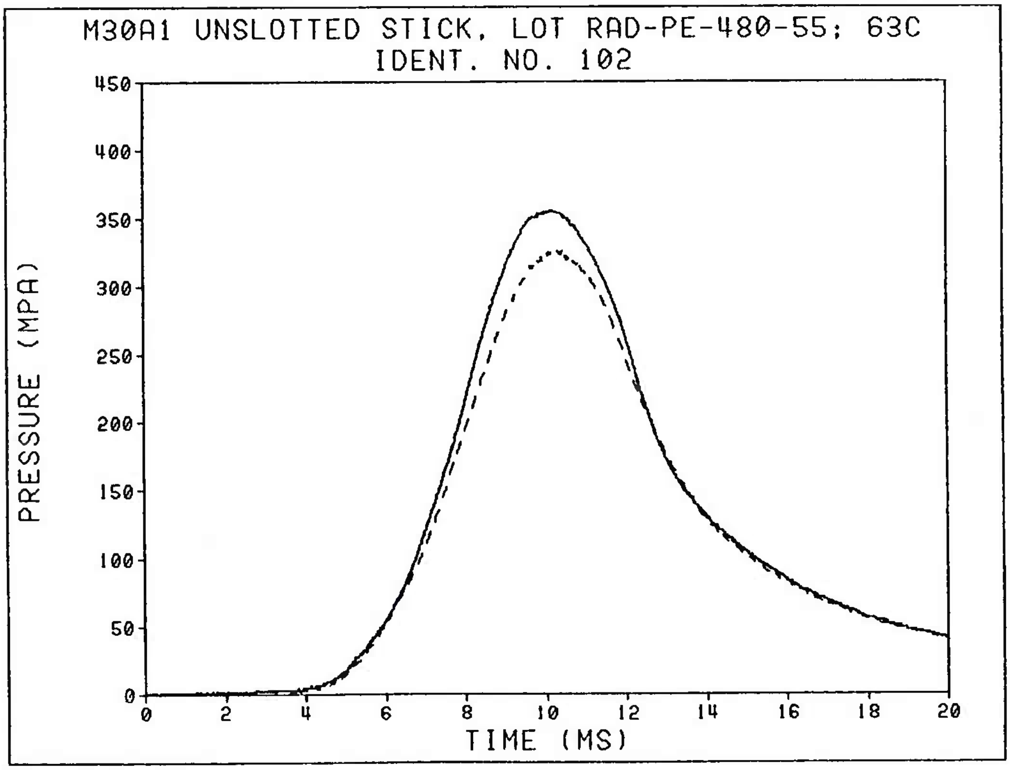
M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; 63C
IDENT. NO. 102
PRESSURE (MPA)
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400
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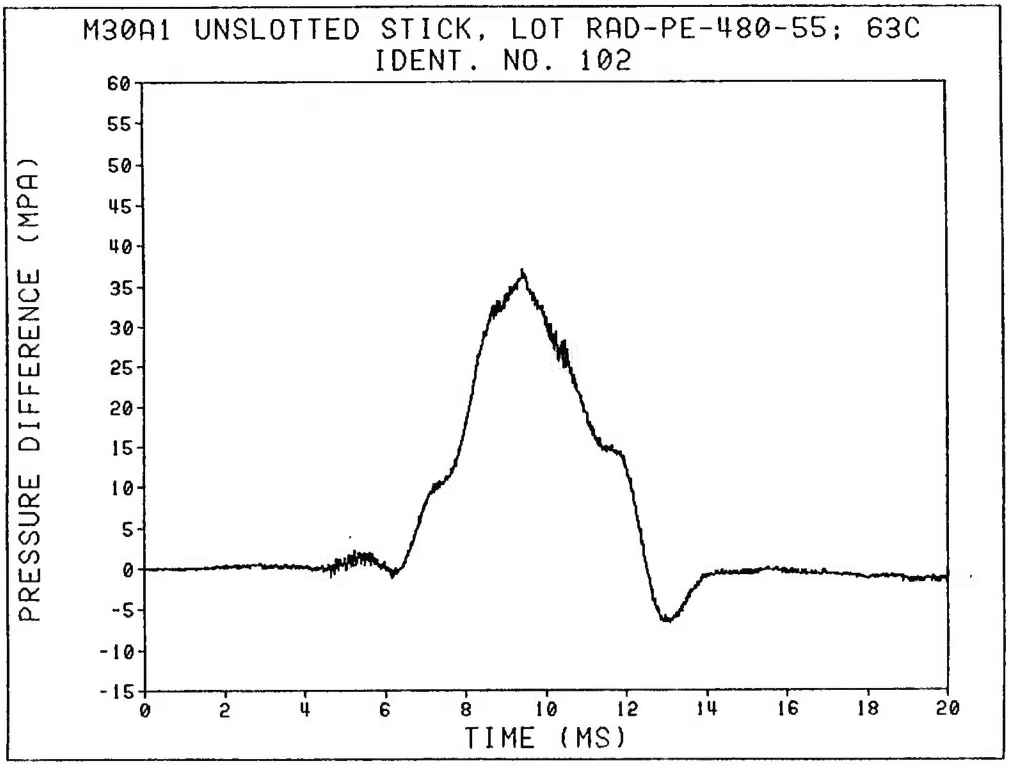
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; 63C
IDENT. NO. 102
PRESSURE DIFFERENCE (MPA)
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55
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45
40
35
30
25
20
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-15
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2
4
6
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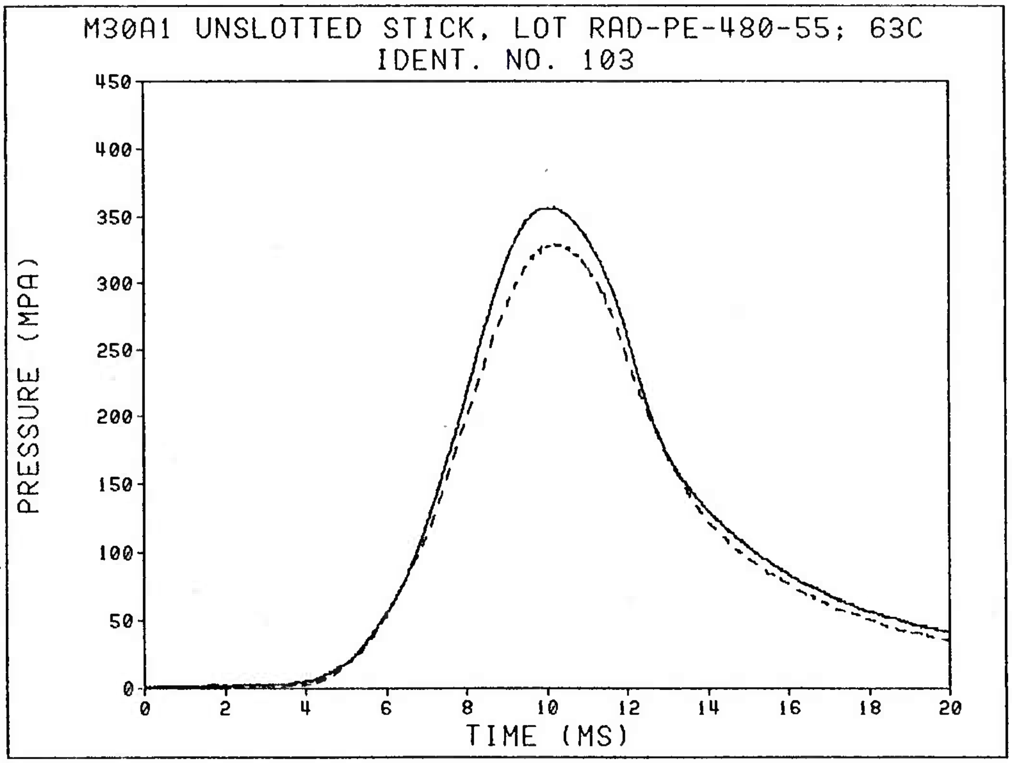
10
12
14
16
18
20
TIME (MS)


M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; 63C
IDENT. NO. 103
PRESSURE (MPA)
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100
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350
400
450
TIME (MS)
0
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4
6
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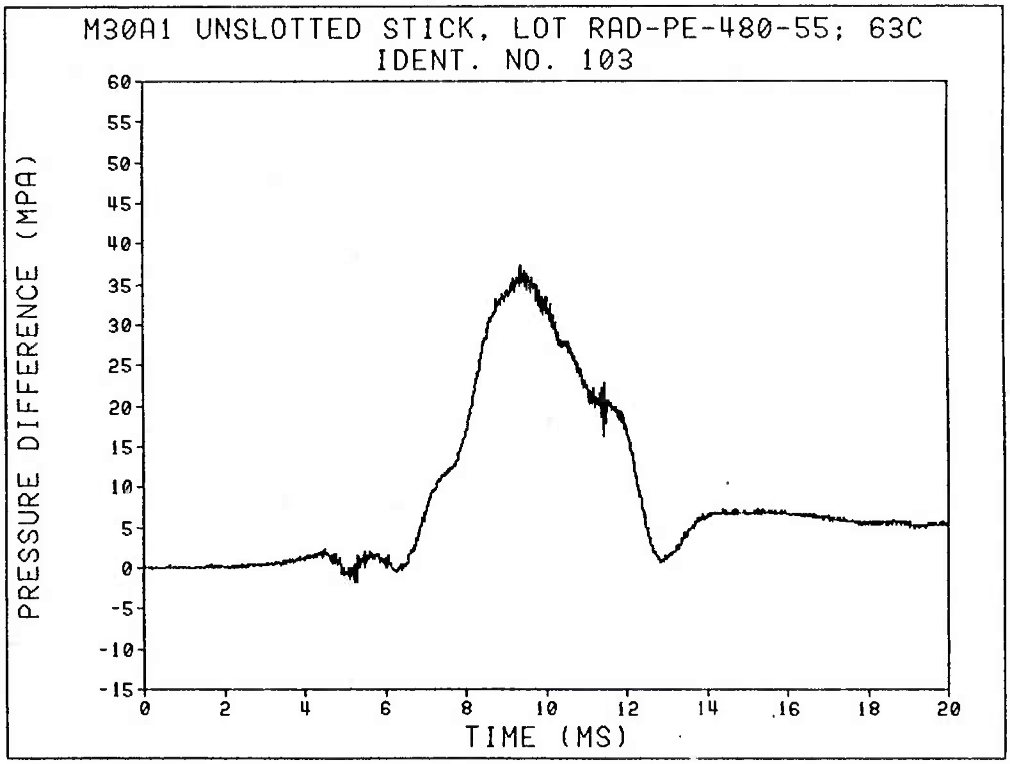
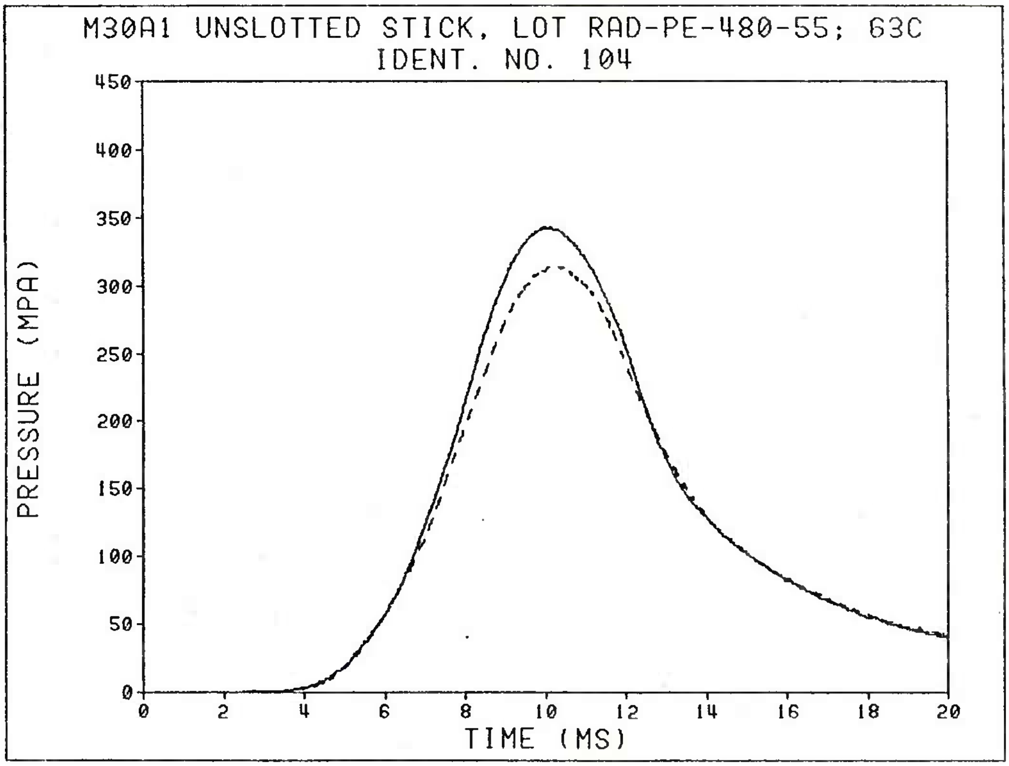
14
16
18
20


M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; 63C
IDENT. NO. 103
PRESSURE DIFFERENCE (MPA)
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
50
55
60
TIME (MS)
0
2
4
6
8
10
12
14
16
18
20


M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; 63C
IDENT. NO. 104
PRESSURE (MPA)
TIME (MS)
450
400
350
300
250
200
150
100
50
0
0
2
4
6
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14
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18
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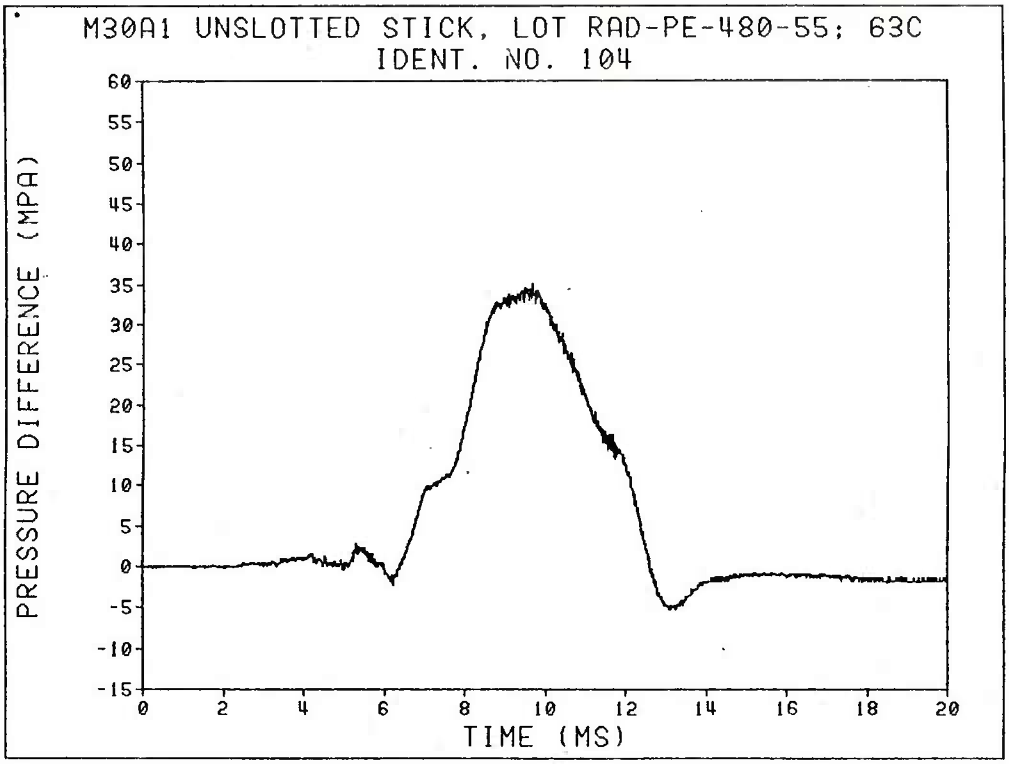
M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; 63C
IDENT. NO. 104
PRESSURE DIFFERENCE (MPA)
TIME (MS)
60
55
50
45
40
35
30
25
20
15
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-5
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-15
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2
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6
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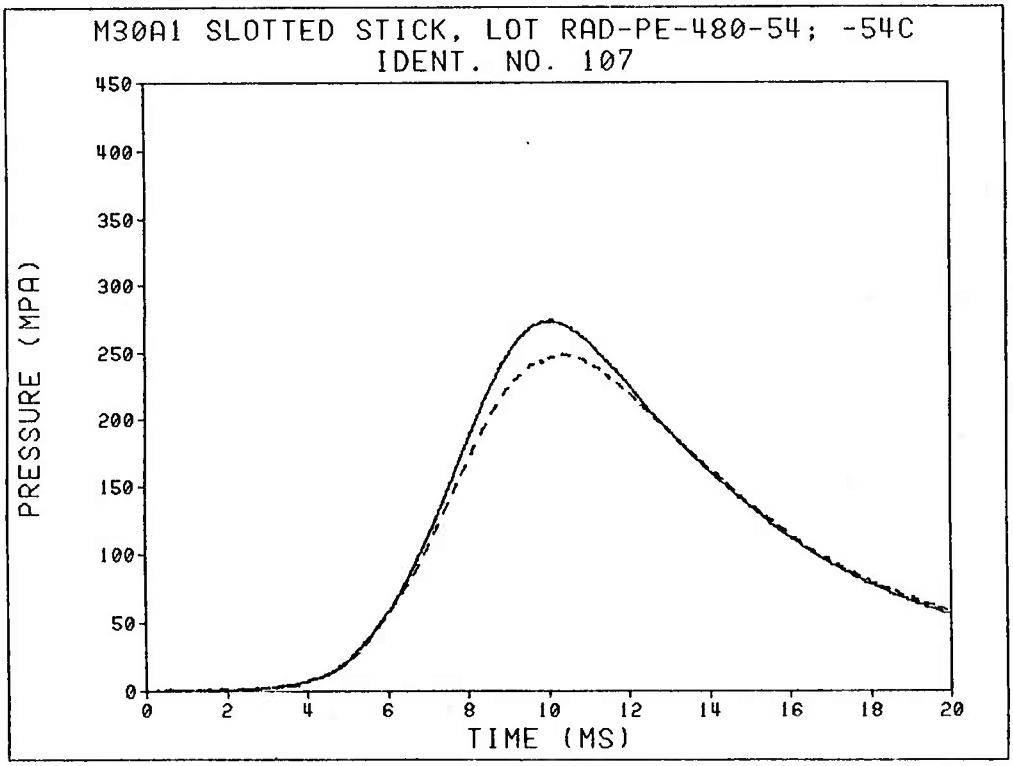
M30A1 SLOTTED STICK, LOT RAD-PE-480-54; -54C
IDENT. NO. 107
PRESSURE (MPA)
TIME (MS)
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100
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200
250
300
350
400
450
0
2
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6
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18
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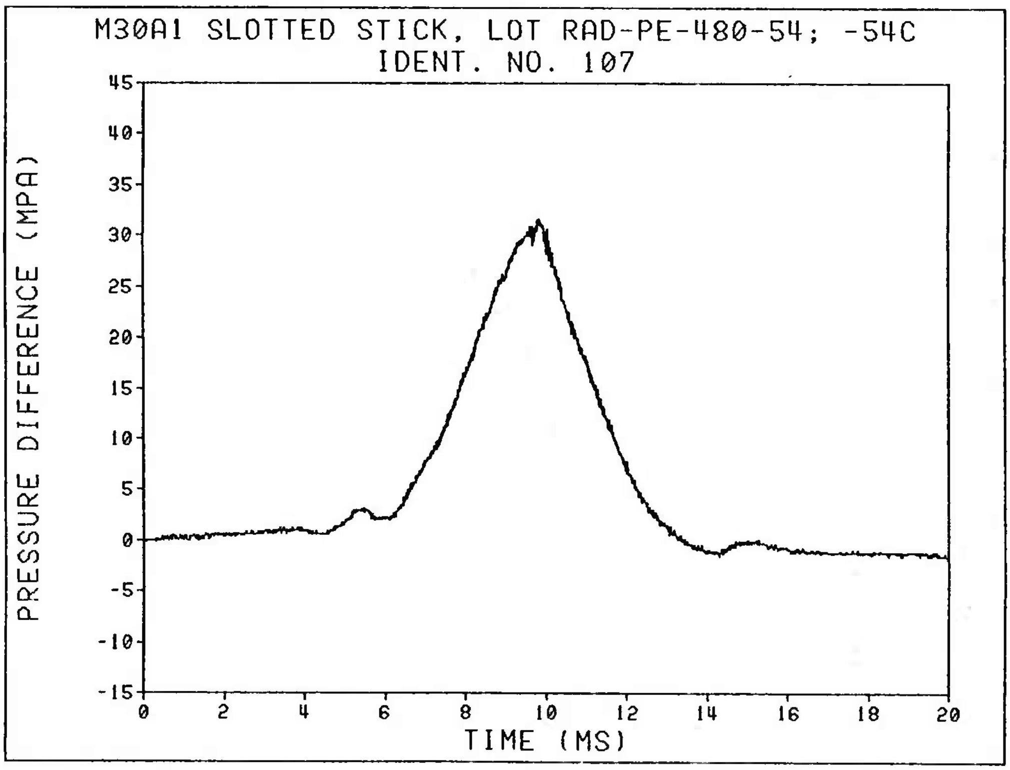
M30A1 SLOTTED STICK, LOT RAD-PE-480-54; -54C
IDENT. NO. 107
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
5
10
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20
25
30
35
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0
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6
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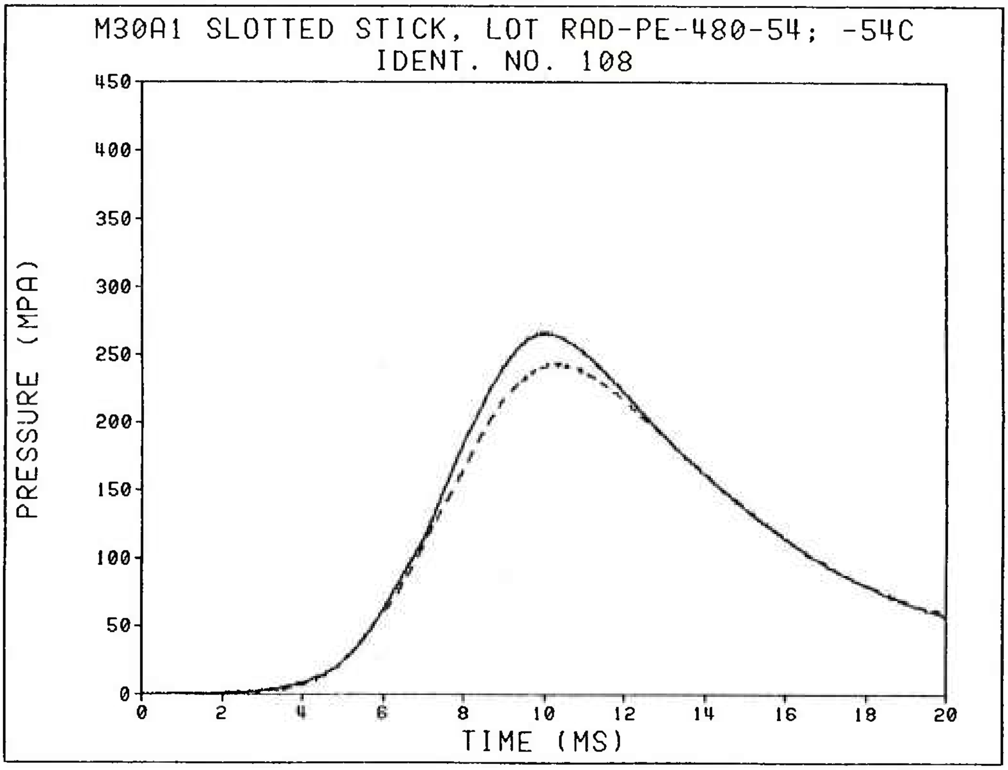
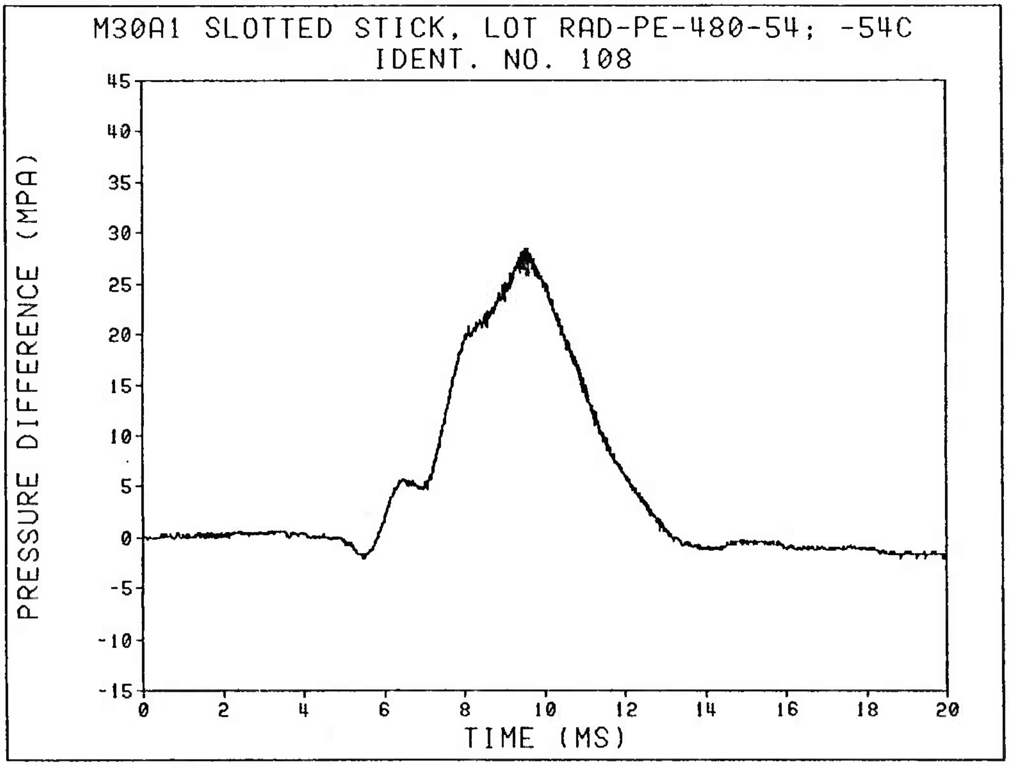
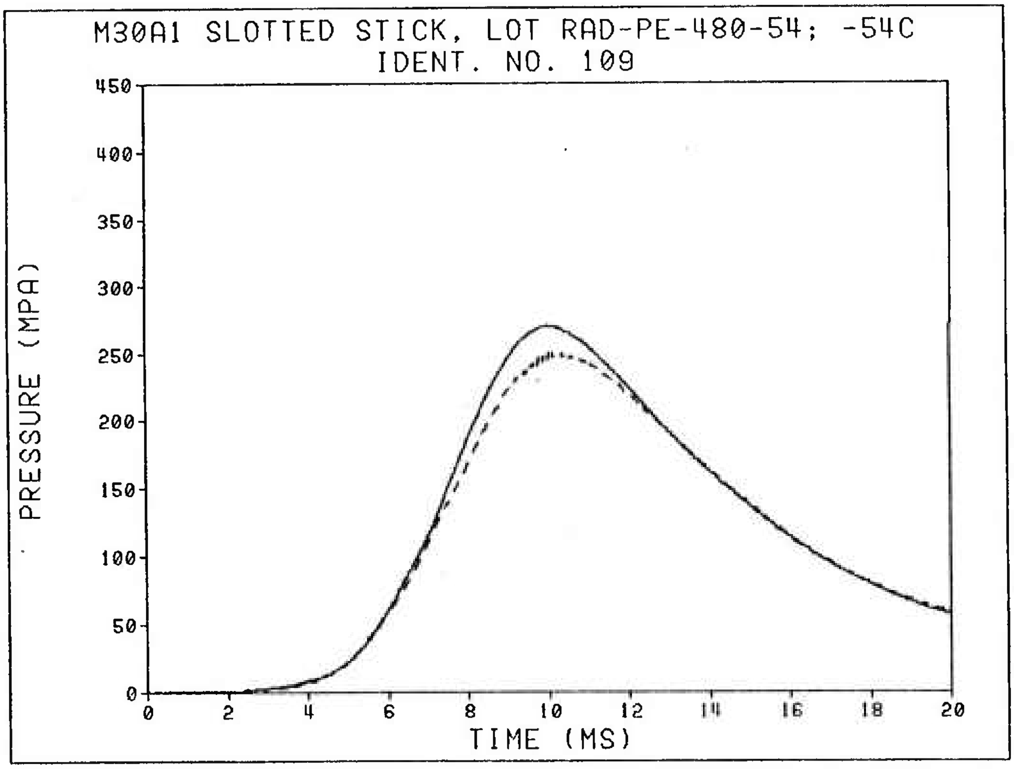

M30A1 SLOTTED STICK, LOT RAD-PE-480-54; -54C
IDENT. NO. 108
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-480-54; -54C
IDENT. NO. 108
PRESSURE DIFFERENCE (MPA)
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-480-54; -54C
IDENT. NO. 109
PRESSURE (MPA)
TIME (MS)
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100
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200
250
300
350
400
450
0
2
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6
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14
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18
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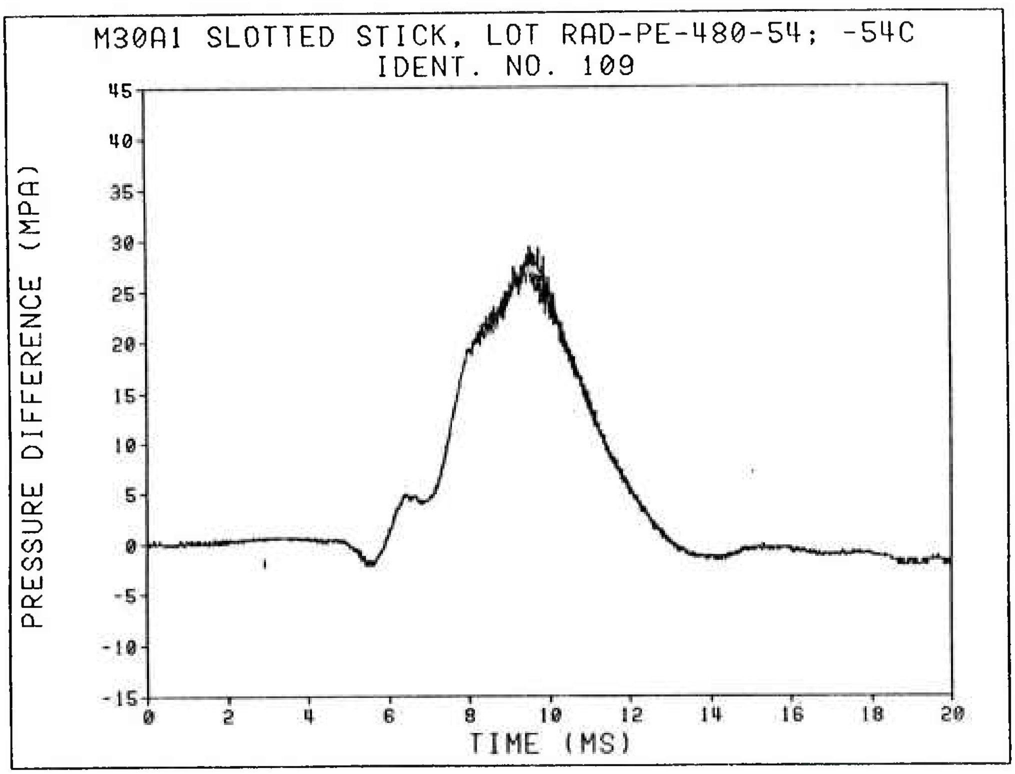
M30A1 SLOTTED STICK, LOT RAD-PE-480-54; -54C
IDENT. NO. 109
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
0
2
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6
8
10
12
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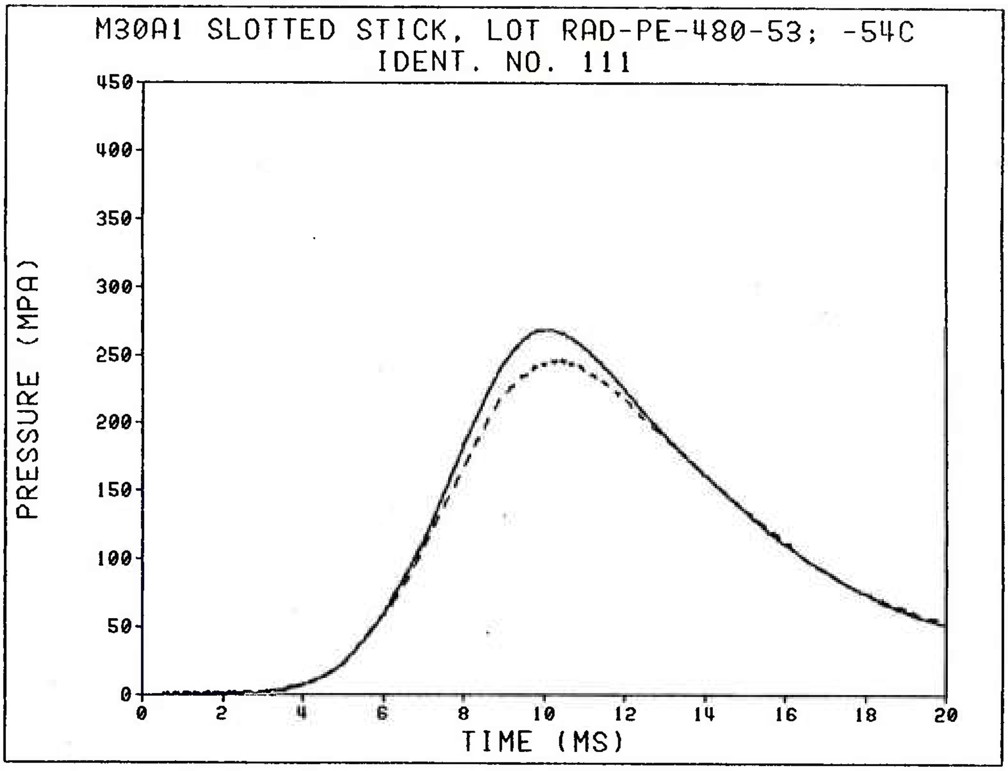
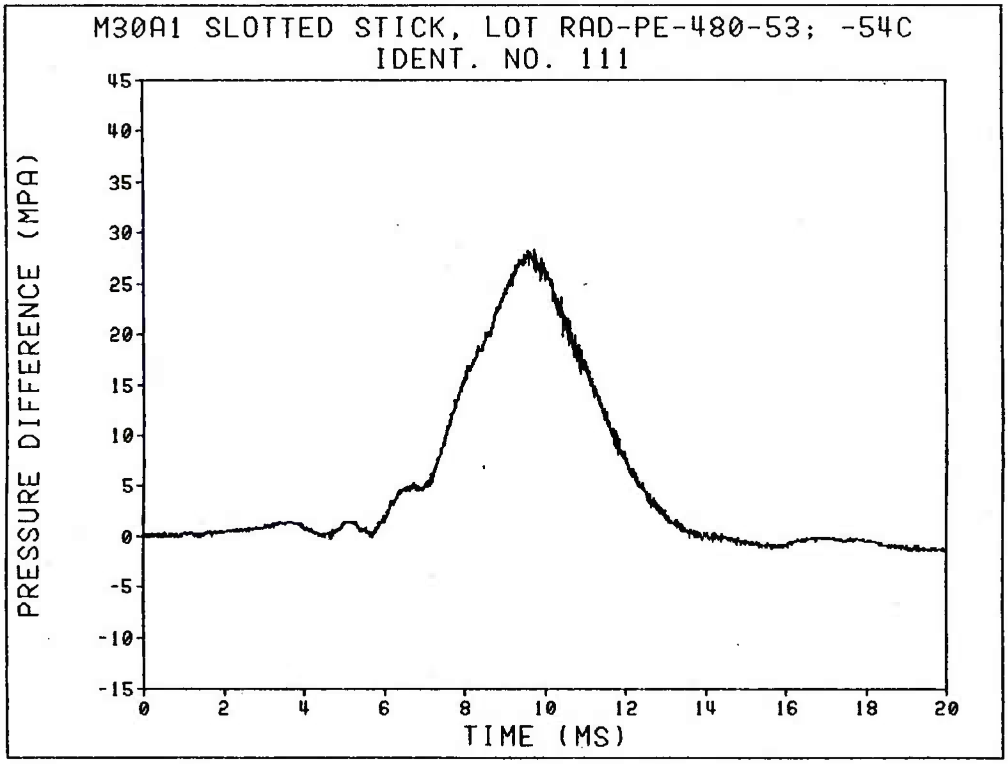
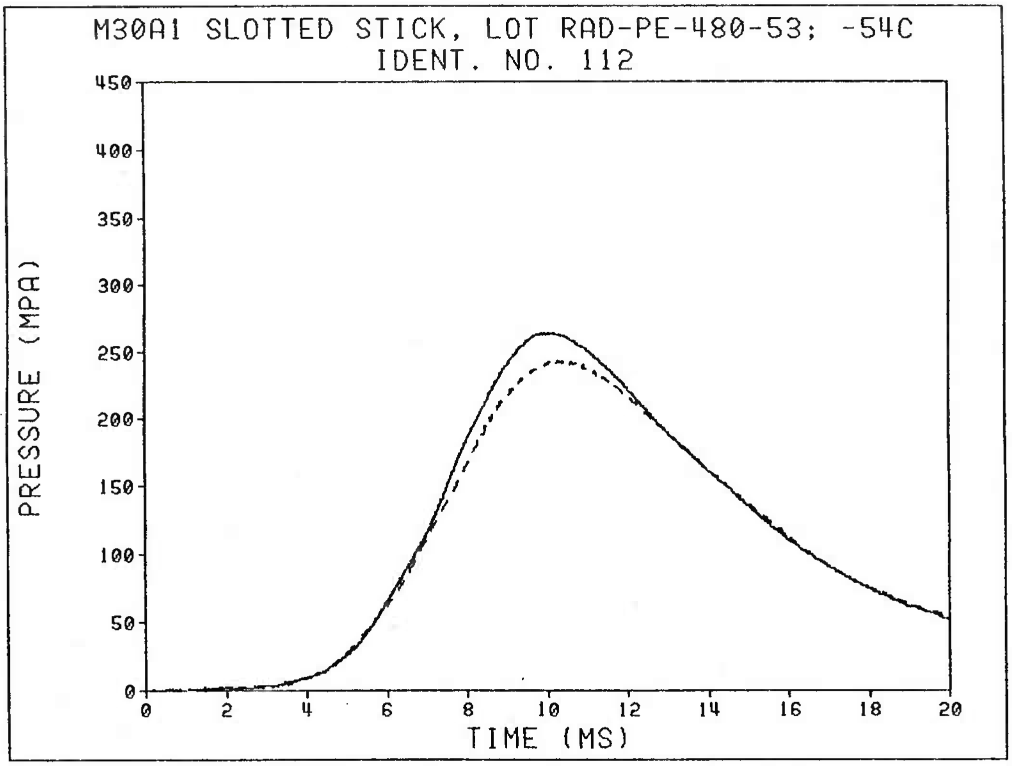


M30A1 SLOTTED STICK, LOT RAD-PE-480-53; -54C
IDENT. NO. 111
PRESSURE (MPA)
TIME (MS)



M30A1 SLOTTED STICK, LOT RAD-PE-480-53; -54C
IDENT. NO. 111
PRESSURE DIFFERENCE (MPA)
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-480-53; -54C
IDENT. NO. 112
PRESSURE (MPA)
TIME (MS)
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400
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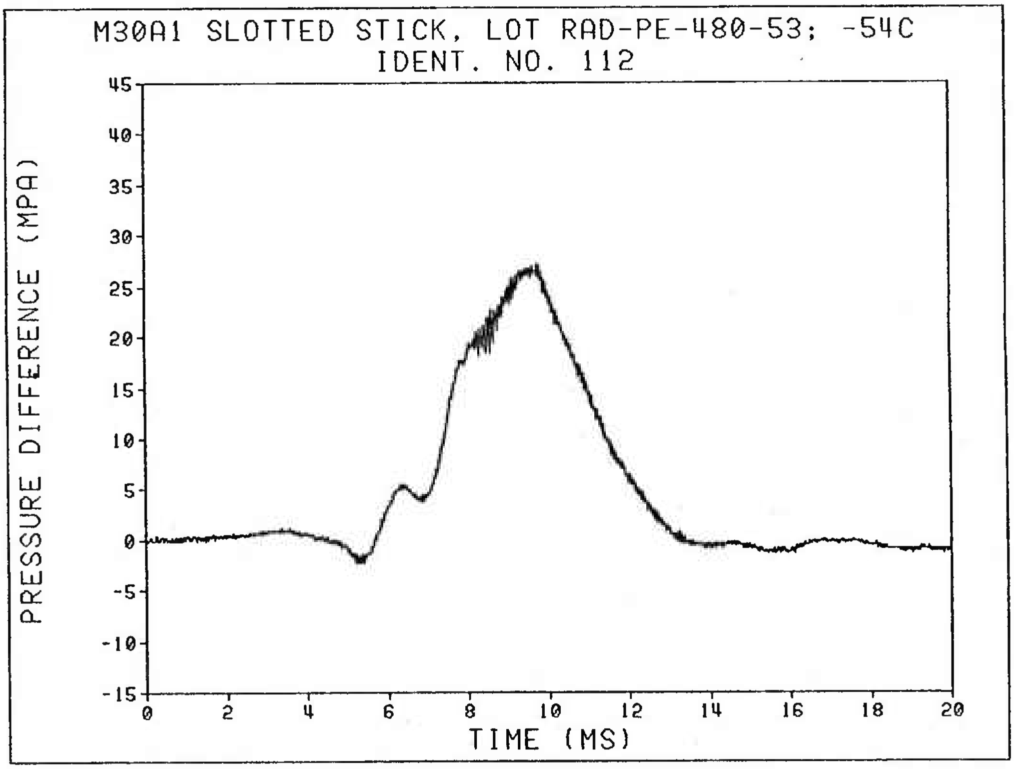
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20


M30A1 SLOTTED STICK, LOT RAD-PE-480-53; -54C
IDENT. NO. 112
PRESSURE DIFFERENCE (MPA)
TIME (MS)
45
40
35
30
25
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10
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0
-5
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-15
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2
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6
8
10
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14
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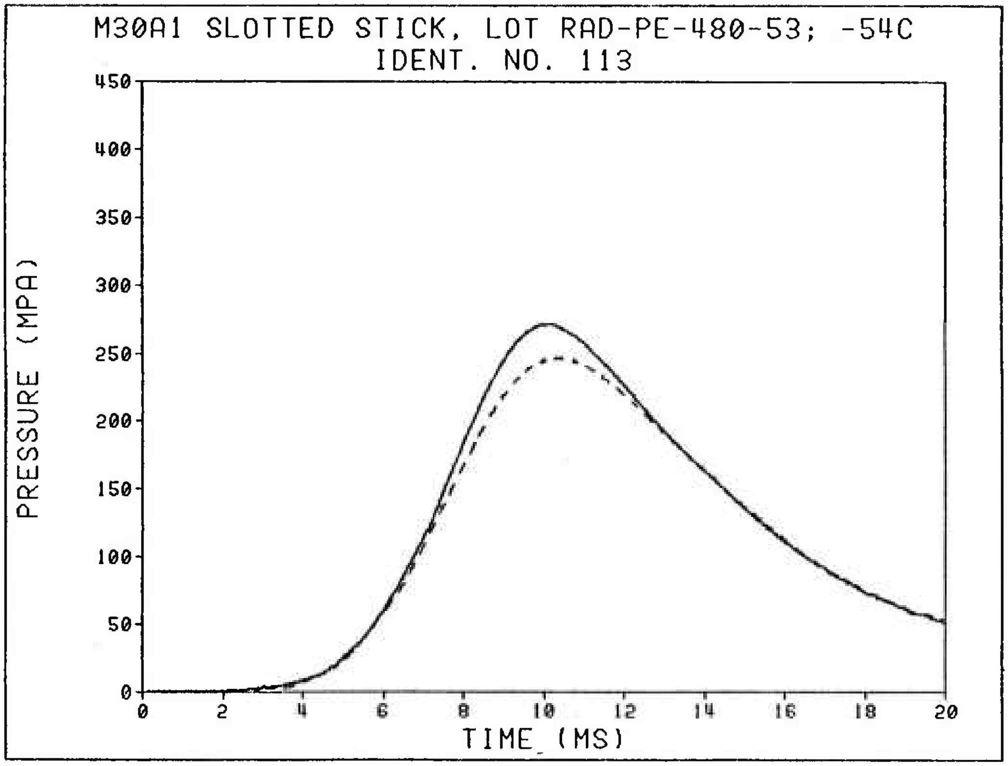
M30A1 SLOTTED STICK, LOT RAD-PE-480-53; -54C
IDENT. NO. 113
PRESSURE (MPA)
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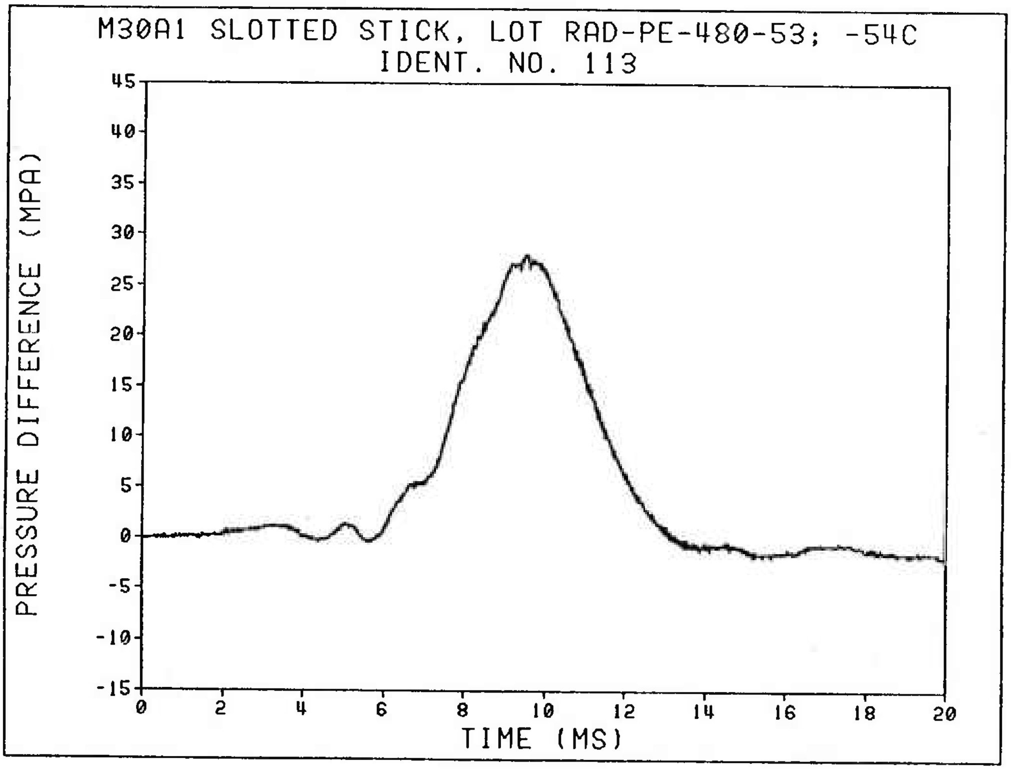
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-480-53; -54C
IDENT. NO. 113
PRESSURE DIFFERENCE (MPA)
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40
35
30
25
20
15
10
5
0
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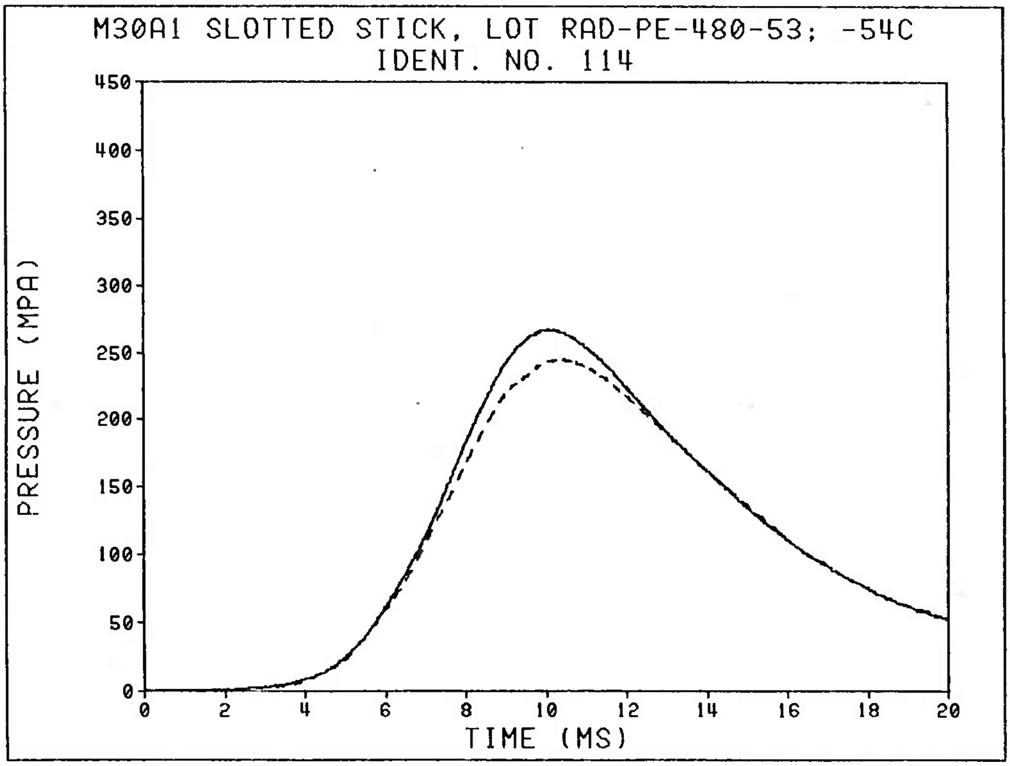
-10
-15
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-480-53; -54C
IDENT. NO. 114
PRESSURE (MPA)
TIME (MS)
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100
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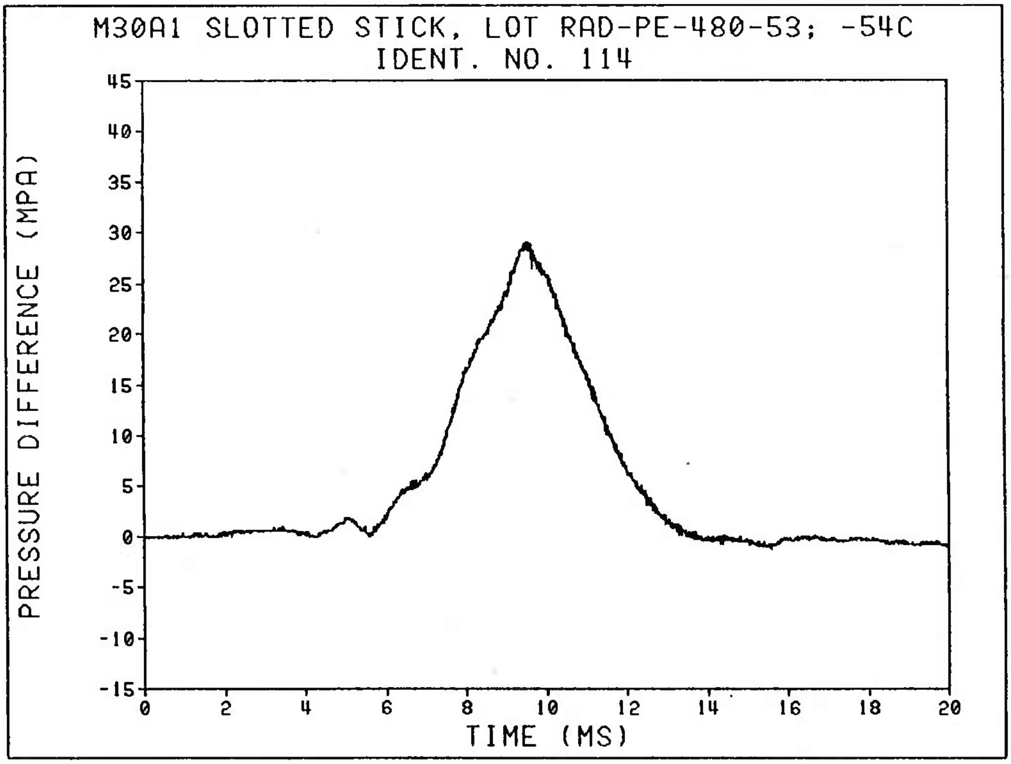
250
300
350
400
450
0
2
4
6
8
10
12
14
16
18
20


M30A1 SLOTTED STICK, LOT RAD-PE-480-53; -54C
IDENT. NO. 114
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
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15
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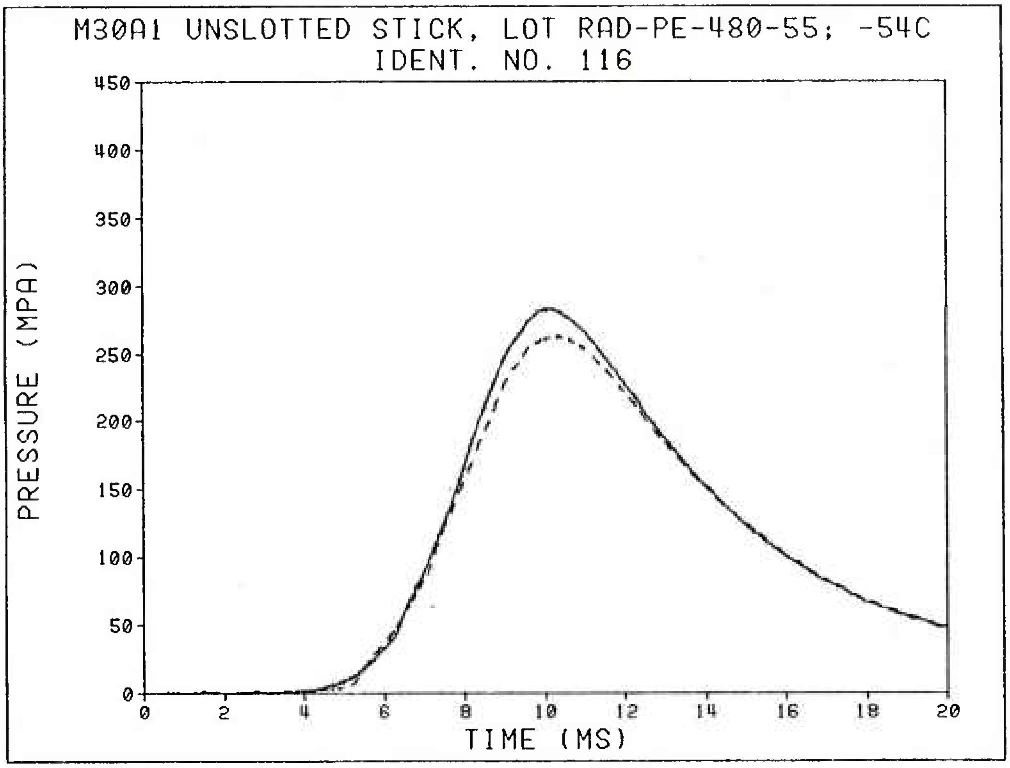
30
35
40
45
0
2
4
6
8
10
12
14
16
18
20


M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; -54C
IDENT. NO. 116
PRESSURE (MPA)
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400
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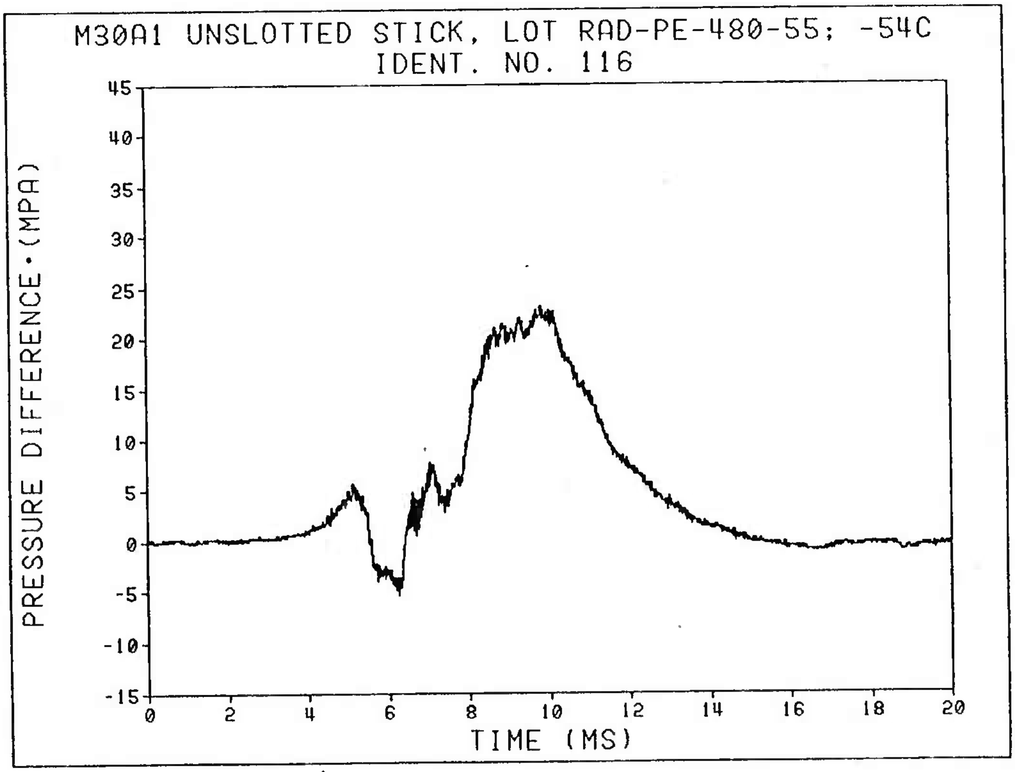
100
50
0
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; -54C
IDENT. NO. 116
PRESSURE DIFFERENCE (MPA)
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40
35
30
25
20
15
10
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0
-5
-10
-15
0
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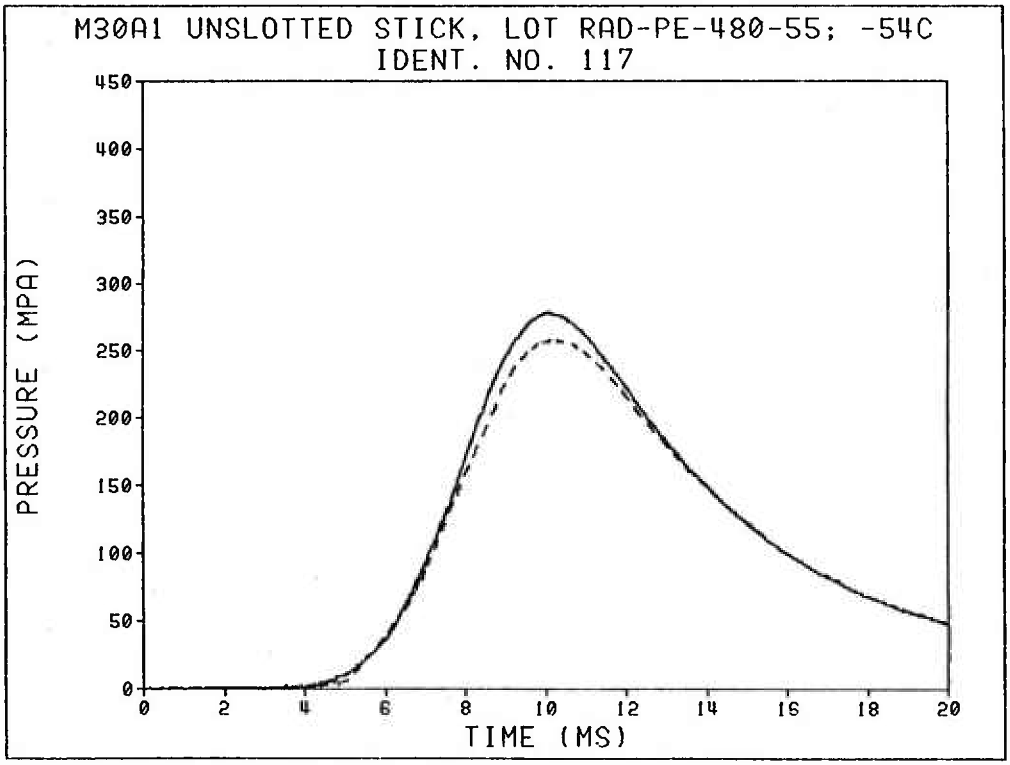
6
8
10
12
14
16
18
20
TIME (MS)



M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; -54C
IDENT. NO. 117
PRESSURE (MPA)
TIME (MS)
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200
150
100
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0
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2
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6
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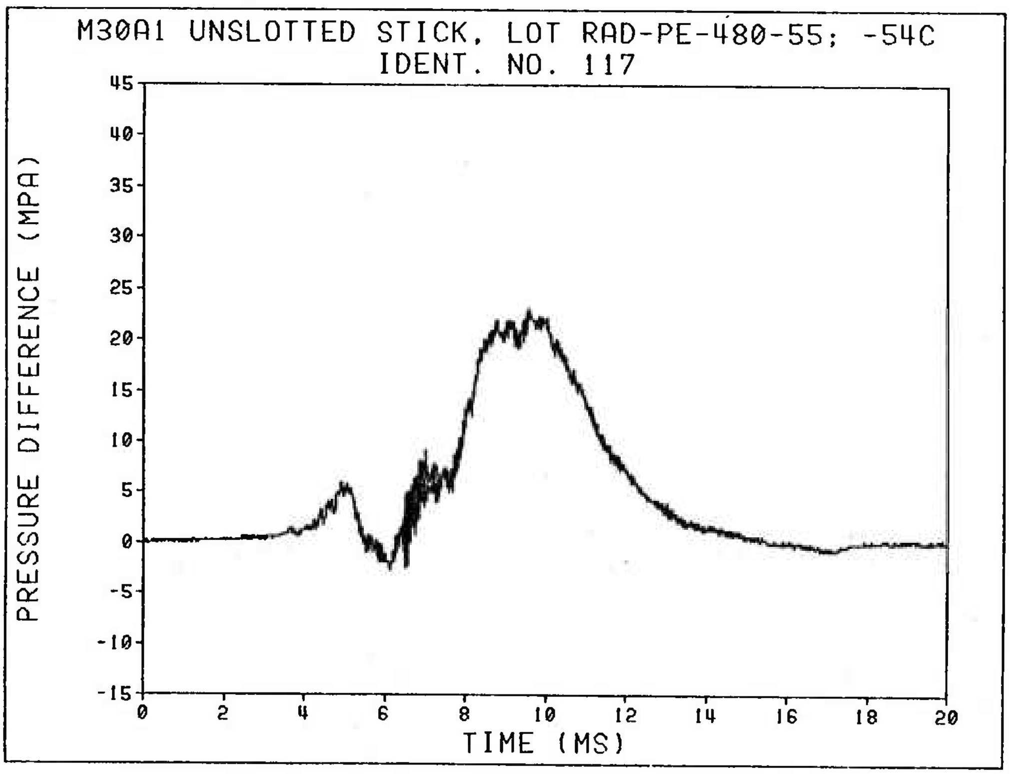
14
16
18
20



M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; -54C
IDENT. NO. 117
PRESSURE DIFFERENCE (MPA)
TIME (MS)
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40
35
30
25
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0
-5
-10
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2
4
6
8
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12
14
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18
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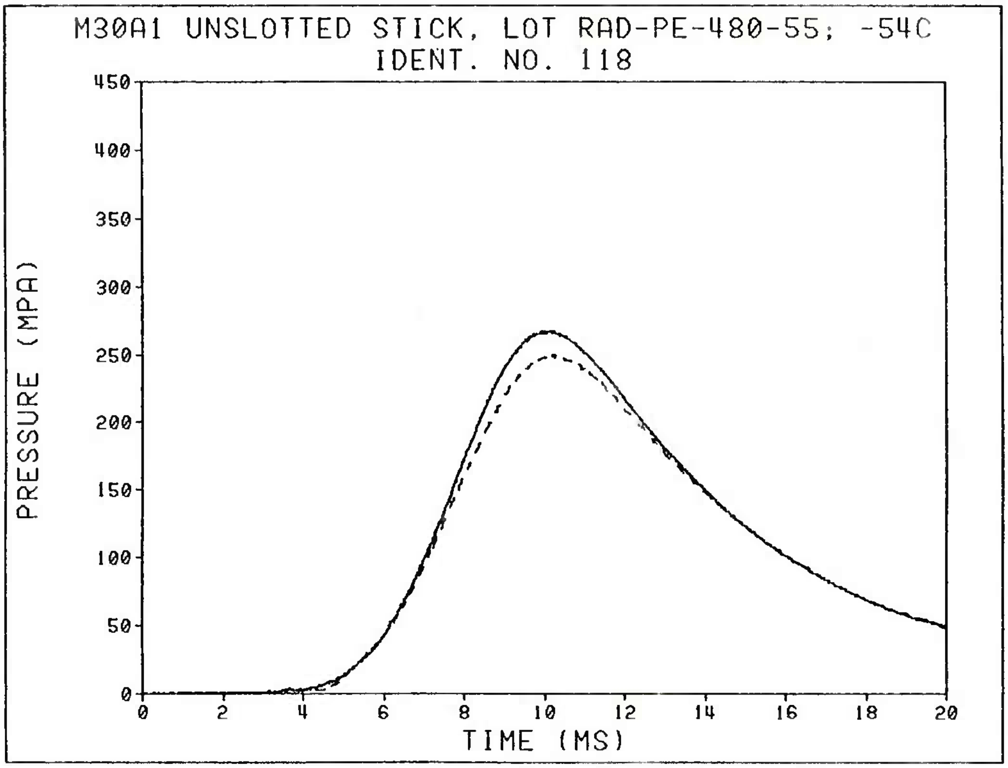
M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; -54C
IDENT. NO. 118
PRESSURE (MPA)
TIME (MS)
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250
200
150
100
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0
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2
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6
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10
12
14
16
18
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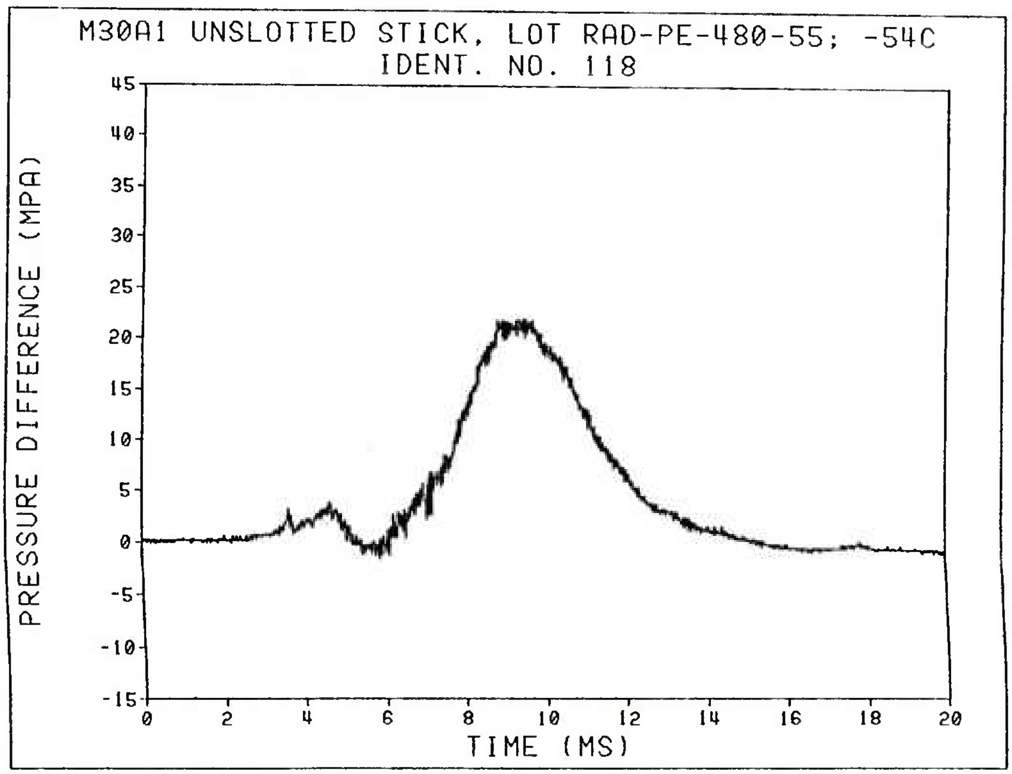
M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; -54C
IDENT. NO. 118
PRESSURE DIFFERENCE (MPA)
TIME (MS)
45
40
35
30
25
20
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10
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0
-5
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-15
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6
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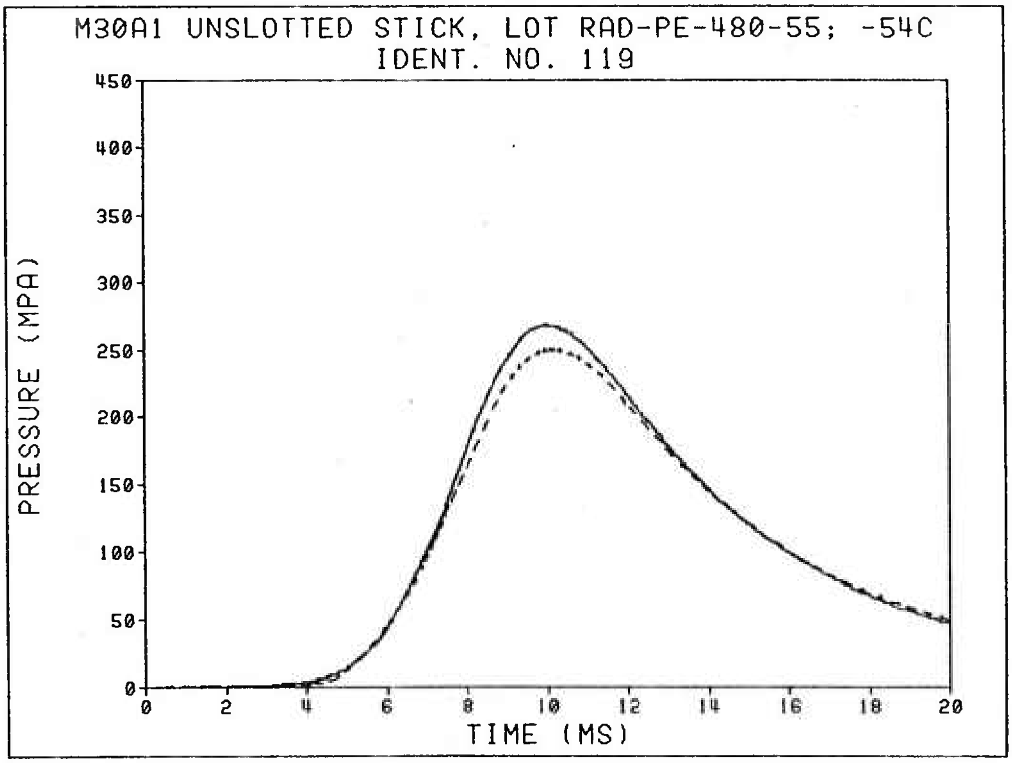
M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; -54C
IDENT. NO. 119
PRESSURE (MPA)
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400
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150
100
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2
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6
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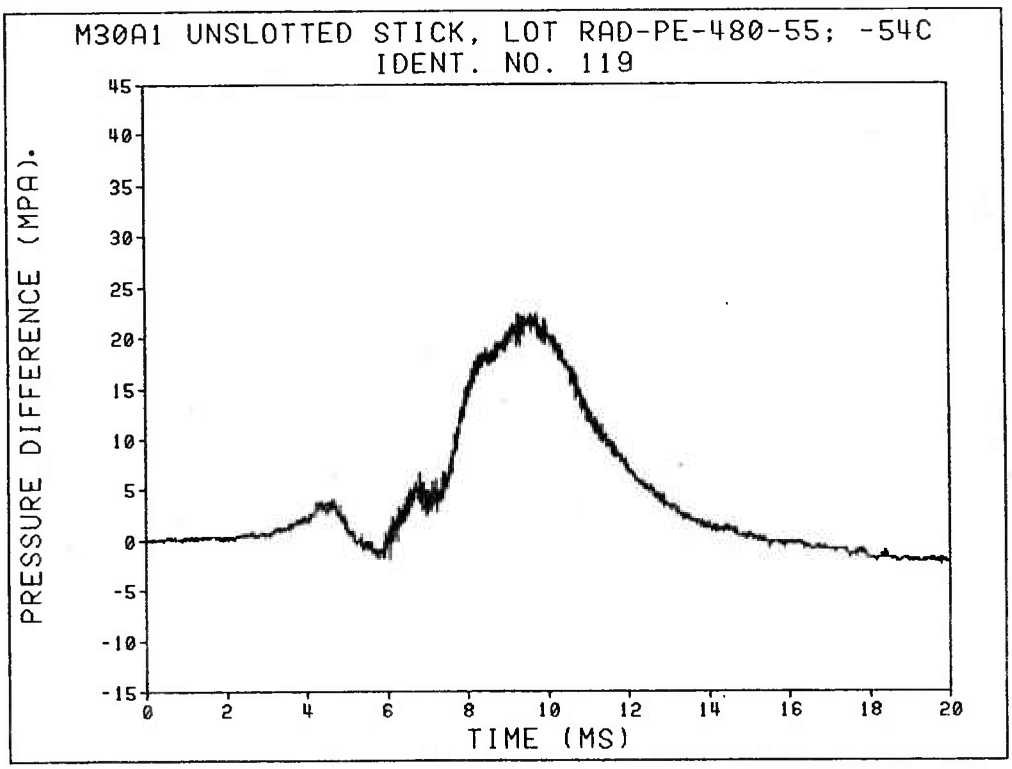
10
12
14
16
18
20
TIME (MS)


M30A1 UNSLOTTED STICK, LOT RAD-PE-480-55; -54C
IDENT. NO. 119
PRESSURE DIFFERENCE (MPA).
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20
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-5
-10
-15
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2
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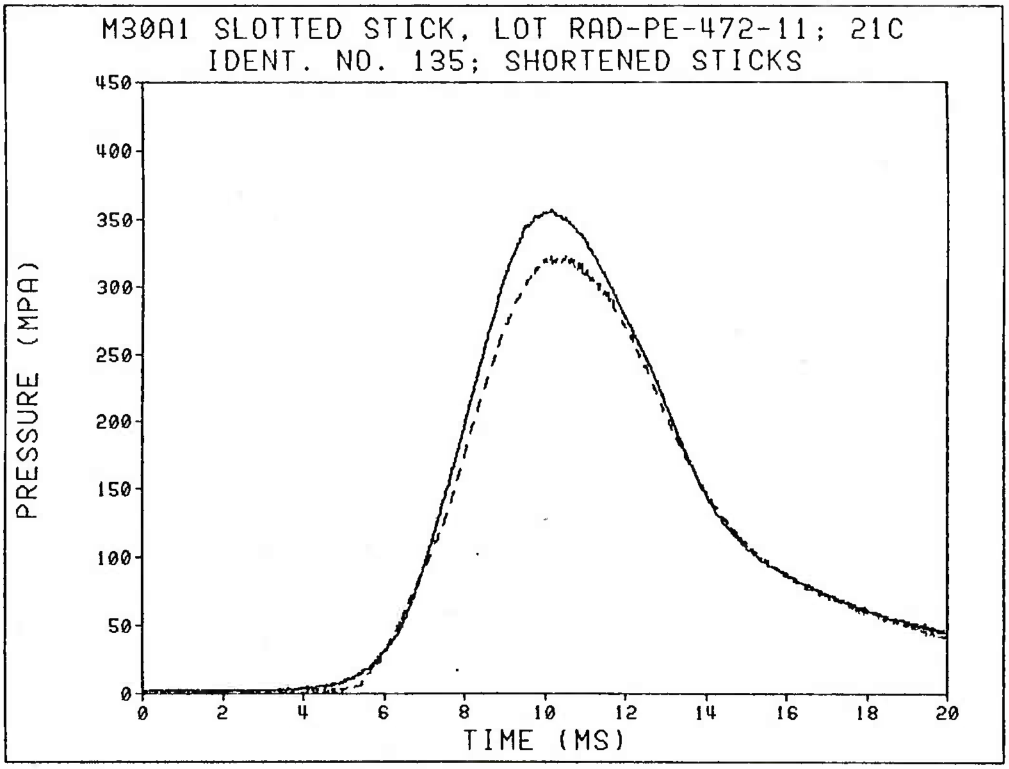
10
12
14
16
18
20
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 21C
IDENT. NO. 135; SHORTENED STICKS
PRESSURE (MPA)
TIME (MS)
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200
250
300
350
400
450
0
2
4
6
8
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14
16
18
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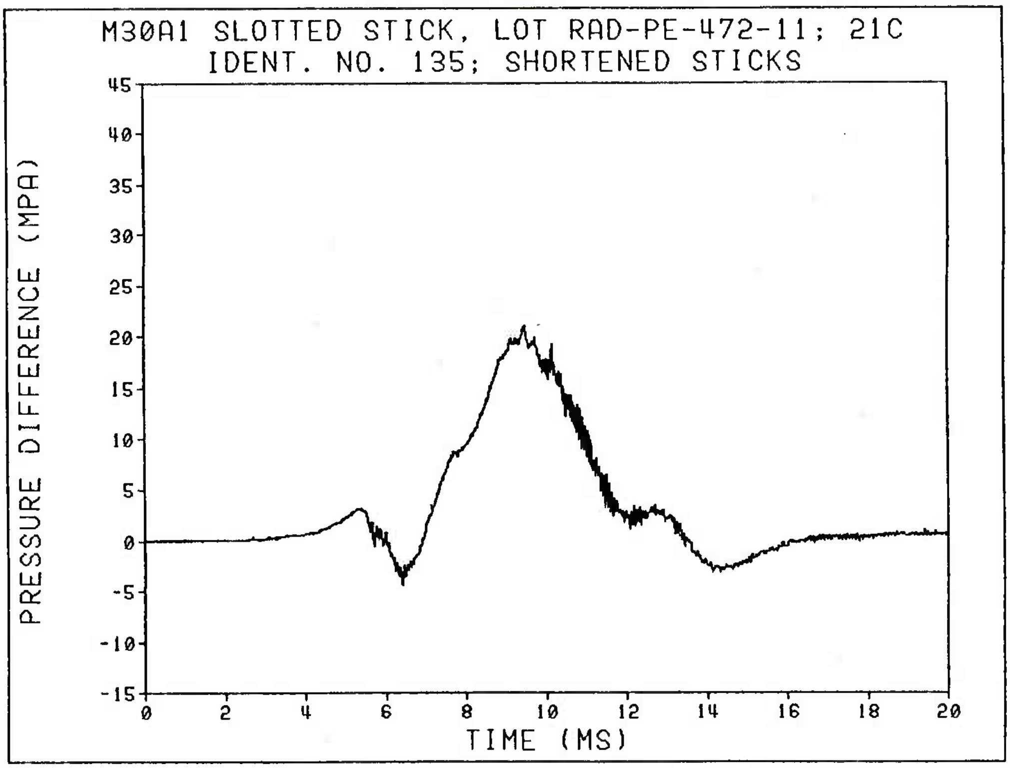
M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 21C
IDENT. NO. 135; SHORTENED STICKS
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
5
10
15
20
25
30
35
40
45
0
2
4
6
8
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18
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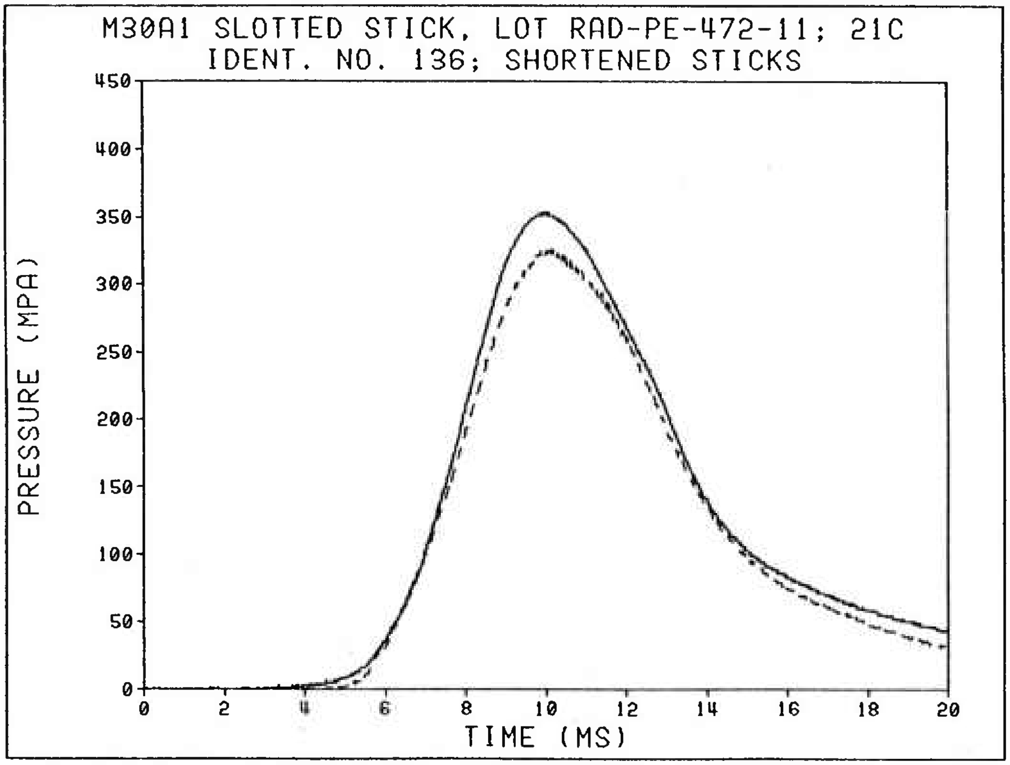
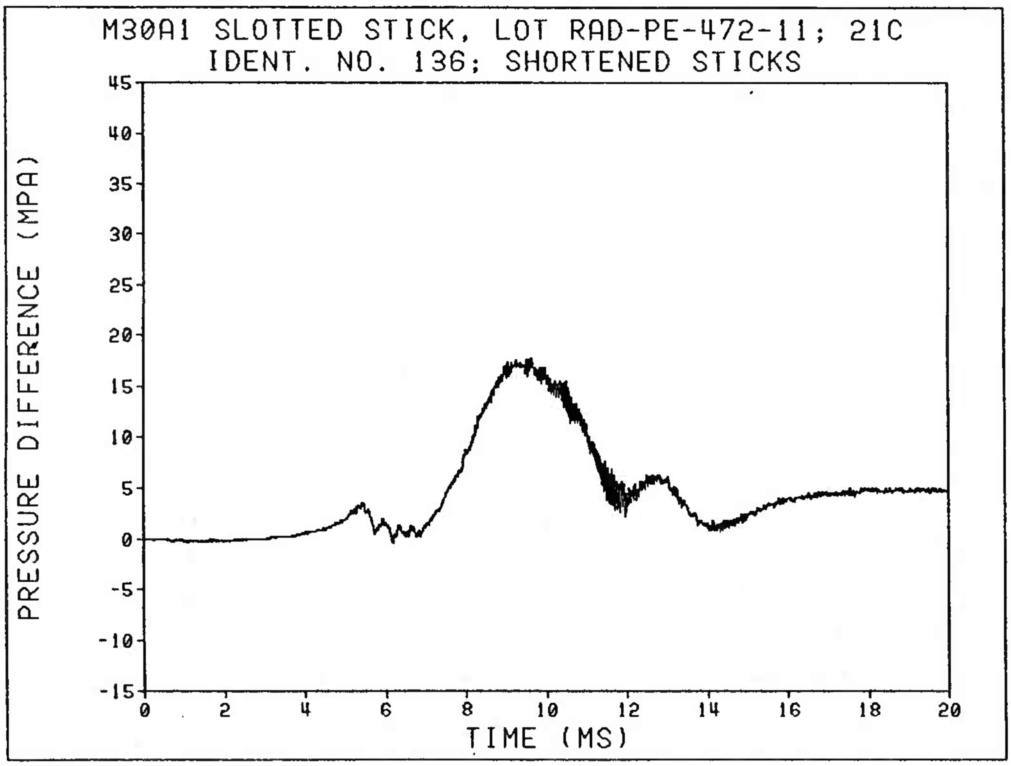
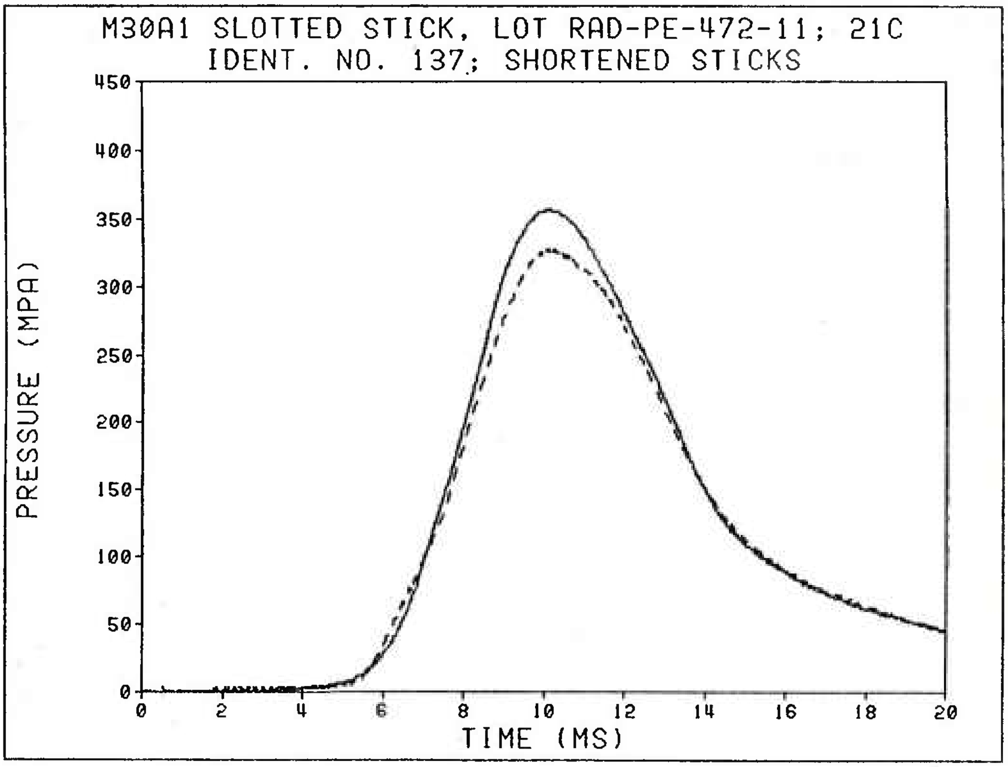

M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 21C
IDENT. NO. 136; SHORTENED STICKS
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 21C
IDENT. NO. 136; SHORTENED STICKS
PRESSURE DIFFERENCE (MPA)
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
0
2
4
6
8
10
12
14
16
18
20
TIME (MS)


M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 21C
IDENT. NO. 137; SHORTENED STICKS
PRESSURE (MPA)
TIME (MS)
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250
300
350
400
450
0
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4
6
8
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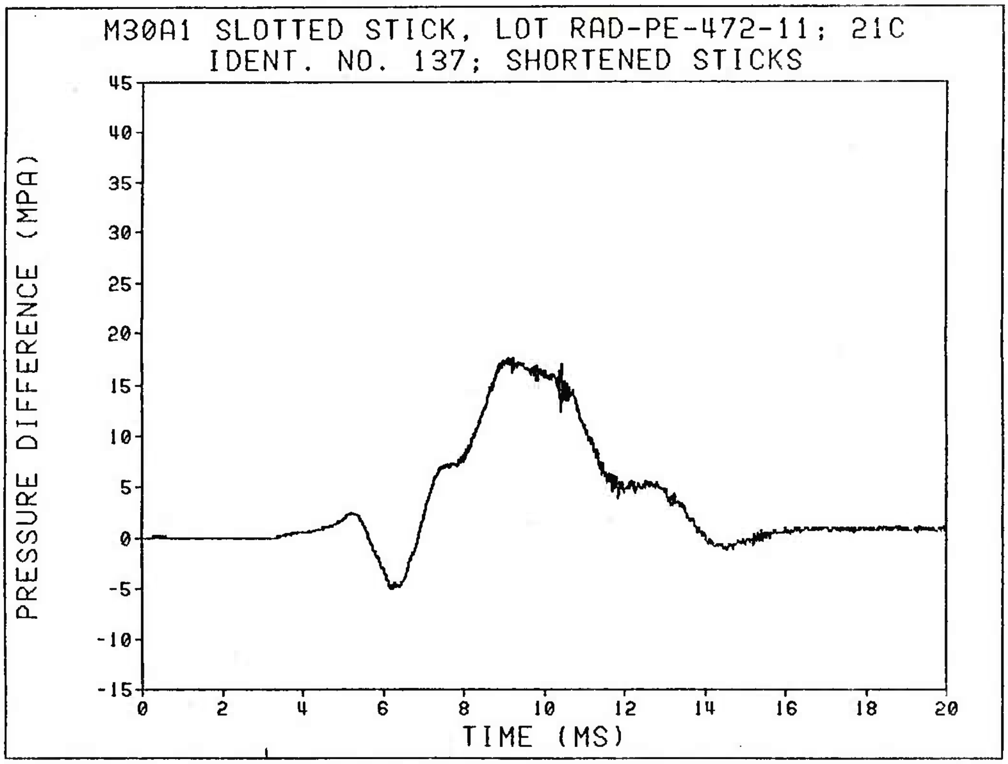
M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 21C
IDENT. NO. 137; SHORTENED STICKS
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
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45
0
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6
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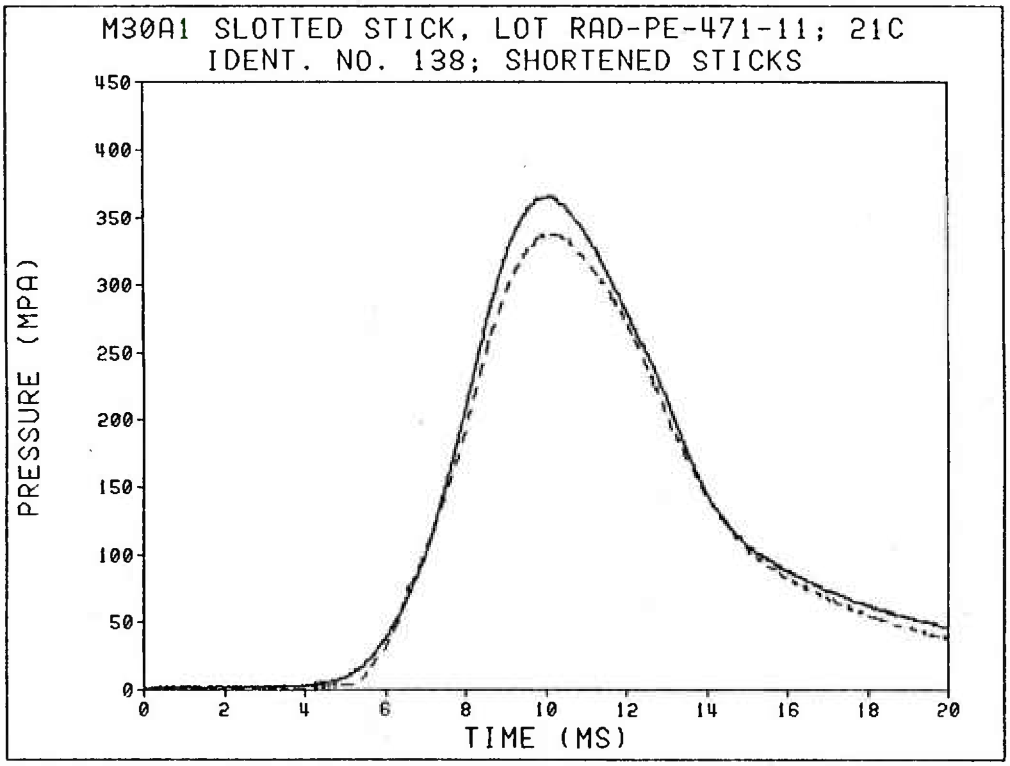
M30A1 SLOTTED STICK, LOT RAD-PE-471-11; 21C
IDENT. NO. 138; SHORTENED STICKS
PRESSURE (MPA)
0
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250
300
350
400
450
TIME (MS)
0
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4
6
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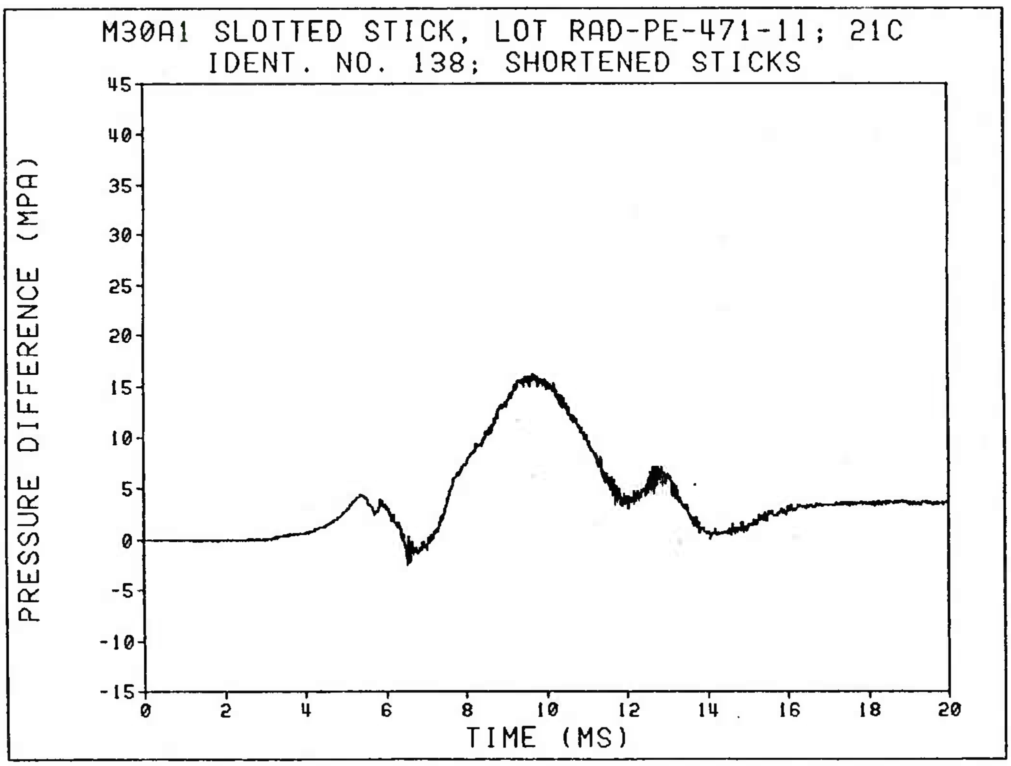
M30A1 SLOTTED STICK, LOT RAD-PE-471-11; 21C
IDENT. NO. 138; SHORTENED STICKS
PRESSURE DIFFERENCE (MPA)
-15
-10
-5
0
5
10
15
20
25
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35
40
45
TIME (MS)
0
2
4
6
8
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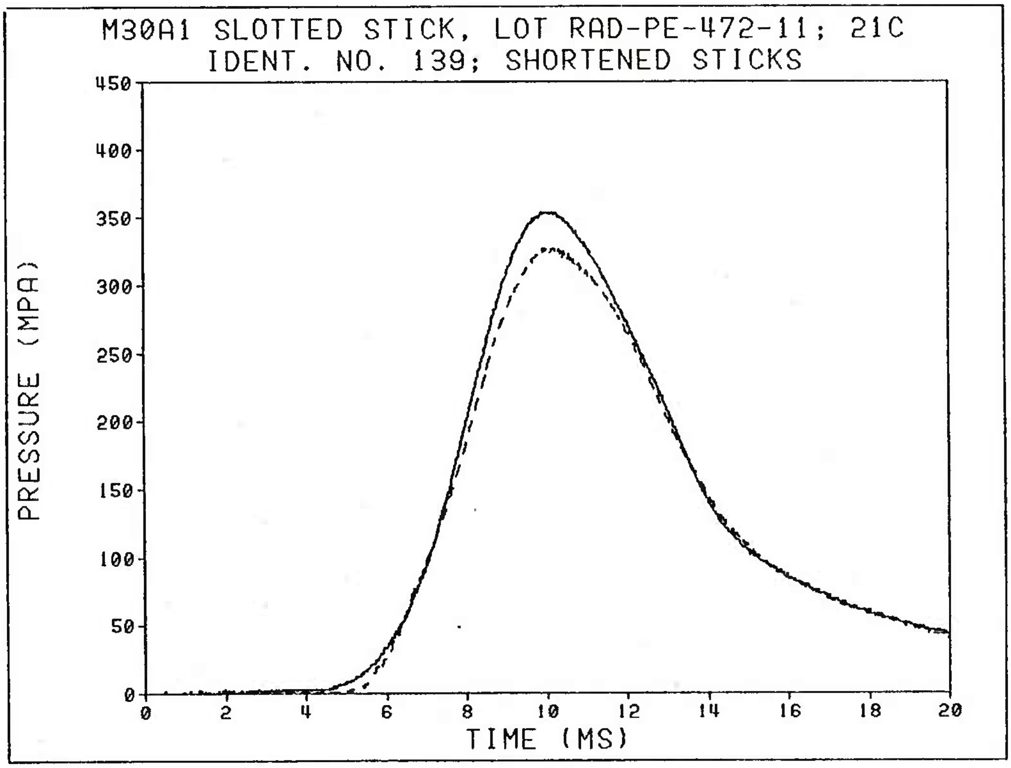
M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 21C
IDENT. NO. 139; SHORTENED STICKS
PRESSURE (MPA)
TIME (MS)
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100
150
200
250
300
350
400
450
0
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4
6
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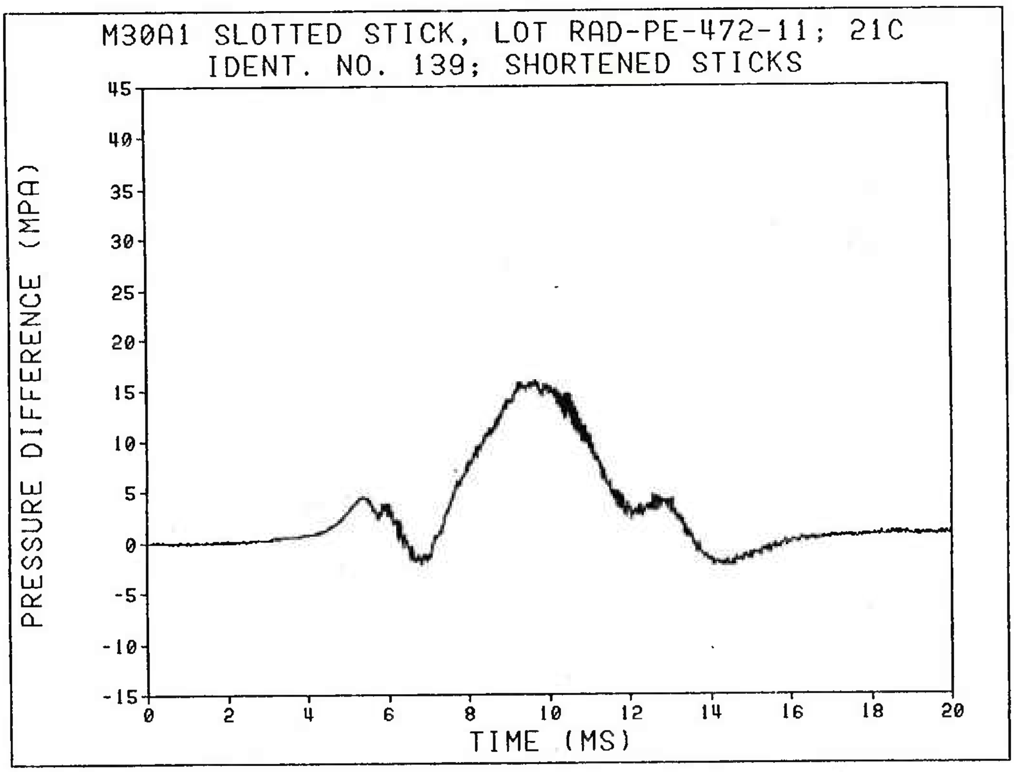
M30A1 SLOTTED STICK, LOT RAD-PE-472-11; 21C
IDENT. NO. 139; SHORTENED STICKS
PRESSURE DIFFERENCE (MPA)
TIME (MS)
-15
-10
-5
0
5
10
15
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25
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45
0
2
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6
8
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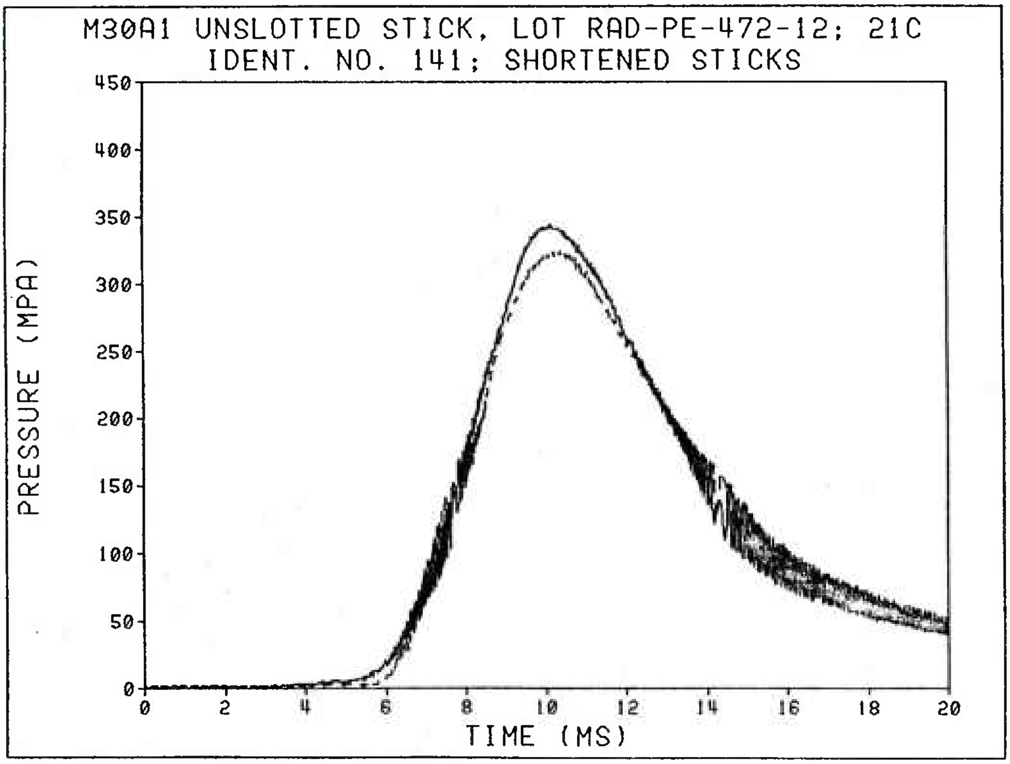
M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; 21C
IDENT. NO. 141; SHORTENED STICKS
PRESSURE (MPA)
TIME (MS)
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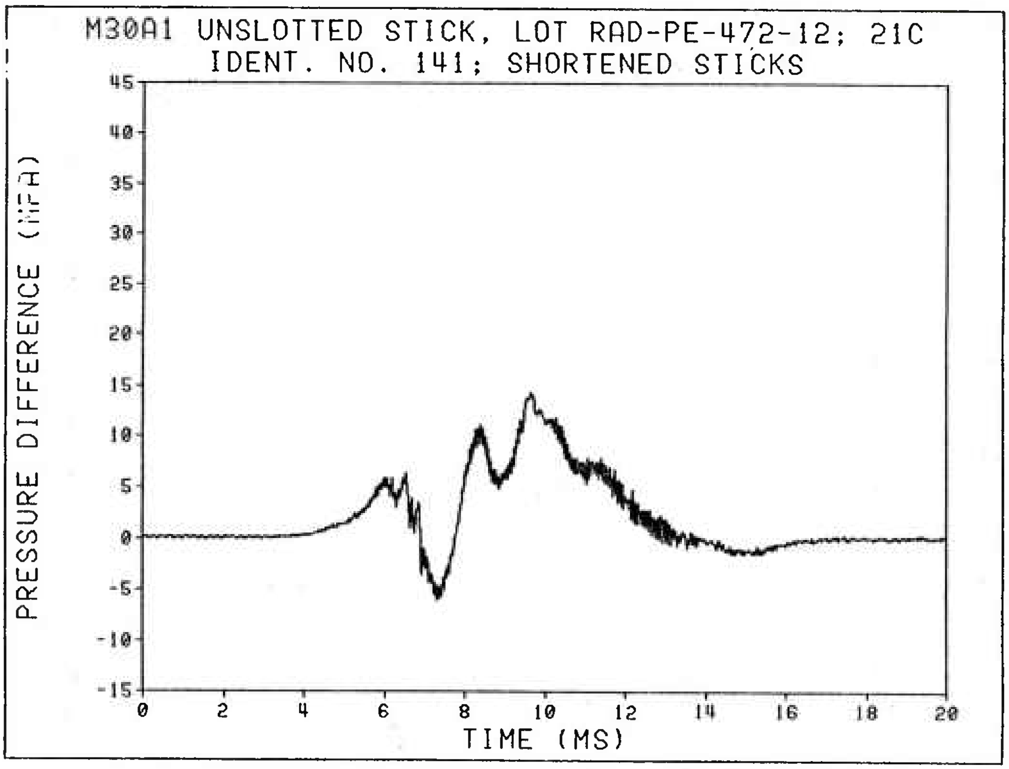
200
250
300
350
400
450
0
2
4
6
8
10
12
14
16
18
20


M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; 21C
IDENT. NO. 141; SHORTENED STICKS
PRESSURE DIFFERENCE (MPA)
TIME (MS)
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-10
-5
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25
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35
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45
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6
8
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14
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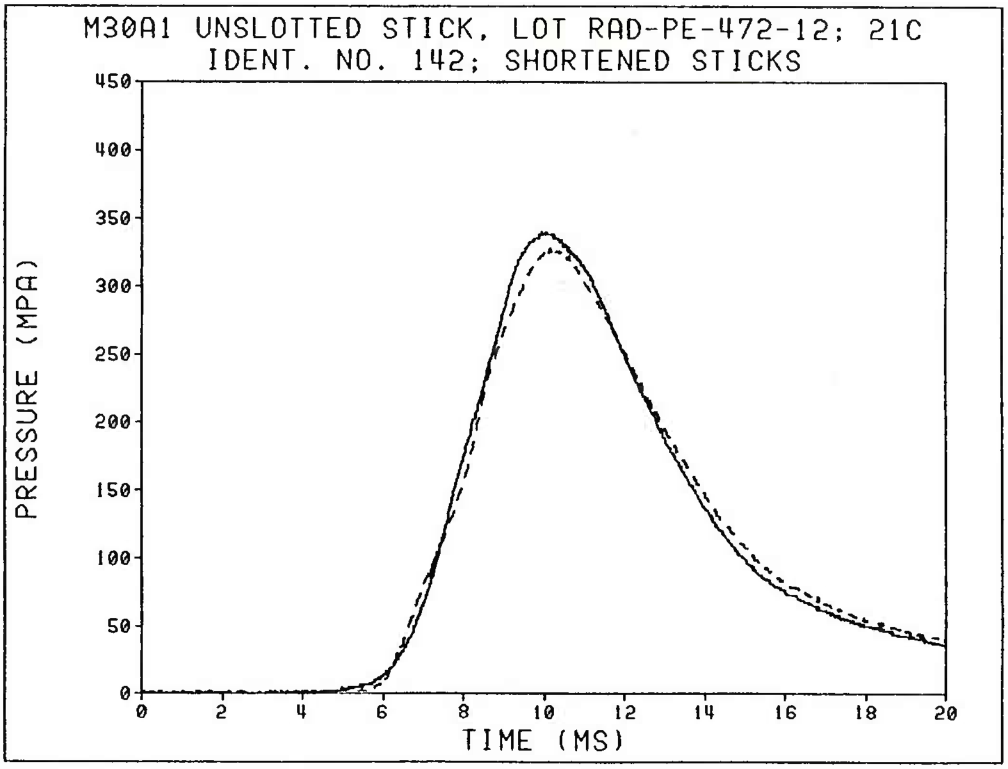
M30A1 UNSLOTTED STICK, LOT RAD-PE-472-12; 21C
IDENT. NO. 142; SHORTENED STICKS
PRESSURE (MPA)
TIME (MS)
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100
150
200
250
300
350
400
450
0
2
4
6
8
10
12
14
16
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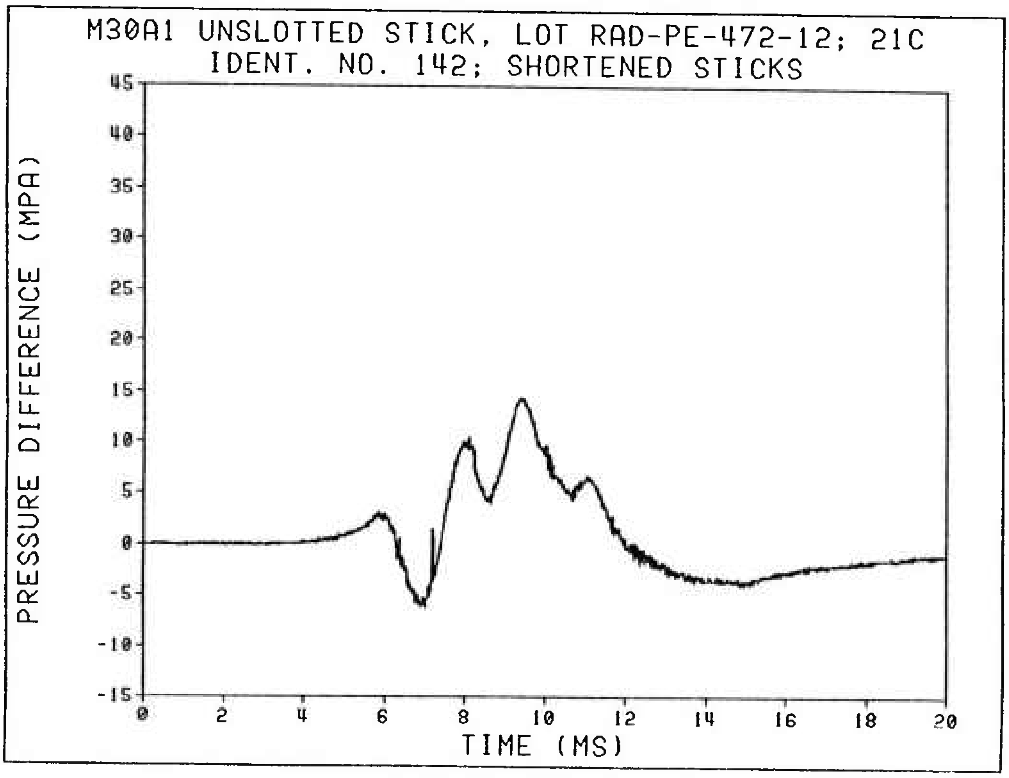
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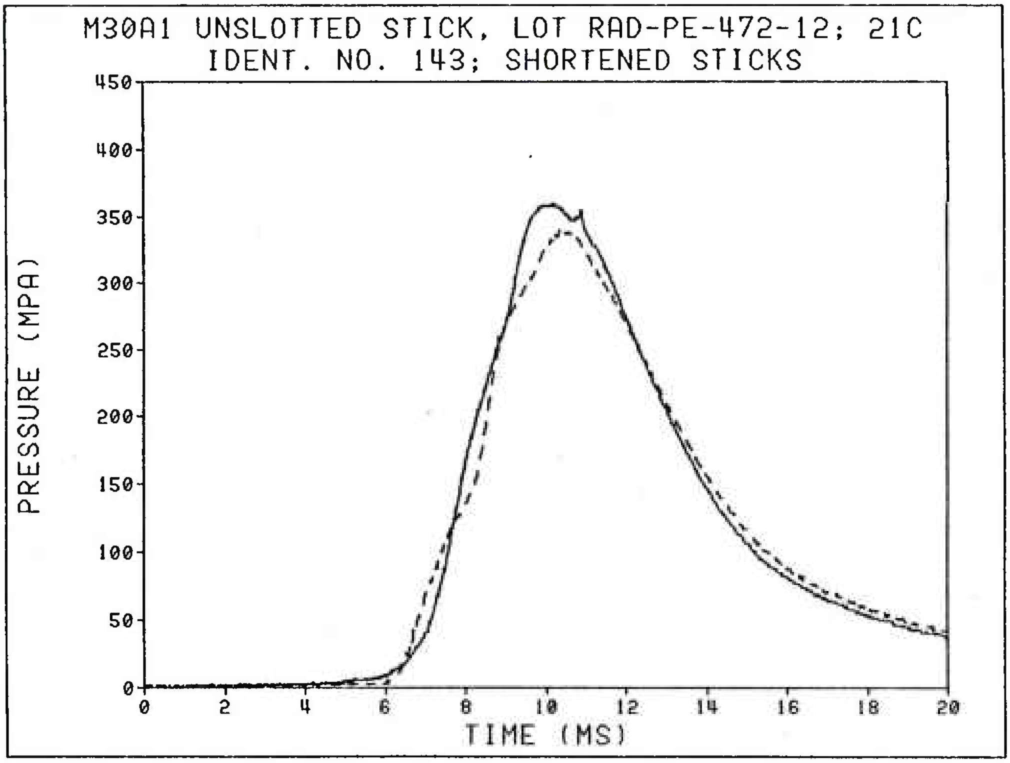
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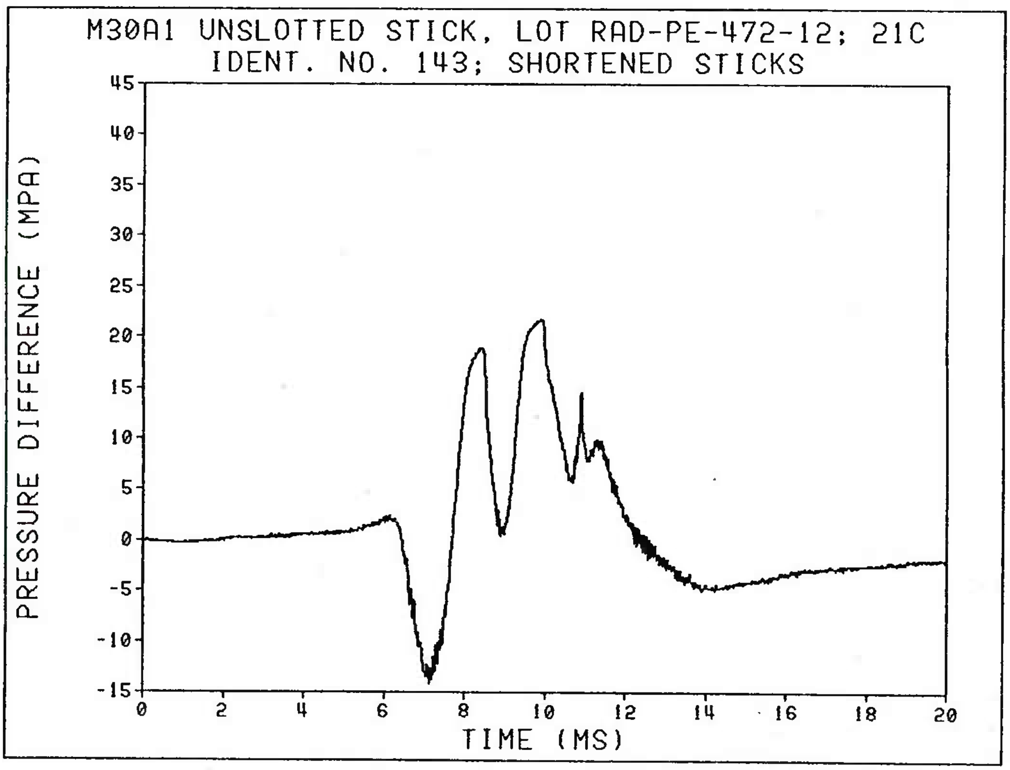
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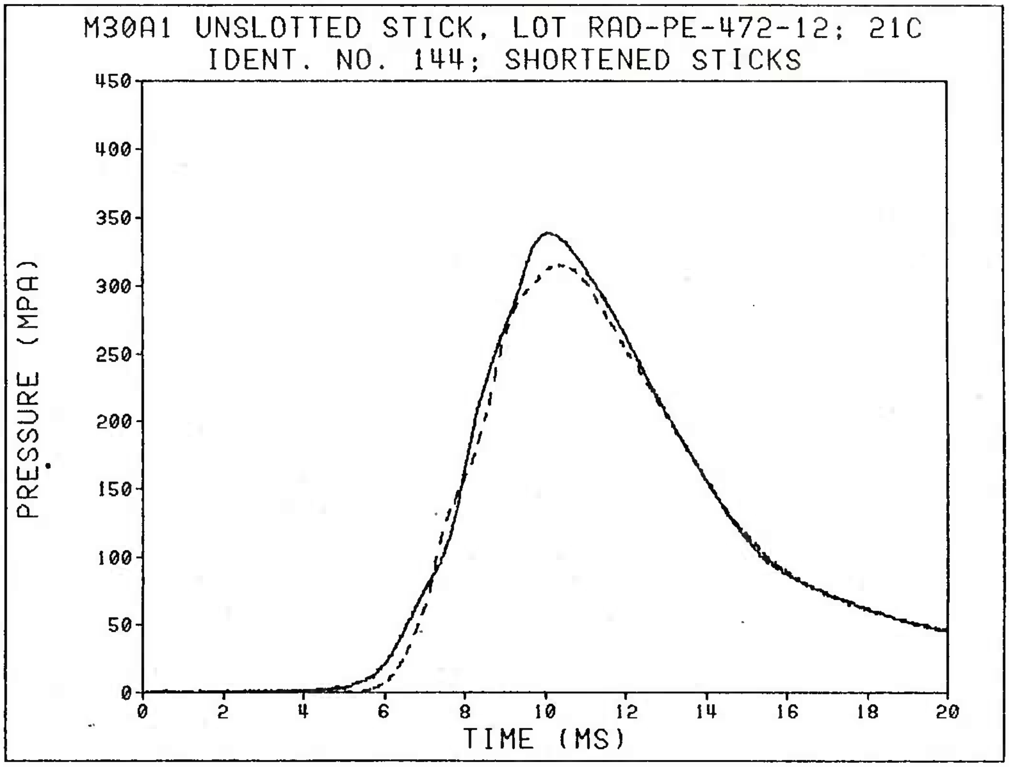
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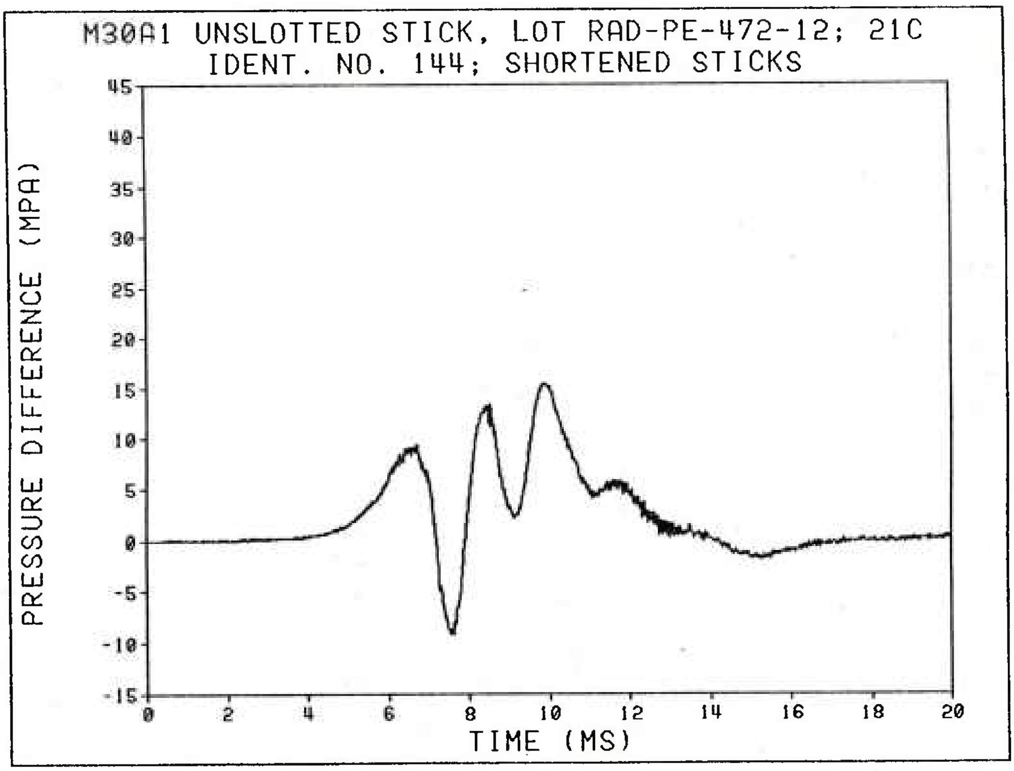
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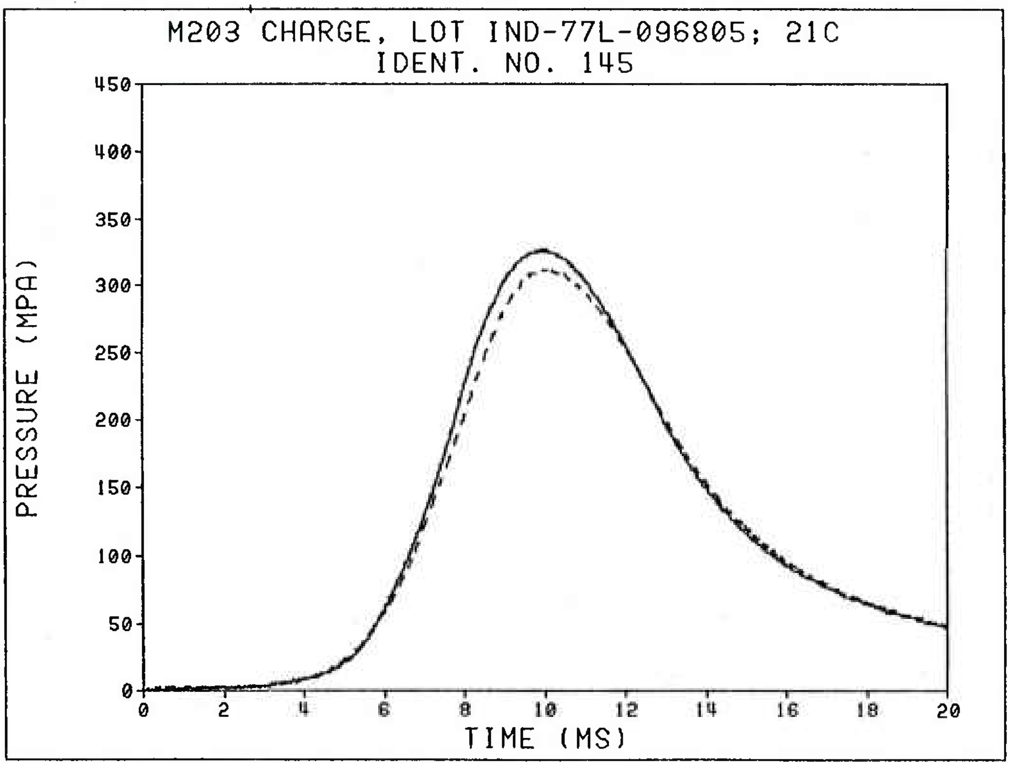
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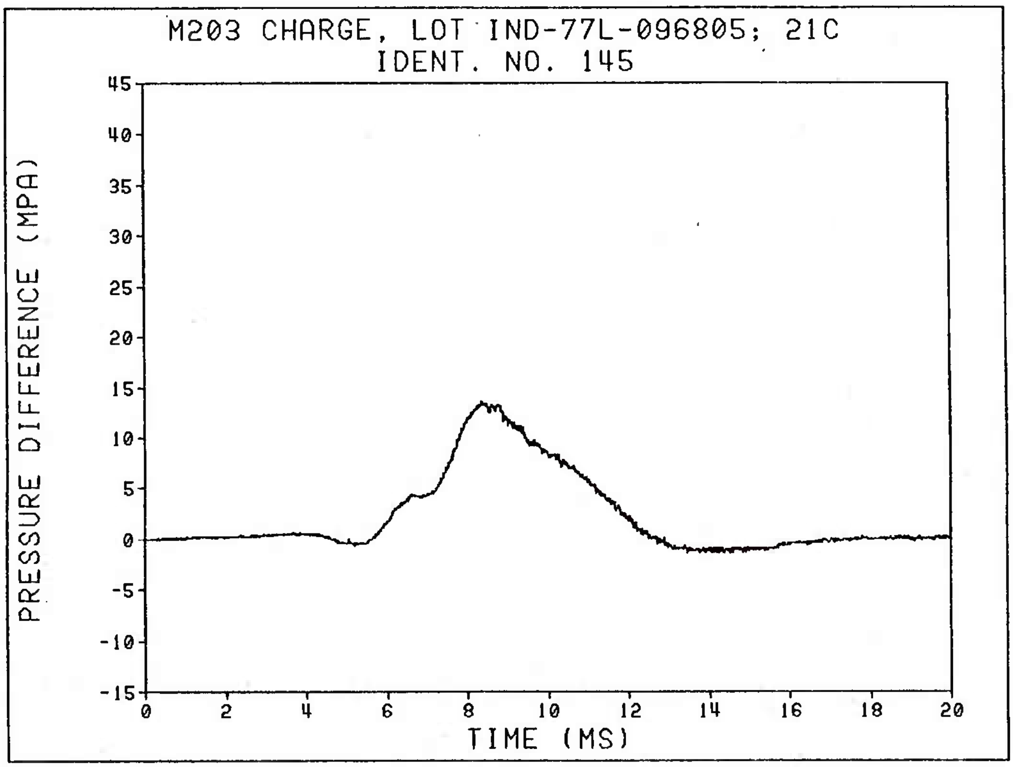
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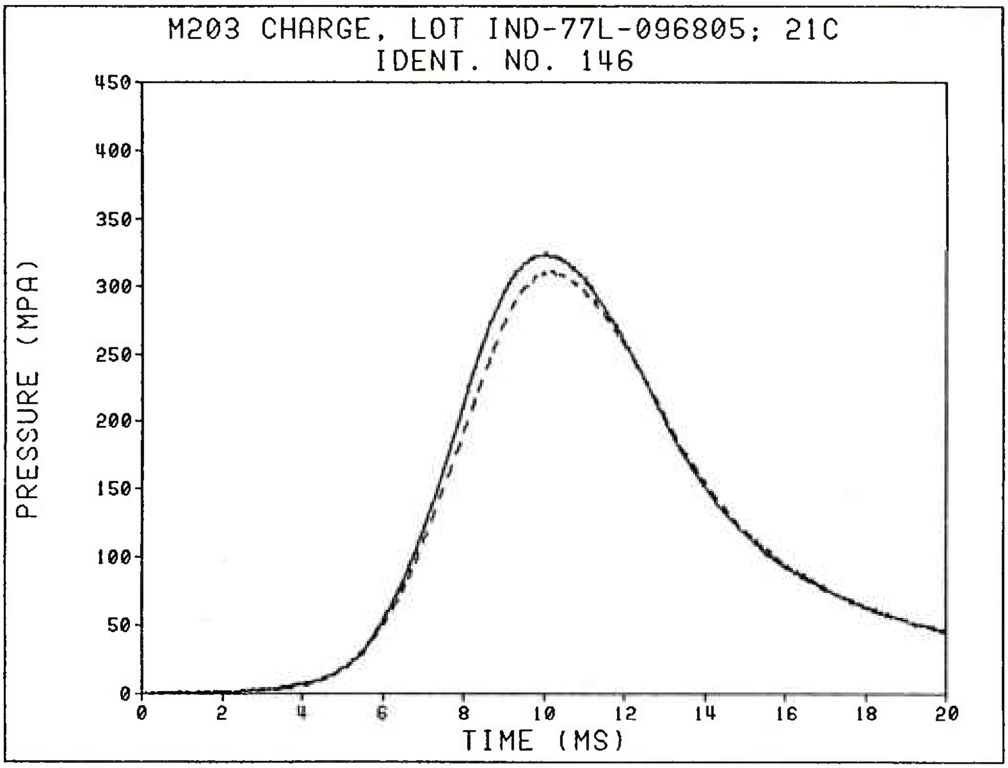
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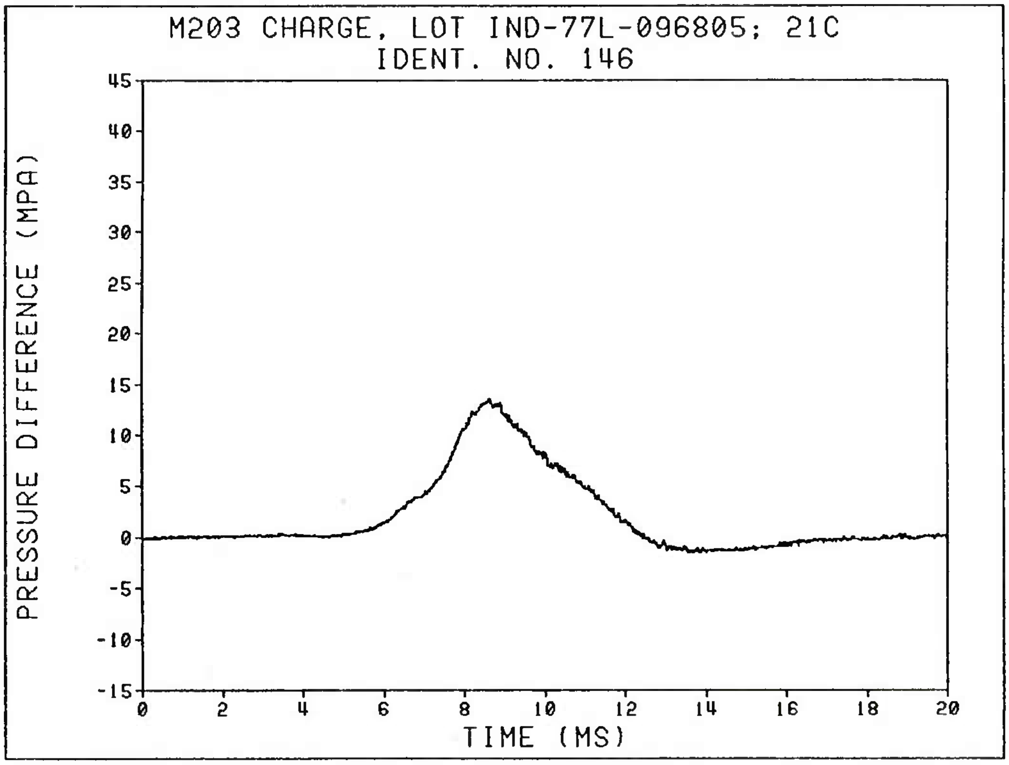
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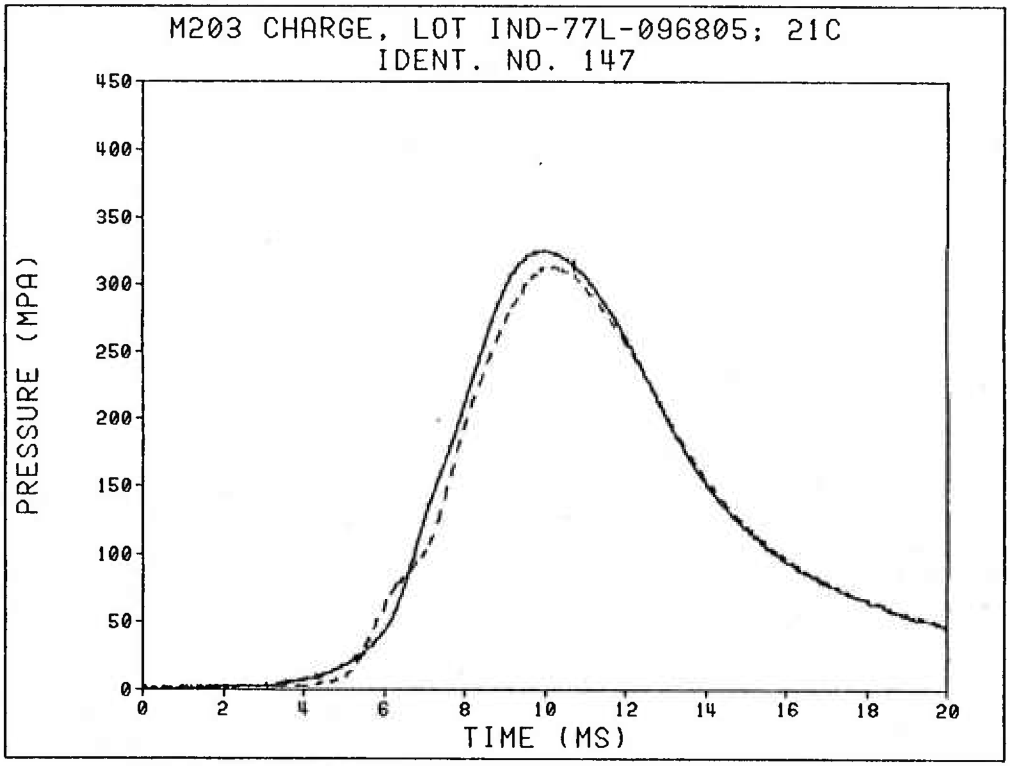
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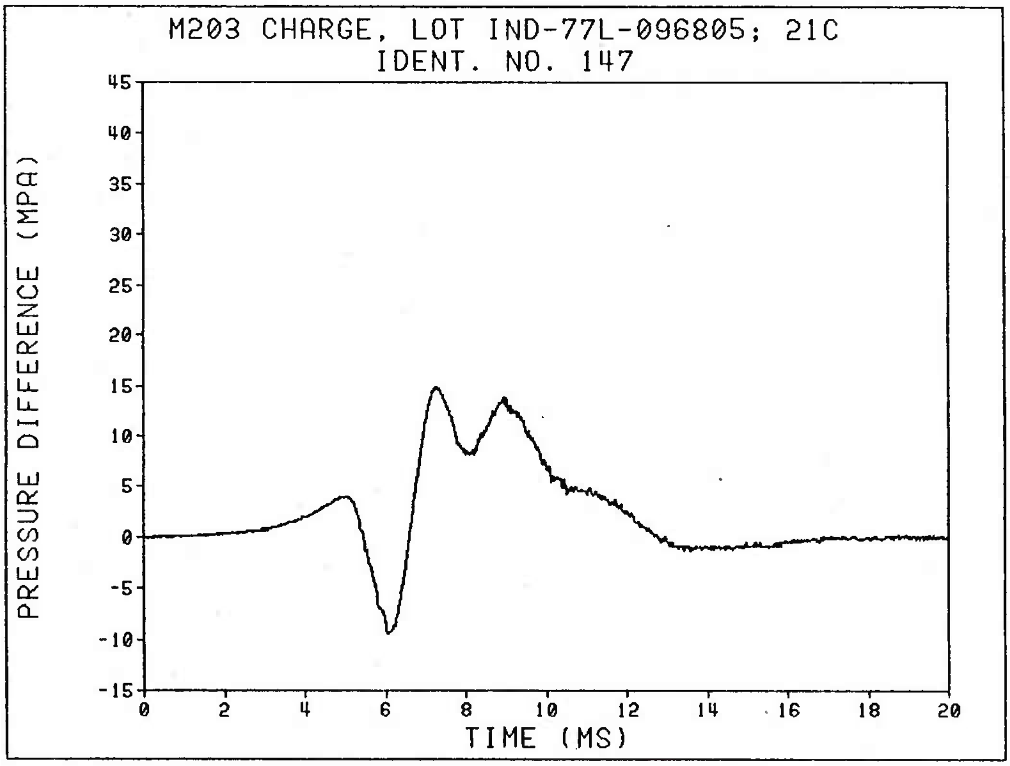
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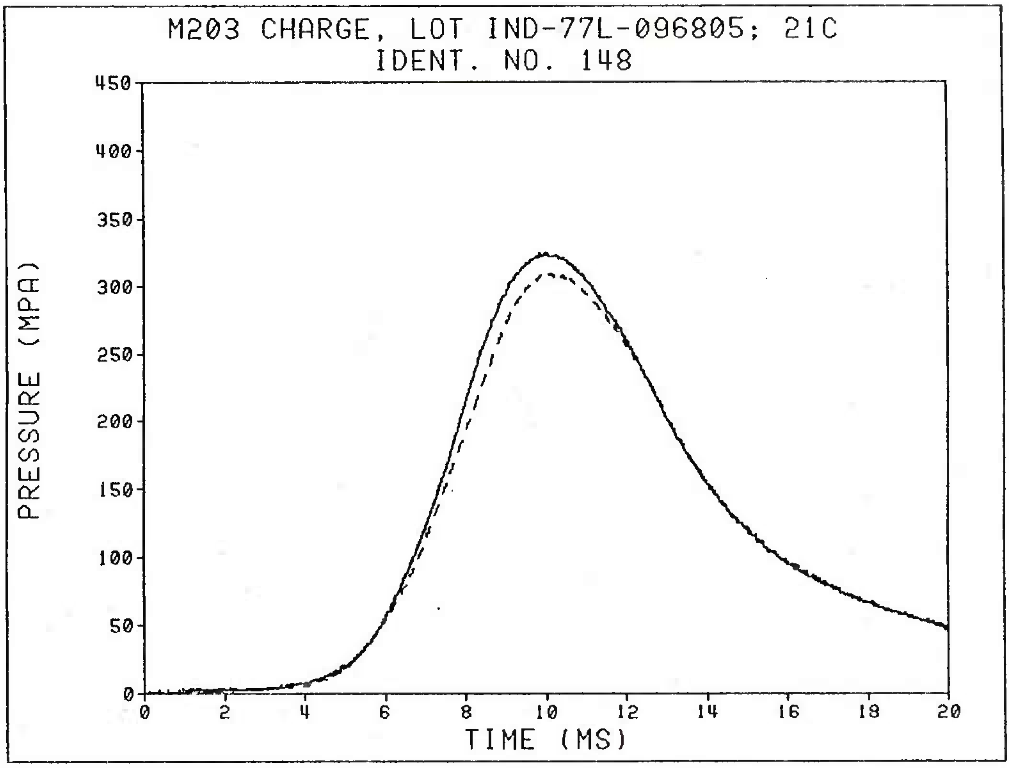
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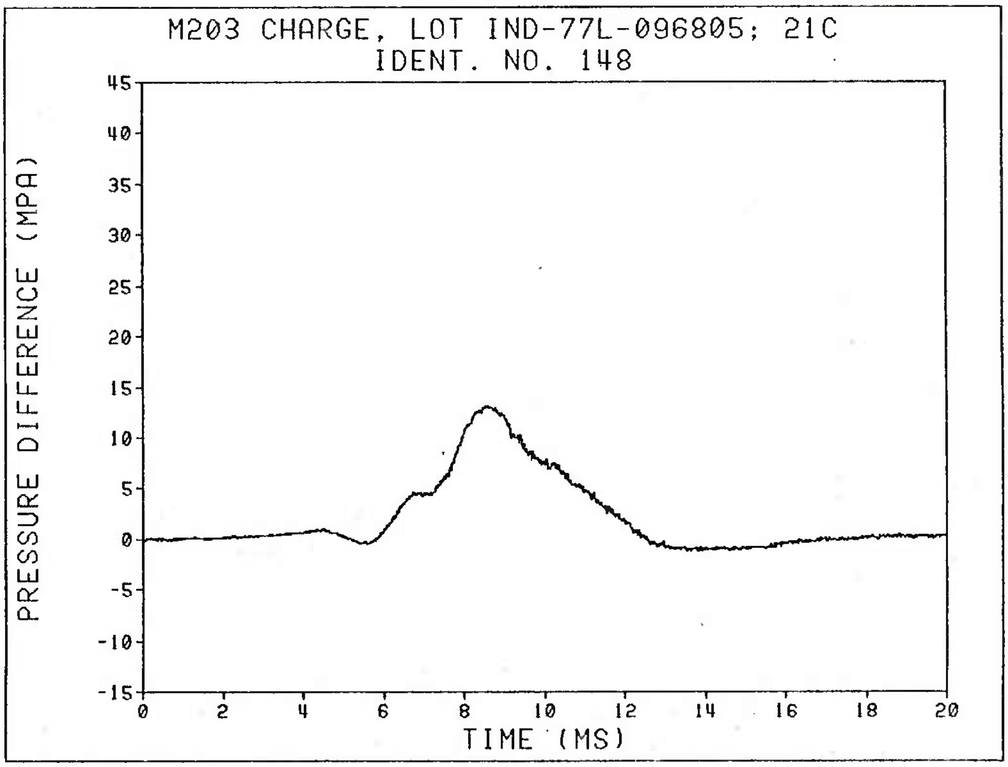
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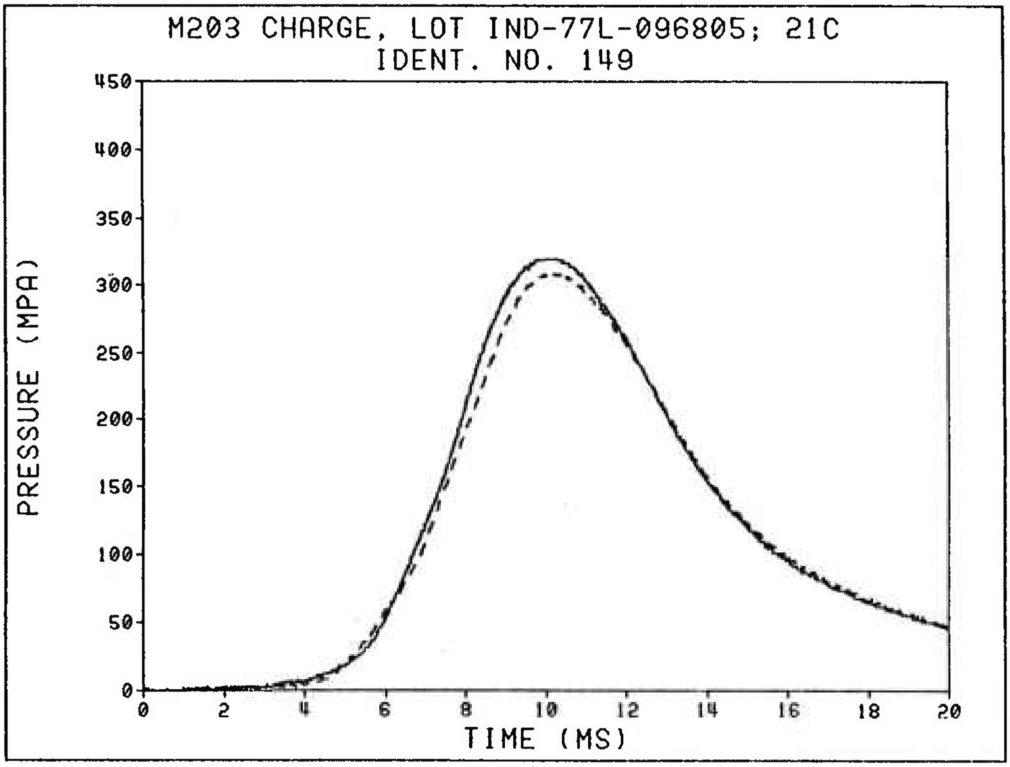
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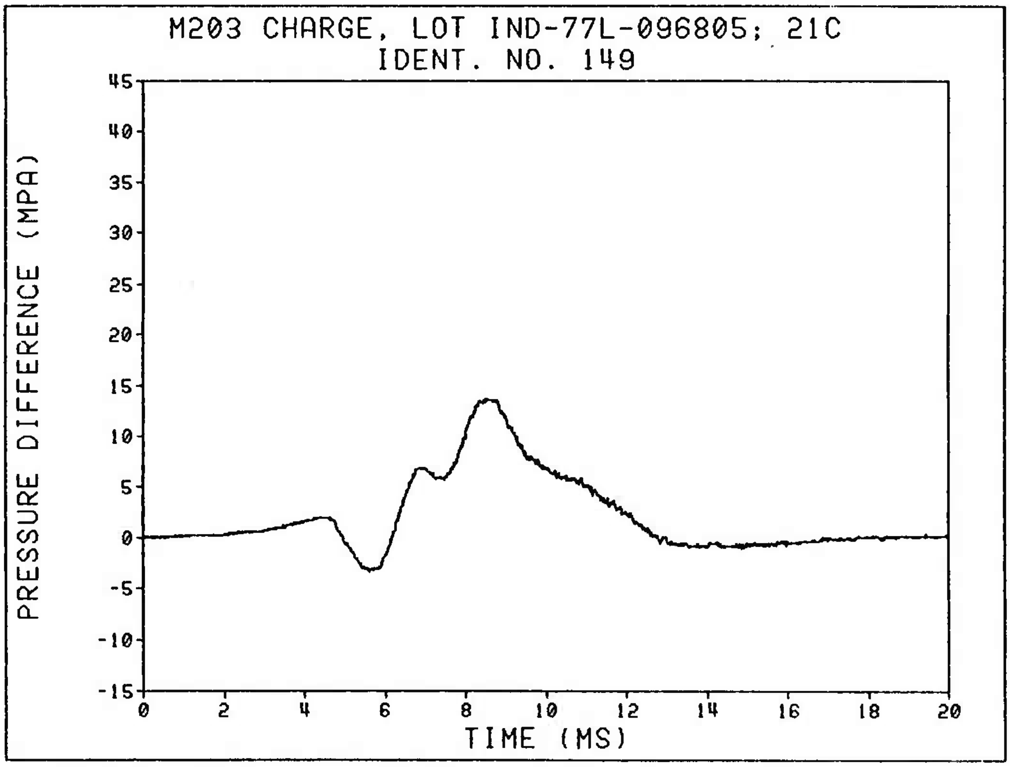
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