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REPORT NO. 1976

REDUCTION OF AIRBORNE LEAD CONTAMINATION IN INDOOR FIRING RANGES USING MODIFIED AMMUNITION

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April 1977

USA ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
USA BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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A study was conducted to evaluate the feasibility of decreasing or eliminating aerosol lead contamination hazards at indoor firing ranges by selectively modifying the ammunition fired. A caliber .38 Special police revolver was used in the study. Firings were conducted in a specially designed container which allowed trapping of particulate weapon effluents for subsequent analysis. Under the conditions of the experiment, conventional caliber .38 Special ammunition yielded an average of 5.64 milligrams of lead per round at the uprange (Cont'd)

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20. ABSTRACT (Cont'd)

position. Under identical conditions, custom-made ammunition, using copper jacketed soft point projectiles and a special lead free primer composition, yielded an average of 13 micrograms of lead per round. The data represented a decrease of lead contaminant produced per round by a factor greater than 400. The ballistic characteristics of the ammunition were also examined. There appears to be a good possibility of ballistically matching the modified ammunition with standard caliber .38 Special ammunition.

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I. INTRODUCTION

Excessive lead levels at indoor firing ranges have become a matter of serious concern to law enforcement officials throughout the country. Recent studies carried out by the National Institute for Occupational Safety and Health have found a number of facilities in violation of existing guidelines relating to aerosol lead levels[1,2,3]. Instances of lead poisoning have also been reported by range personnel. The extent of the problem can be judged by a recent event in which a newly completed police indoor range facility was forced to close due to excessive lead contamination[4]. In one approach to solve the problem, a review of ventilation requirements in police ranges is underway[5]. The renovation of all existing police indoor range facilities, however, to comply with stricter ventilation requirements, would be an extremely expensive solution to the problem. Moreover, this approach would not really cut down on the amount of lead contamination generated, it would merely dilute it. On an overall basis, a better solution might be to reduce the lead contamination at its source, the ammunition itself. The Ballistic Research Laboratory (BRL) was asked by the Law Enforcement Standards Laboratory (LESC) of the National Bureau of Standards (NBS) to address this approach.

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1. Thomas L. Anania, James B. Lucas and Joseph A. Seta, "Lead Exposure at an Indoor Firing Range", HEW Publication No. (NIOSH) 74-100, 1974.

2. David Sundin, Joseph Seta, Ralph Bicknell and Ray Hervin, "An Industrial Hygiene Investigation at the Kansas City Police Department Indoor Firing Range, Kansas City, Kansas, January 9-11, 1974", Project No. 74-30, Division of Technical Services, National Institute for Occupational Safety and Health, US Department of Health, Education and Welfare, Cincinnati, Ohio 45202.

3. Joseph A. Seta, David S. Sundin and Ray Hervin, "An Industrial Hygiene Investigation of the Indoor Firing Range in the Federal Reserve Bank of Kansas City, Missouri, January 9-11, 1974", Project No. 74-31, Division of Technical Services, National Institute for Occupational Safety and Health, US Department of Health, Education and Welfare, Cincinnati, Ohio 45202.

4. Michael J. Clark, "Excessive Lead Found at Howard Police Range", The Baltimore Sun, September 16, 1976.

5. Private Communication from Mr. Ronald Dobbyn, Law Enforcement Standards Laboratory, NBS, Washington, D.C., 20234, to A.A. Juhasz, Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland 21005.

The two possible sources of lead contamination from ammunition are the projectile and the primer. The lead projectile may produce microscopic airborne fragments due to mechanical effects in the barrel and at impact and erosive effects from the propellant gases. The primer mix (generally a composition containing lead styphnate) produces lead-containing decomposition products.

Two areas of concern in the ranges are in the vicinity of the gunner (uprange) and in the impact area (downrange). Lowering uprange contamination would involve reducing or eliminating the lead containing components in the primer and reducing or eliminating the amount of lead torn from the projectile by the barrel rifling and the propellant gases. Reducing downrange lead contamination would probably involve the use of soft targets for lead containing ammunition or the elimination of lead from the projectiles altogether.

Copper-jacketed, lead projectiles are commercially available. These are of a partially jacketed, soft point type. The base of the projectile, as well as its sides, is protected by a layer of copper. This type of projectile would prevent formation of lead particles due to the cutting action of the rifling, as well as gas wash at the base of the projectile. The copper fragments which may be formed are not nearly as toxic as lead.

Commercial primer systems are generally mixtures of lead styphnate and barium nitrate. Exact compositional data are not available from the manufacturers. Examination of a table of compositions of military primer mixes[6], however, provides a general understanding of the situation. The data are presented in Table I. None of these compositions would be suitable for producing a lead-free primer mix. In the past, mercury fulminate had been widely used in many primer compositions. These, however, would not be suitable compositions, since one would be merely substituting one toxic heavy metal for another. During the early 1970's, the Army experimented with some lead-free primer compositions as part of its Caseless Ammunition Program[7]. Several promising compositions were tested. Among these were compositions CP-27 (30-percent Mannitol hexanitrate/70-percent tetracene), CP-34 (30-percent diazodinitrophenol/70-percent tetracene), and CP-35 (40-percent diazodinitrophenol/60-percent tetracene)[8,9]. Ultimately, both the Caseless Ammunition Program and the

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6. Headquarters, US Army Materiel Command, Engineering Design Handbook, Explosives Series, Explosive Trains, Pamphlet AMCP 706-179, Washington 25, DC, 1965.

7. Aloysius J. Duffy, "Caseless Ammunition Technology (5.56mm & 7.62mm)", Frankford Arsenal Technical Report No. FA-TR-75040, May 1975.

8. T. Johnson, J. Kenney and J. Scanlon, "Development of Ashless Primers", Remington Arms Co., Inc., Report No. AB-70-4 (Contract DAAA25-67-C-0903), May 1970.

9. J. Kenney, "Development of Ashless Primers", Remington Arms Co., Inc., Report No. AB-71-3 (Contract DAAA25-67-C-0903), June 1971.

TABLE I. Ingredients of Common Military Priming Compositions

Ingredients	Composition (percent by weight)						
	FA70	FA90	PA100	PA101	793	NOL60	NOL130
Lead Styphnate, Basic	--	--	--	53	39	60	40
Lead Styphnate, Normal	--	--	38	--	--	--	--
Barium Nitrate	--	--	39	22	44	25	20
Lead Azide	--	--	--	--	--	--	20
Tetracene	--	--	2	5	2	5	5
Lead Dioxide	--	--	5	--	--	--	--
Calcium Silicide	--	--	11	--	14	--	--
Aluminum Powder	--	--	--	10	--	--	--
Antimony Sulfide	17	12	5	10	--	10	15
Lead Sulphocyanate	25	25	--	--	--	--	--
PETN	--	10	--	--	--	--	--
TNT	5	--	--	--	--	--	--
Potassium Chlorate	52	53	--	--	--	--	--

the primer project were terminated. However, the Remington Arms Corporation, which had originally developed these primers for the Army, fired each of the mixes in standard 30-06 rounds. In response to BRL's requests for information, they provided the following data (Table II)[10].

TABLE II. Remington Arms Corporation Data on the Performance of Lead Free Primer Compositions, 30-06 Round

Primer	Muzzle Velocity (m/sec)	Maximum Pressure (MPa)
Standard	818	356
CP-27	814	346
CP-34	802	336
CP-35	819	362

10. *Private Communication from Mr. Joseph Kenney, Remington Arms Co., Inc., Bridgeport, Connecticut to A.A. Juhasz, Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland.*

The performance characteristics of the three lead-free primers were reasonably similar to the standard. Based on discussions with both Frankford Arsenal[11] and Remington Arms personnel, CP-27 was judged to be the most promising mix. The composition does have its problems. It does not pass the required Army thermal stability tests[11] and it is less sensitive than conventional primer mixes. Nevertheless, it appeared highly promising for tests designed to evaluate the concept of decreasing indoor lead contamination by the use of special ammunition.

A study was undertaken to determine the relative amounts of airborne lead contaminants generated by conventional caliber .38 Special ammunition and custom made ammunition having lead-free primers and copper jacketed projectiles.

II. EXPERIMENTAL

The firing tests were conducted at the indoor range facilities of the Propulsion Division of the Ballistic Research Laboratory. Chemical analyses and scanning electron microscopy were performed under contract by the E.I. DuPont Analytical Services Laboratory, Wilmington, Delaware. The weapon used was a Smith and Wesson Caliber .38 Special, Model 10 Police Revolver (Serial no. 0310282) supplied by the Law Enforcement Standards Laboratory, NBS. Ballistic data were obtained on a specially built test fixture. The ammunition used in the study was supplied to BRL's specifications by the Remington Arms Corporation, Bridgeport, Connecticut.

A. Firing Fixture for Lead Trapping (Figure 1)

1. Firing Chamber

The firing chamber consisted of a box constructed of 6-mm thick aluminum (62.2-cm long x 40.6-cm wide x 31.8-cm high) provided with a Ransom pistol rest and a firing solenoid actuated by a sequence timer. The lid of the chamber was machined at two points to accept an 0.8-μm Millipore aerosol filter. The front of the chamber was machined to provide a port for bullet exit.

2. Bullet Trap

The bullet trap consisted of a 6-mm thick steel plate placed at a 45-degree angle to the horizontal and located 9.14 metres from the firing chamber. The bullet trap was provided with a mounting arrangement

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11. *Private Communication from Mr. Earl VanArtsdalen, Frankford Arsenal, Philadelphia, PA, to A.A. Juhasz, Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland.*

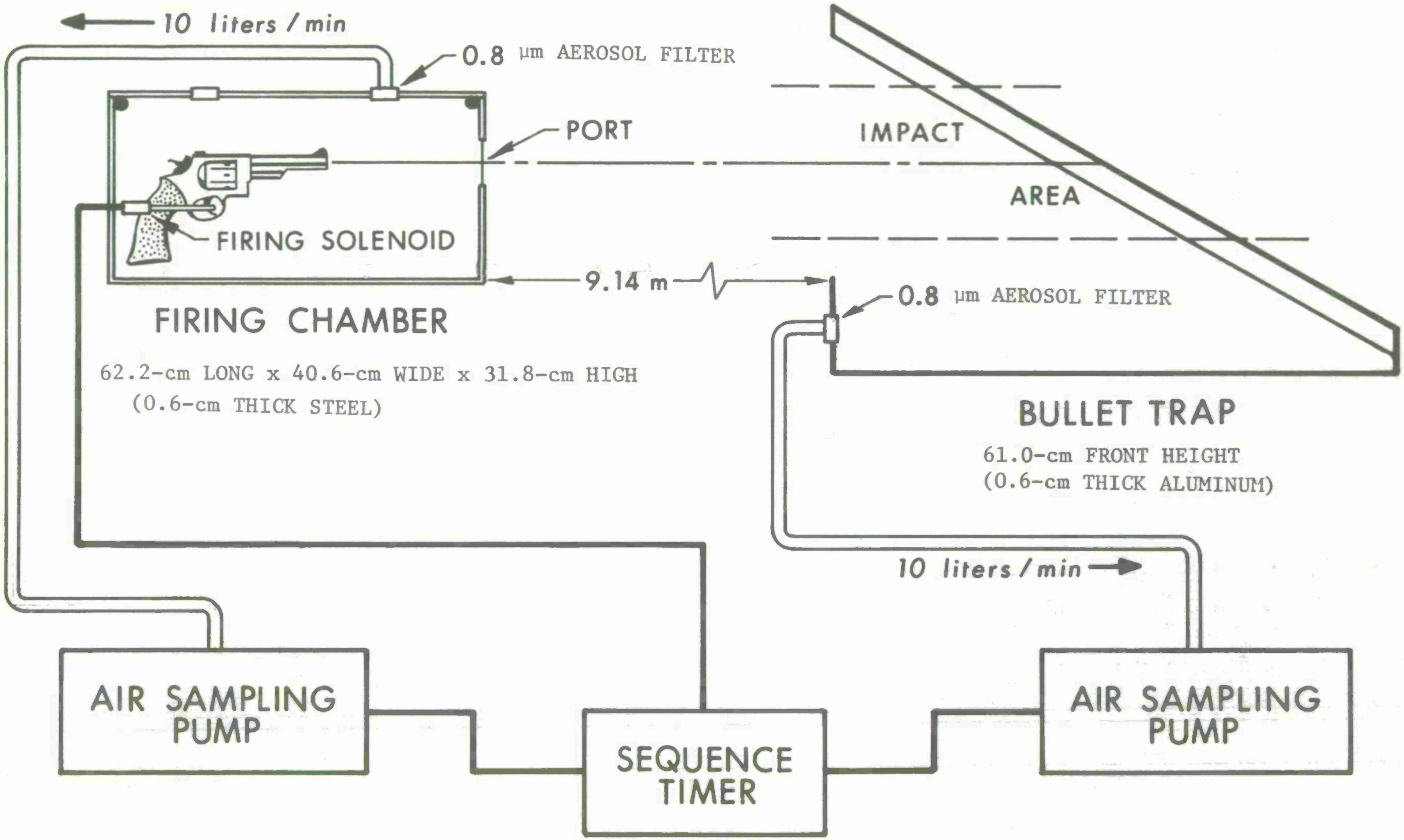

Figure 1. Schematic of Firing Fixture for Obtaining Uprange and Downrange Lead Samples.

for an aerosol filter identical to the one used at the uprange station. The filter element was located 30.5 cm from the expected point of impact.

3. Aerosol Sampling

Samples were collected using Millipore aerosol monitoring kits. The kits provide 0.8-μm filters in a disposable housing as well as all the associated pumping equipment needed for sample collection. Samples were collected at pumping speeds of 10 liters per minute. The pumps were controlled by a sequence timer which also controlled the gun firing. Normally the pumps were started eight seconds before firing the gun. Pumping was continued for two minutes after the gun was fired.

4. Sampling for Particle Analysis

Uprange samples for lead particle size and shape analysis were collected by using adhesive coated witness papers located inside the firing chamber. The relative locations of witness papers and the gun are given in Figure 2. During the course of the experiments, the blast from the muzzle caused partial destruction of the witness papers at Sites II and III. To correct this, a 20-cm diameter cylinder were slipped over the barrel and cylinder portion of the gun and the witness papers located inside the cylinder. Sections of the paper with the residues were removed and submitted for scanning electron microscopy and x-ray microanalysis.

B. Ballistic Tests

The device used for ballistic testing of the ammunition appears in Figure 3. The fixture consisted of a 13.97-cm long Caliber .38 barrel section (same specifications as the pistol) fitted with a Kistler 607 C4 pressure transducer and a solenoid operated firing pin assembly. The transducer signal was fed into a charge amplifier and recorded on magnetic tape. Muzzle velocities were calculated from data taken on a set of four velocity screens located at various known distances downrange.

C. Sample Analyses

1. Lead and Barium

The samples and the filter element on which they were collected were wet digested using $HNO_3 - HC\ell O_4$ to destroy organic material. The sample solutions were analyzed for lead using atomic absorption spectroscopy and for barium by x-ray fluorescence. Data are reported on the basis of total micrograms of metal per sample.

2. Scanning Electron Microscopy - X-Ray Microanalysis

Four adjacent 1.27 x 1.27 cm squares were cut from the adhesive paper in Sample Areas I, II and III (See Figure 2). These were examined

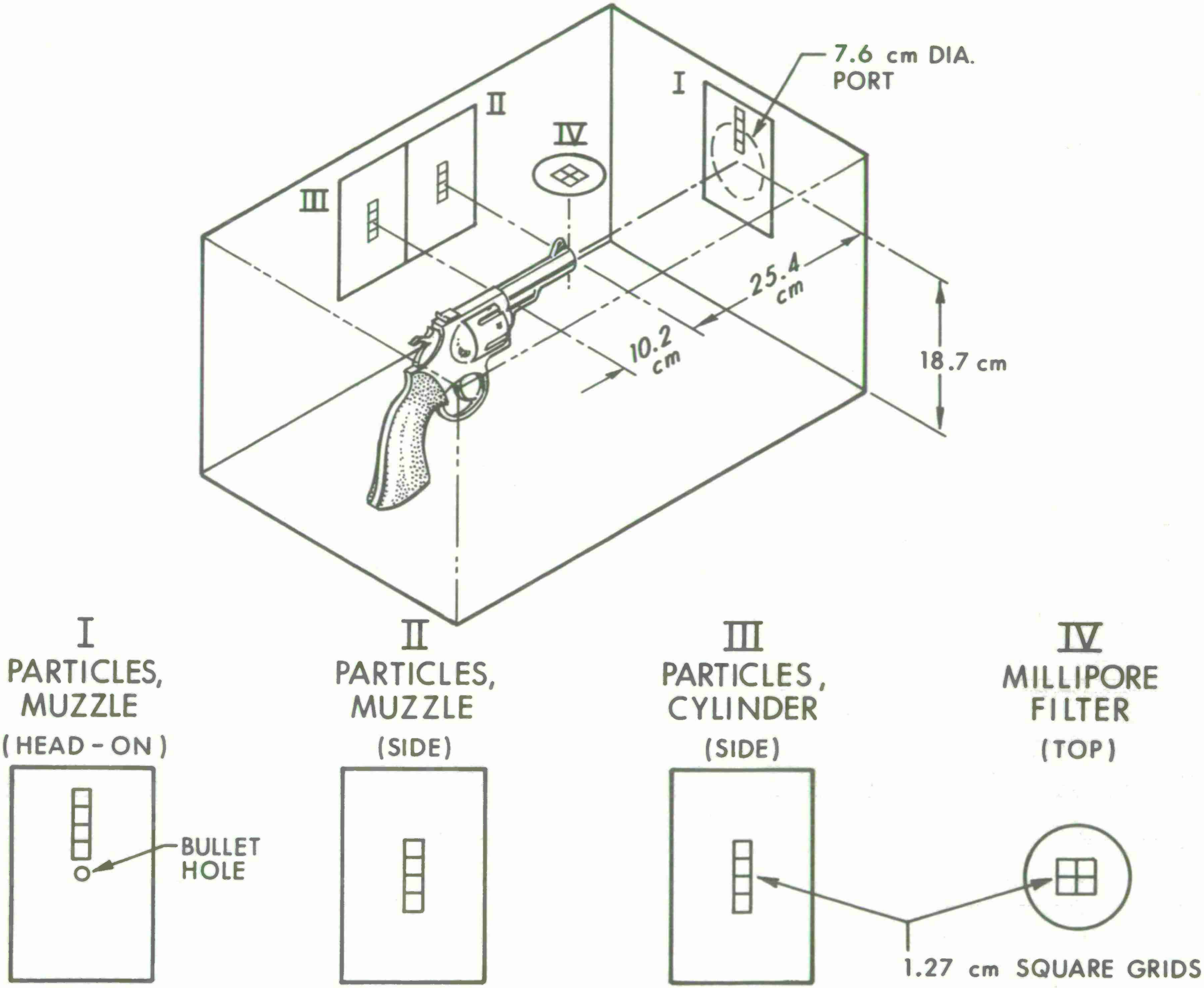

Figure 2. Location of Sampling Areas for Particle Analyses.

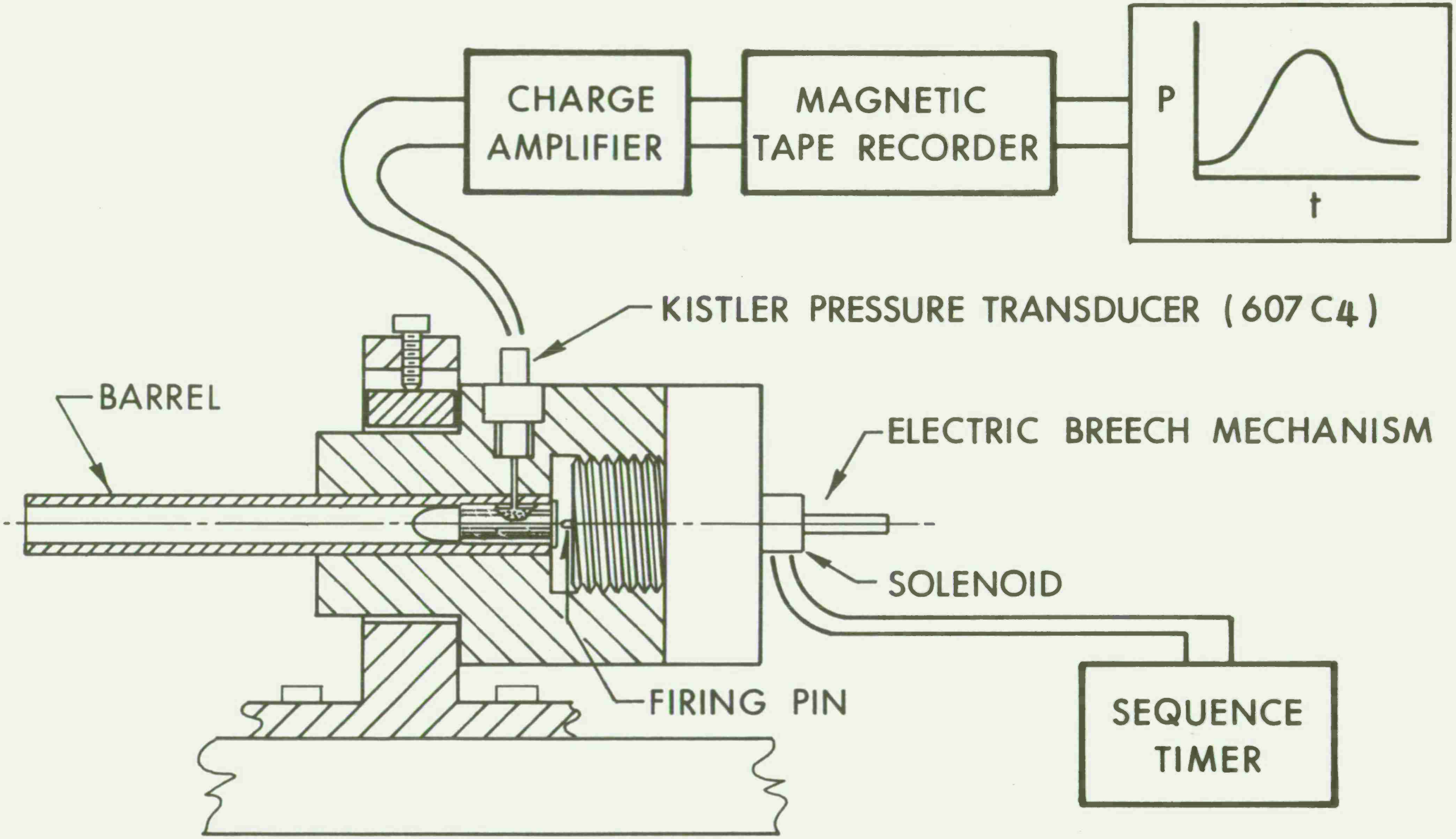

Figure 3. Caliber .38 Firing Fixture for Obtaining Ballistic Data.

at increasing magnifications. Four additional samples of the same size were cut from the Millipore filter (See Area IV in Figure 2) and similarly examined. X-ray microanalysis was used to identify the lead particles in the sample.

D. Ammunition

(1) (LBLP), Caliber .38 Special, with a 10.24 g (158-grain) lead bullet and conventional (lead containing) No. 1 1/2 primer. A total of 0.233 g (3.6 grains) of HPC 1 propellant is used.

(2) (LBLFP), Caliber .38 Special, with a 10.24 g (158-grain) lead bullet and a lead free primer composition (CP-27). A total of 0.233 g (3.6 grains) of HPC 1 propellant is used in the charge.

(3) (CJBLP), Caliber .38 Special, with a 10.24 g (158-grain) soft point, copper jacketed bullet and a conventional (lead containing) No. 1 1/2 primer. A total of 0.233 g (3.6 grains) of HPC 1 propellant is used.

(4) (CJBLFP), Caliber .38 Special, with a 10.24 g (158-grain) soft point, copper jacketed bullet and a lead free primer composition (CP-27). A total of 0.233 g (3.6 grains) of HPC 1 propellant is used in the charge.

(5) The composition of HPC 1 propellant is:

Nitrocellulose (13.2%N)	To Balance
Nitroglycerin	37-40%
Ethyl Centralite	0.5-1.5%
K_2SO_4	0.5-2.0%
Total Volatiles	2.35% Max.

All the test rounds were hand loaded by Remington Arms as part of a single order. Propellant and projectile weights were consistent throughout. The CP-27 primer composition was charged into standard No. 1 1/2 primer cups.

III. RESULTS AND DISCUSSION

Firing the four types of ammunition was expected to provide data on both the relative contribution of primer and projectile to the contamination level and on the relative improvement achieved by use of the jacketed projectile and no-lead primer. The procedure as previously described resulted in the trapping and analysis of material from a 20-liter air sample following each firing. The 20-liter air sample size was determined empirically. The technique does not trap all the contaminants produced per round, but it does give a reasonably reproducible sample from round to round. The opened sampling chamber with the gun in position is shown in Figure 4.

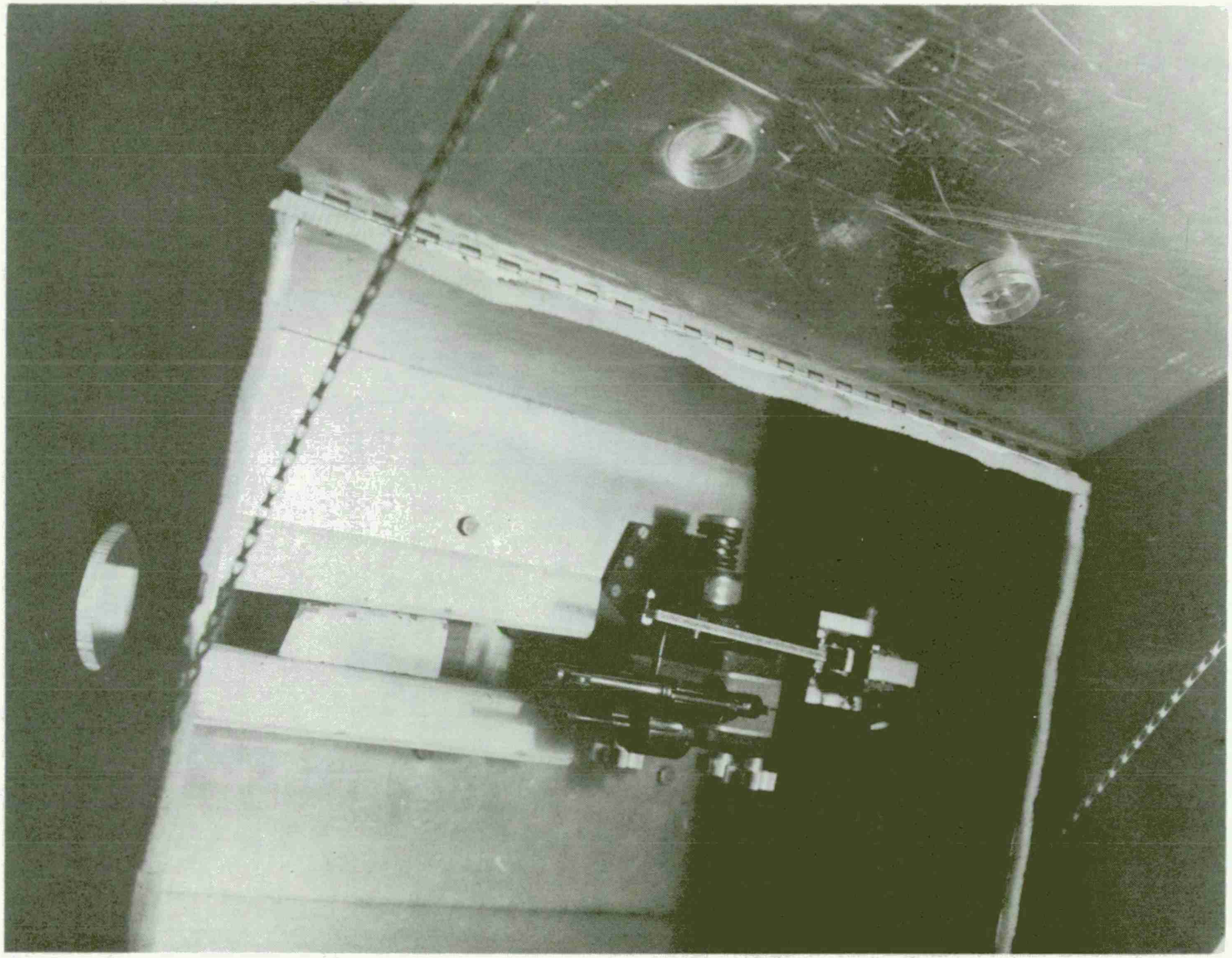

Figure 4. Opened Firing Box Showing Pistol, Firing Solenoid, and Sampling Filter Element.

A. Particle Studies

The primary objective of this part of the effort is to determine the suitability of the 0.8-μm filter for trapping the analytical samples. The experiment proved to be quite interesting since it not only proved the suitability of the filters for the problem, but also provided some interesting insights concerning the type of lead particles trapped at various positions relative to the gun. Some of these are discussed below.

Figures 5 and 6 are groupings of photomicrographs of particles trapped in front of the gun (See Area I, Figure 2). The photographs in Figure 5 were taken from an area approximately two centimeters from the bullet hole. A large particle in the range of 30 μm is visible. The shape of this particle, as well as of many of the others, is highly irregular. Photographs 5B, C and D show increasing magnifications of a section of Photograph 5A. The smaller particle sizes are more spherical in shape. Particles as small as 0.1 μm are readily distinguished in Photograph 5D.

Figure 6 is a grouping of photomicrographs of a region located 3.81 cm from the bullet exit hole (Area I, Figure 2). Photograph 6A shows a cluster of large irregular particles together with a scattered multitude of small fragments. Photographs 6B, C and D provide enlargements of a portion of the picture. A large number of spherical particles in the one micrometer range is evident in addition to a variety of irregularly shaped fragments. In all, it was found that the lead particle size forward of the barrel ranged from 0.02 - 0.03 μm to 100 μm. The average particle size decreases as the distance from the bullet exit hole increases. Approximately five centimeters from the bullet hole, the average particle size falls below the micrometer size.

Figure 7 is a set of photomicrographs of particles trapped in the area beside the muzzle. There appeared to be little difference in the character of the residues from Areas II and III of Figure 2. The particles are all small, most of them in the half micrometer range or less. Many of the particles are spherical in shape with some particles looking like clusters of smaller fragments.

Figure 8 is a set of photomicrographs of particles trapped on the 0.8-μm millipore filter. The sample appears composed of two widely dissimilar particle ranges: 10 to 50 μm and 0.1 to 0.5 μm, respectively. Photograph 8A shows the larger, irregularly shaped particles dispersed over the sample. Photographs 8C and 8D show the smaller particles. Many of the smaller particles appear to have agglomerated, possibly along the fibers of the filter element. Photograph 8B provides a good view of both the large and the small particles.

Examples of the particle identification method are given in Figures 9 and 10. The figures are composed of scanning electron micrographs

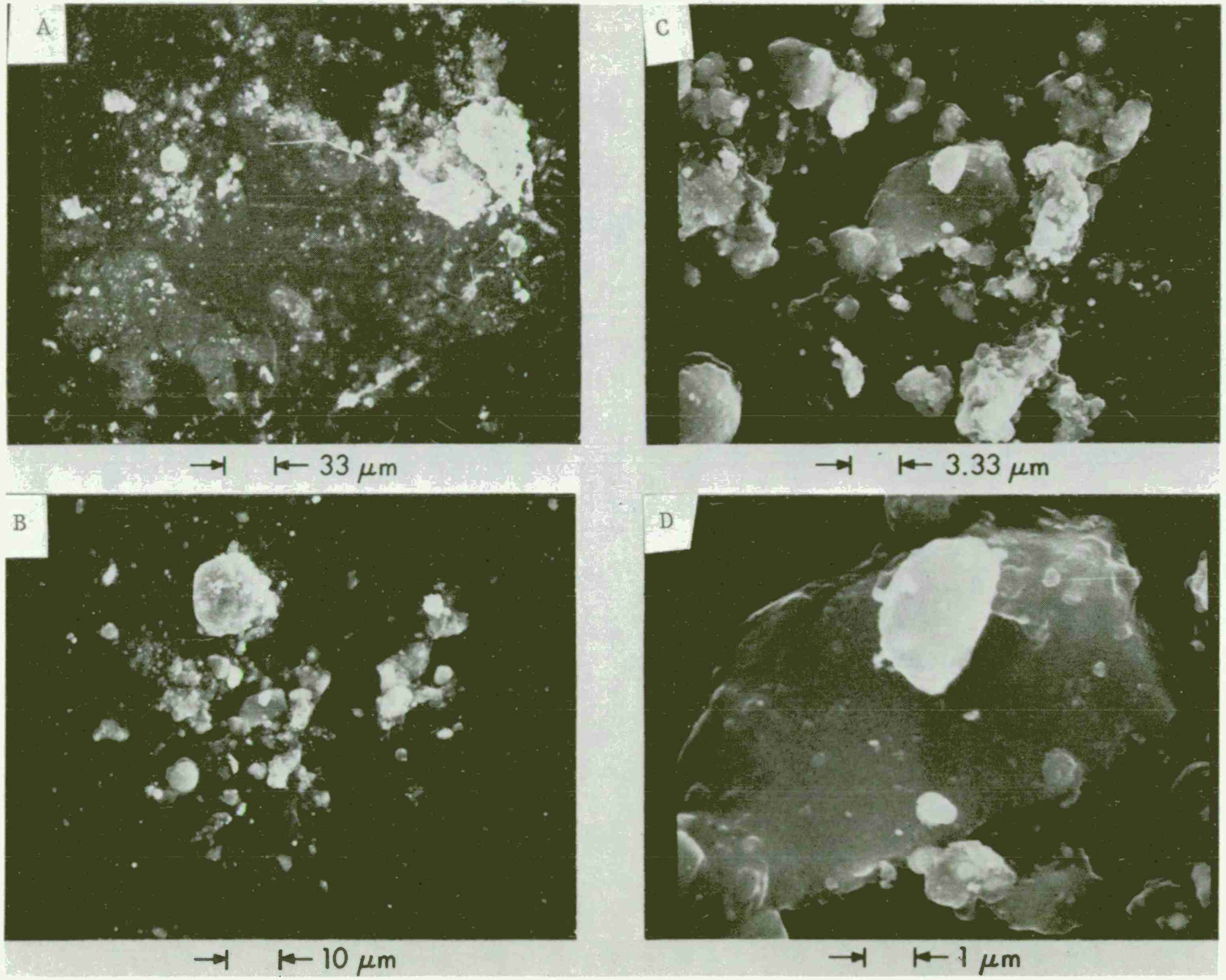

Figure 5. Scanning Electron Micrographs from Particulate Matter Trapped in Front of the Gun. Area Approximately 1.91 cm from Bullet Hole.

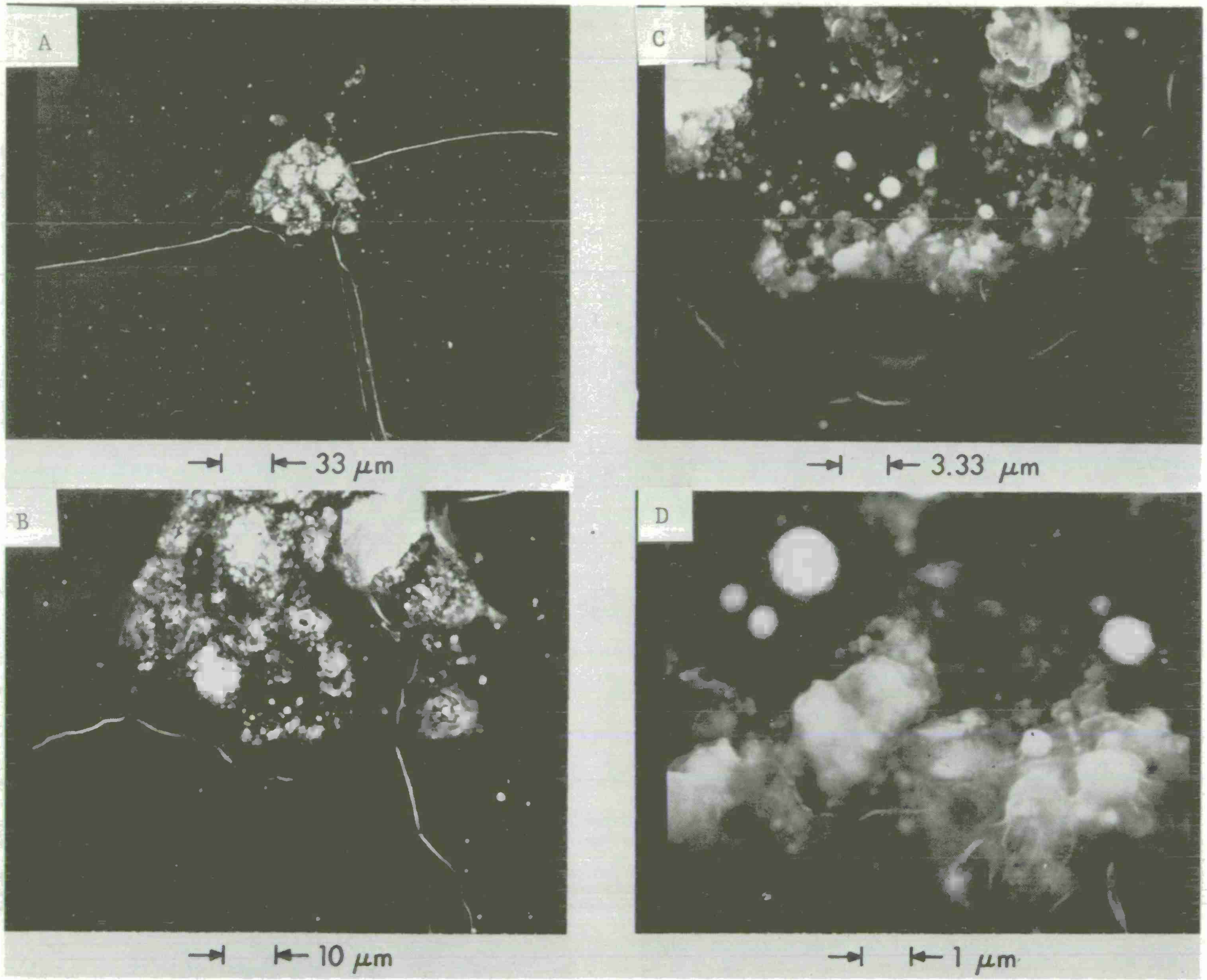

Figure 6. Scanning Electron Micrographs from Particulate Matter Trapped in Front of the Gun. Area Approximately 3.81 cm from Bullet Hole.

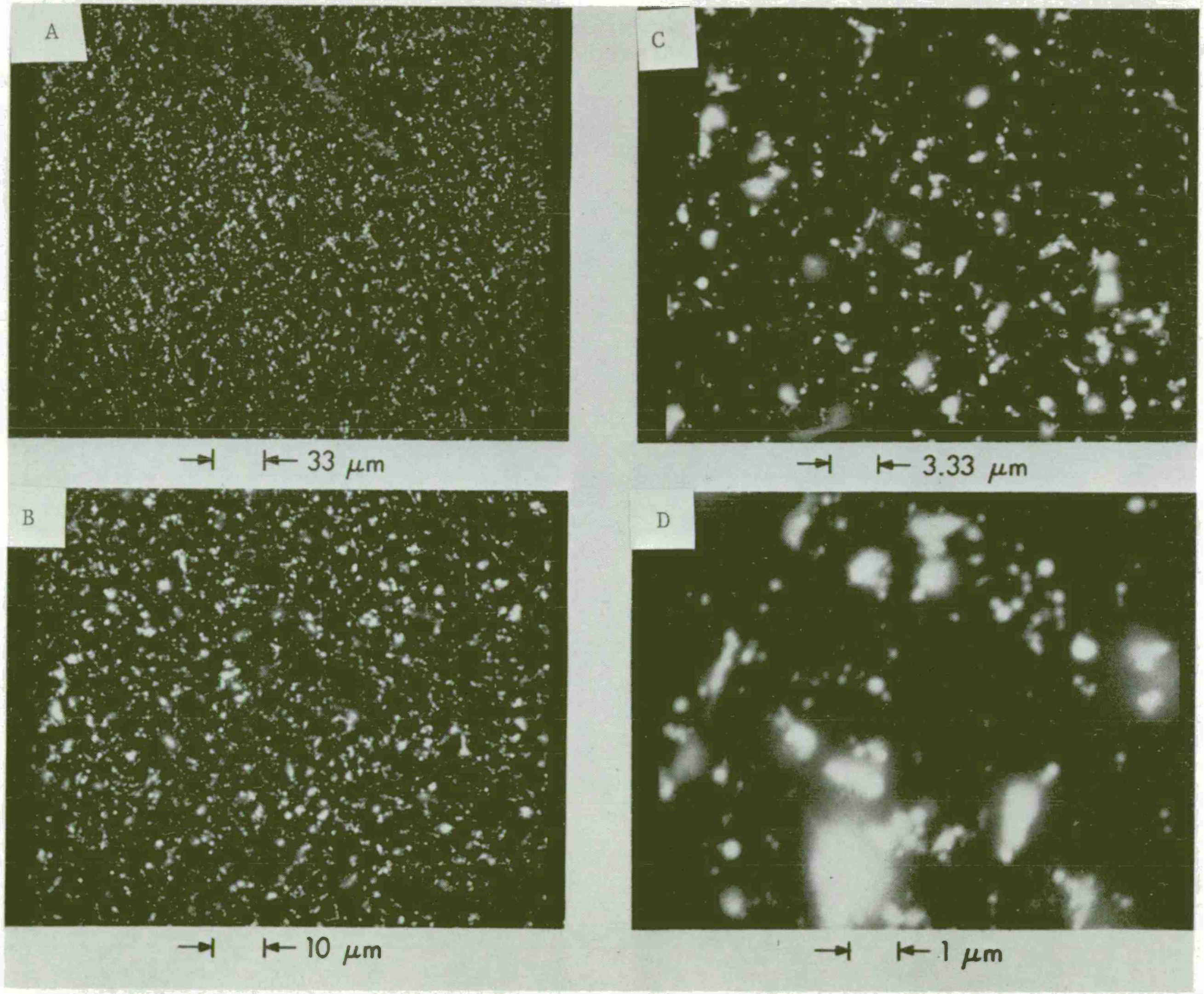

Figure 7. Scanning Electron Micrographs from Particulate Matter Trapped Beside the Muzzle.

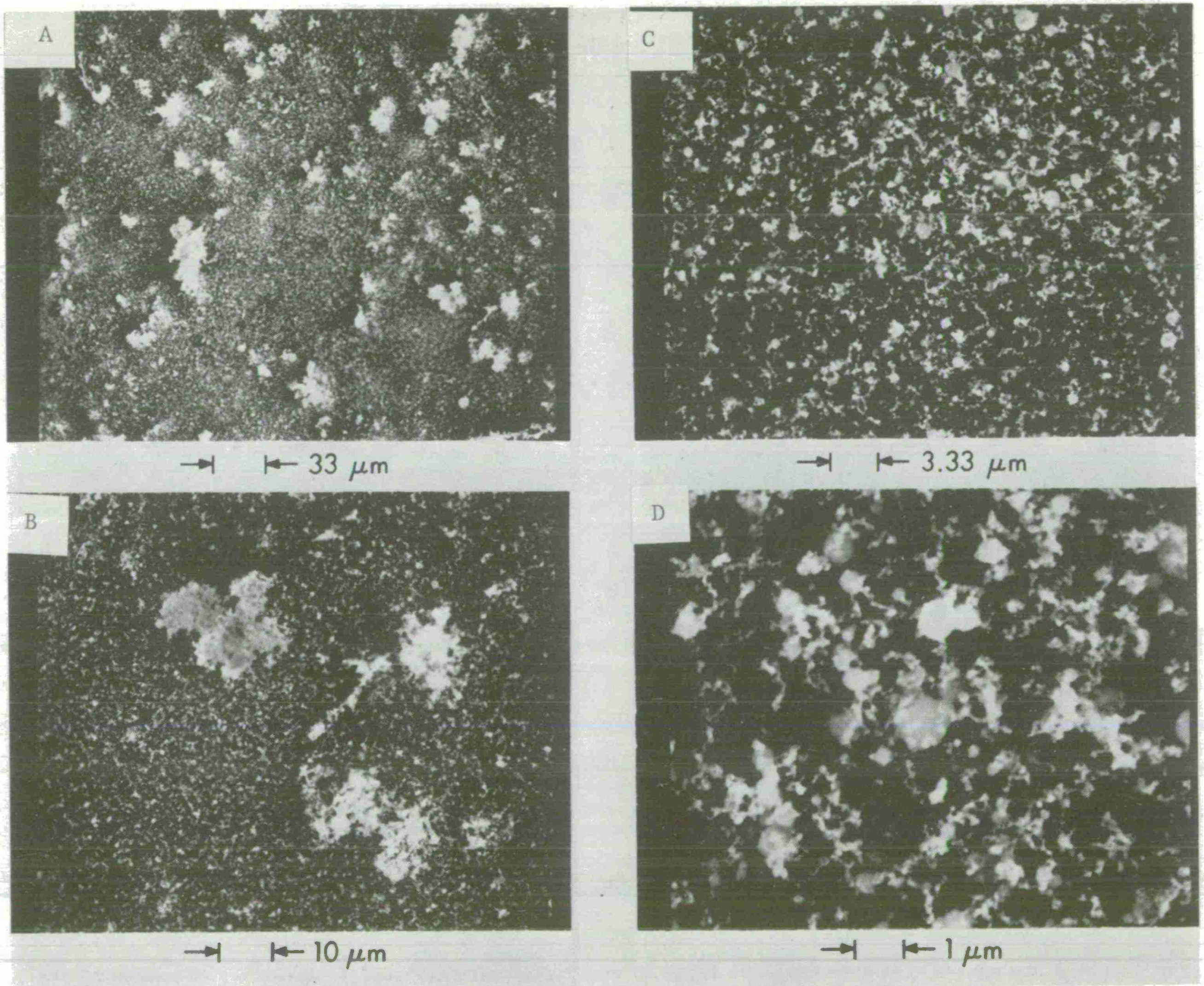

Figure 8. Scanning Electron Micrographs from Particulate Matter Trapped on the 0.8-µm Filter.

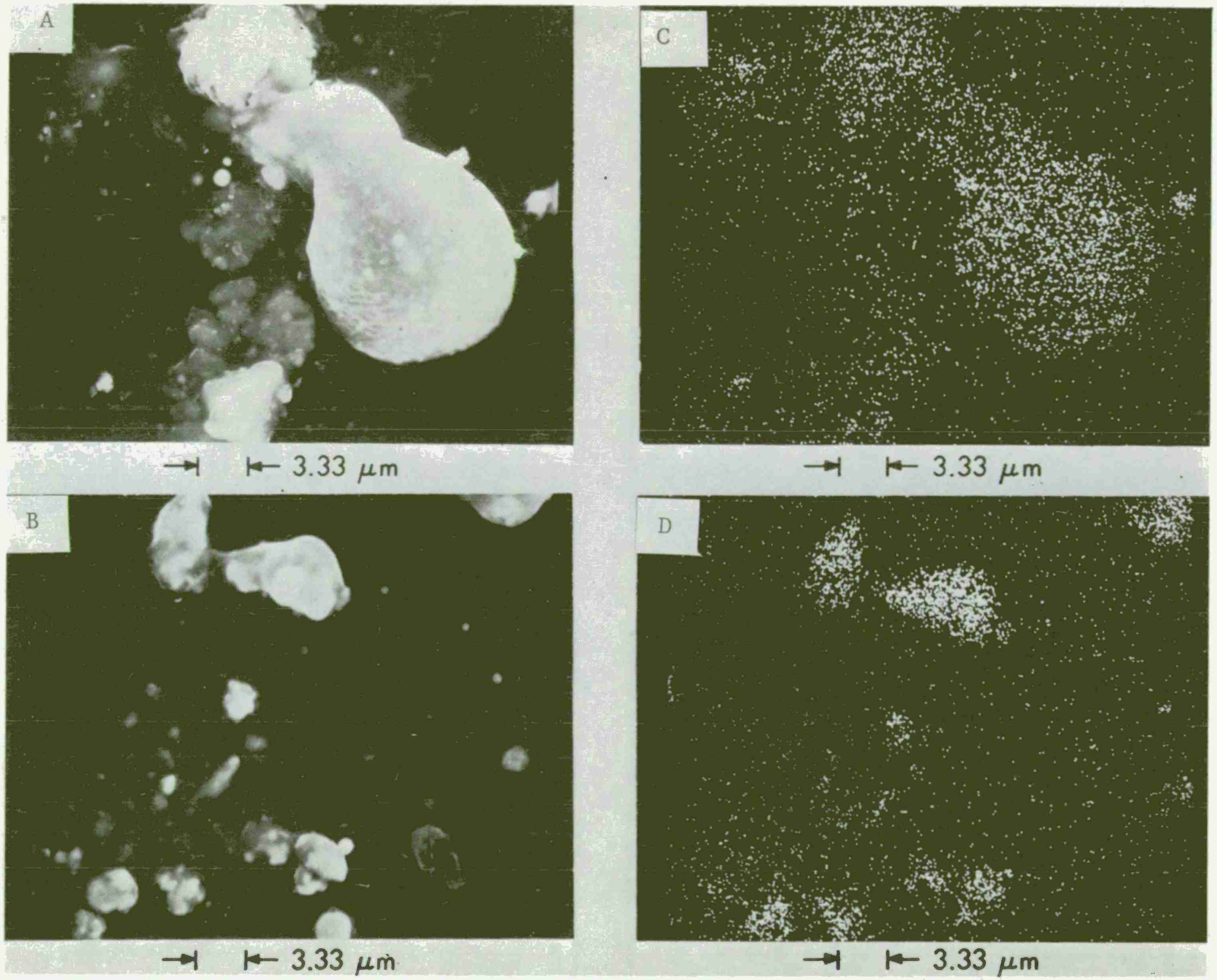

Figure 9. Scanning Electron Micrographs and Matching Lead Maps from Samples Trapped in Front of the Gun.

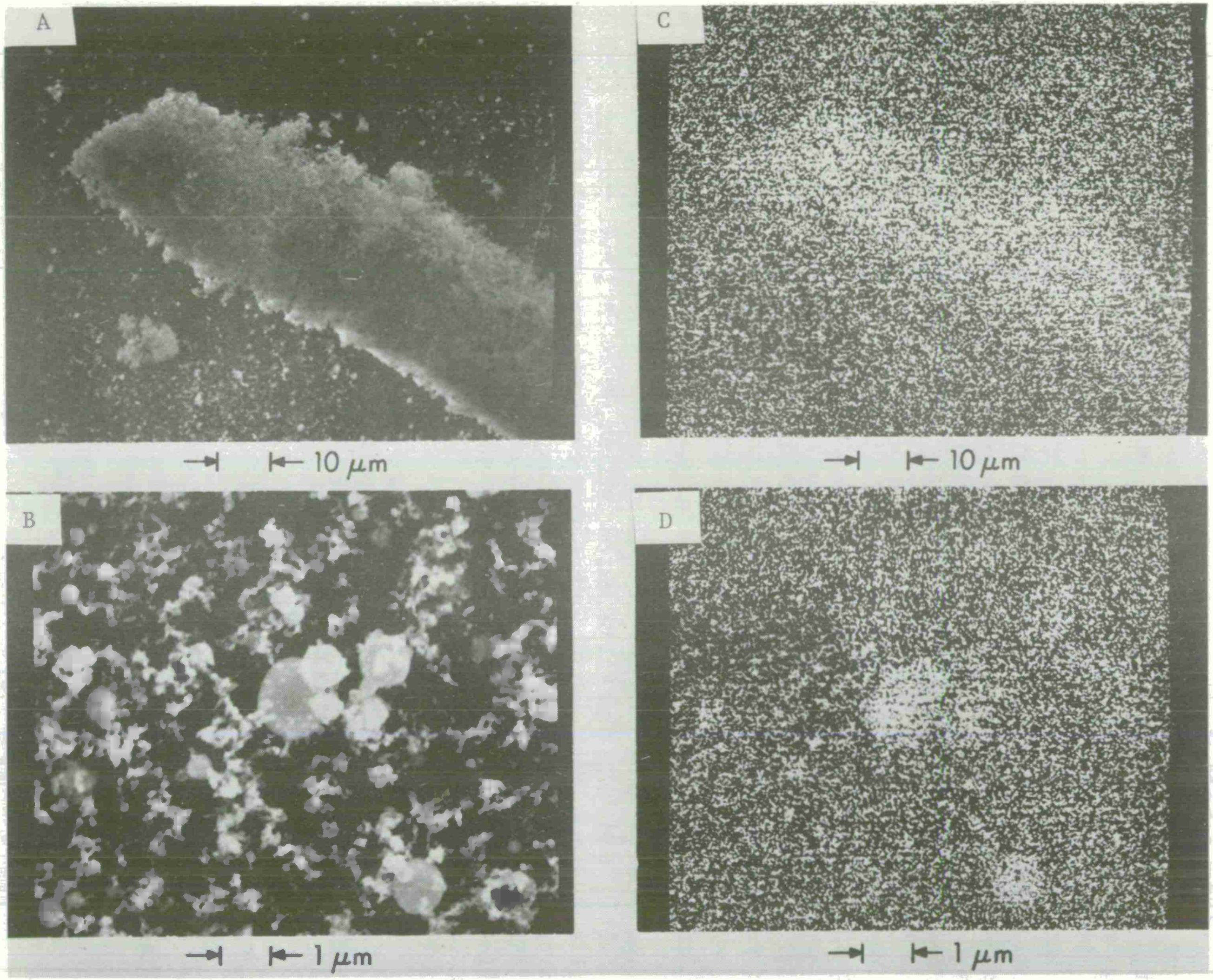

Figure 10. Scanning Electron Micrographs and Matching Lead Maps from Samples Trapped on the 0.8-μm Filter.

with matching "lead maps". The photographs on the right (9C and D) provide the same field of view as those on the left (9A and B), but the pictures on the right are composed of positive signals for lead as obtained by the x-ray microanalysis technique. The density of signals is qualitatively indicative of the amount of lead present. The samples in Figure 9 were taken from in front of the muzzle. The globular species is identified as lead by the matching shape in the lead map. Similarly, the large particles in 9B are identified as lead containing species in 9D. Figure 10 similarly shows matching scanning electron micrographs (10A and B) and their lead maps (10C and D) of samples trapped on the 0.8-μm filter. Photographs 10A and C show the two views of a section containing a large fragment and many small ones. (See discussion of Figure 8.) Figures 10B and D show an expanded view of the smaller fragments. Note especially that in both pictures the density of light dots (positive signals for lead) is greatly increased over what was found on the sample taken from in front of the muzzle.

Altogether, the particle size range of lead containing residues from the gun firing was found to go from 0.02 μm to 100 μm. The 0.8-μm Millipore filter appeared to be capable of trapping most of the particles in both the major size ranges observed. The filter was actually capable of retaining particles in the range of one-tenth micrometer and below.

B. Relative Lead Contamination from Primer and Projectile

Firing tests were carried out using both the lead bullet, conventional primer (LBLP) and the copper jacketed bullet, conventional primer (CJBLP) ammunition. Since the copper jacket was expected to prevent the formation of lead particles from the projectile, comparison of the two types of rounds fired was expected to provide information on the contribution of the bullet to the overall uprange lead contamination. Tables III and IV summarize the data obtained.

TABLE III. Chemical Analysis, Uprange Samples Trapped from LBLP Ammunition

Sample No.	Barium Level (μg/round)	Lead Level (μg/round)
1	200	5600
2	210	4500
3	230	6100
4	230	4200
5	260	5300
6	---*	7500
7	---*	6300
	Avg. 226	Avg. 5643

* No barium analyses performed for these samples.

TABLE IV. Chemical Analysis, Uprange Samples Trapped from CJBLP Ammunition

Sample No.	Barium Level (μg/round)	Lead Level (μg/round)
1	220	441
2	220	415
3	210	347
4	220	407
	Avg. 217	Avg. 403

A comparison of Tables III and IV indicates that the predominant contribution to the trapped lead comes from the projectile rather than the primer. In fact, the lead levels were fourteen times as high for the lead projectile as they were for the copper jacketed projectile. The barium levels remained about the same in both cases. This is expected, since the same primer composition was used in both sets of firings. It is interesting to note that under the conditions of the experiment, 0.2 mg of barium and 5.6 mg of lead were trapped per round. Since this represents the results of an incomplete trapping procedure, in fact even larger amounts of heavy metal contaminants were produced per round. Figure 11 gives a good qualitative feel of the amount of particulate matter trapped from each of the ammunition types fired. Note especially the large amounts of contaminant trapped from the rounds using lead projectiles (A & C of Figure 11).

C. Results from Non-Lead Primer Ammunition

Firing tests were carried out using lead bullet, lead free primer (LBLFP) and copper jacketed bullet, lead free primer (CJBLFP) ammunition. The first set of firings was expected to provide additional data on the amount of lead contaminant coming from the projectile. The second set of firings was expected to eliminate the lead contaminants formed. In these and other tests utilizing lead free primer ammunition, an external spring was connected to the hammer of the weapon to increase the striking power of the firing pin in order to ignite the less-sensitive CP-27 primer. The results from the first series appear in Table V.

TABLE V. Chemical Analysis, Uprange Samples Trapped from LBLFP Ammunition

Sample No.	Barium Level (μg/round)	Lead Level (μg/round)
1	20	3700
2	<10	3200
3	<10	3200
4	<10	3300
5	<10	3500
	Avg. <12	Avg. 3380

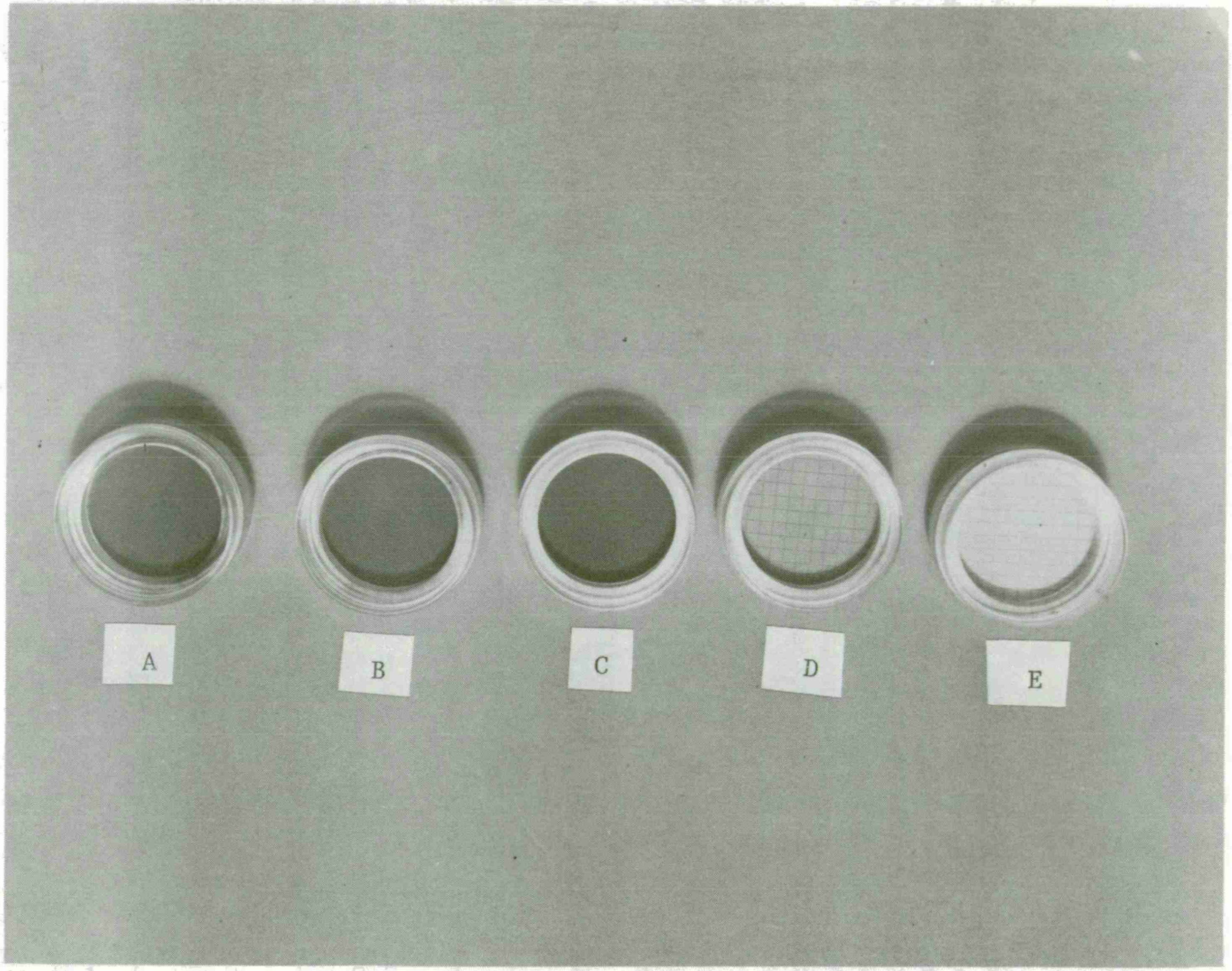

Figure 11. Samples Trapped from Individual Gun Firings on 0.8-μm Filter. A. Lead Projectile, Conventional Primer; B. Copper Jacketed Projectile, Conventional Primer; C. Lead Projectile, CP-27 Primer; D. Copper Jacketed Projectile, CP-27 Primer; E. Blank Filter

The lead levels in Table V average 3380 μg per round fired. These values are low compared with the data in Table III (5643 μg/round) even if the correction for the primer contribution (403 μg/round) is subtracted. It is conceivable that in the case of the LBLP ammunition, the large particulate matter formed from the projectile provided agglomeration sites for the much smaller fragments formed from the primer, thus enhancing the trapping efficiency. The results from the second set of firings appear in Table VI.

TABLE VI. Chemical Analysis, Uprange Samples Trapped from CJBLFP Ammunition

Sample No.	Barium Level (μg/round)	Lead Level (μg/round)
1	43	354
2	20	183
3	20	109
4	30	156
5	30	88
	Avg. 29	Avg. 178

Although negligible amounts of lead and barium had been expected, significant amounts were obtained. The cause was ascribed to cross-contamination from previously fired rounds. Compare, for instance, the barium levels obtained in Table V. A number of rounds having conventional primers and projectiles had been fired in the box between the two series. To prevent this type of interference, the experiment was repeated after the pistol and the firing chamber (See Experimental section) were properly cleaned. The results of the next series of firings appear in Table VII.

TABLE VII. Chemical Analysis, Uprange Samples Trapped from CJBLFP Ammunition. Series 2

Sample No.	Barium Level (μg/round)	Lead Level (μg/round)
1	<10	340
2	<10	115
3	<10	75
4	<10	38
5	<10	72
6	<10	55
7	<10	34
8	<10	32
	Avg. <10	Avg. 95

As a result of the cleaning procedures, the barium levels in Table VII have fallen to essentially baseline levels. The less than ten microgram designation indicates that some barium was observed, but under the conditions of our experiment, the x-ray fluorescence technique really could not reliably provide exact numerical data in this range. The values for lead, however, are higher than expected. Moreover, they show the same decreasing trend with number of rounds fired as was evident in Table VI. It was postulated, therefore, that the lead contamination was coming from the barrel of the weapon* and that the copper jacketed projectiles tended to clean the lead contaminants from the bore. Prior to taking the next set of data, therefore, twenty rounds of copper jacketed projectile, lead free primer ammunition were fired. The weapon was then cleaned using normal procedures. The firing box was thoroughly cleaned as before. The results of the firing tests are given in Table VIII.

TABLE VIII. Chemical Analysis, Uprange Samples Trapped from CJBLFP Ammunition. Series 3

Sample No.	Barium Level (μg/round)	Lead Level (μg/round)
1	<10	23
2	<10	83
3	<10	27
4	<10	12
5	<10	13
6	<10	27
7	<10	37
8	<10	25
9	<10	22
10	<10	18
	Avg. <10	Avg. 23**
		Std. Dev. 8

** Sample 2 was not used in the computed average since the difference between its value and the average is greater than three sigma.

The data in Table VIII show a significant reduction in the amount of uprange lead trapped. Furthermore, the data show only scatter, without the decreasing trend noted previously. The background level measured

* *At the end of the study, the gun was sacrificed to demonstrate this point directly. The build up of lead in the bands and grooves of the weapon was readily shown using SEM-X-Ray Microanalysis. Conventional cleaning techniques did not remove the lead fouling.*

while taking these data averaged 5 micrograms, therefore, the actual amount of lead trapped per sample was 18 micrograms.

To see if further improvement could be obtained, the front ends of several partially jacketed projectiles were machined out to 1.6 mm below the lips of the copper jackets. The recesses were filled with epoxy. Figure 12 shows both the copper jacketed, soft point projectile and the modified version. These rounds were fired immediately after the series in Table VIII. The results are given in Table IX.

TABLE IX. Chemical Analysis, Uprange Samples Trapped from CJBLFP Ammunition. Series 4

Sample No.	Barium Level (μg/round)	Lead Level (μg/round)
1	<10	22
2	<10	45
3	<10	23
4	<10	20
5	<10	12
	Avg. <10	Avg. 19*
		Std. Dev. 5

* Sample 2 was rejected from the computed average.

The data in Table IX are essentially similar to the data in Table VIII. The corrected average value for Table IX is 14 micrograms per round. (Compare with 18 micrograms from Table VIII.) There may be a slight improvement for the modified rounds.

In a final series of experiments, the barrel and cylinder of the weapon were cleaned using six normal nitric acid. No lead fouling would be expected to survive the treatment. (The washings gave positive tests for lead.) After cleaning and oiling the weapon (and cleaning the firing box) a series of rounds was fired using partially copper jacketed projectiles. The results obtained are given in Table X.

The average background level observed during this series was five micrograms. The corrected average, therefore, is 13 μg per round. As may be seen from Tables VIII, IX and X the experiment had hit the point of diminishing returns. No further efforts at reducing the amount of lead were made.

Compared with the data in Table III, which contains the results of firings of conventional caliber .38 special ammunition, the data in Table X are quite satisfying. On the average, the data in Table X show a reduction in lead per round by a factor greater than four hundred. On a practical level, under the experimental conditions, one would have to fire 434 rounds of the low lead ammunition to produce the amount of lead contaminant generated by a single conventional round.

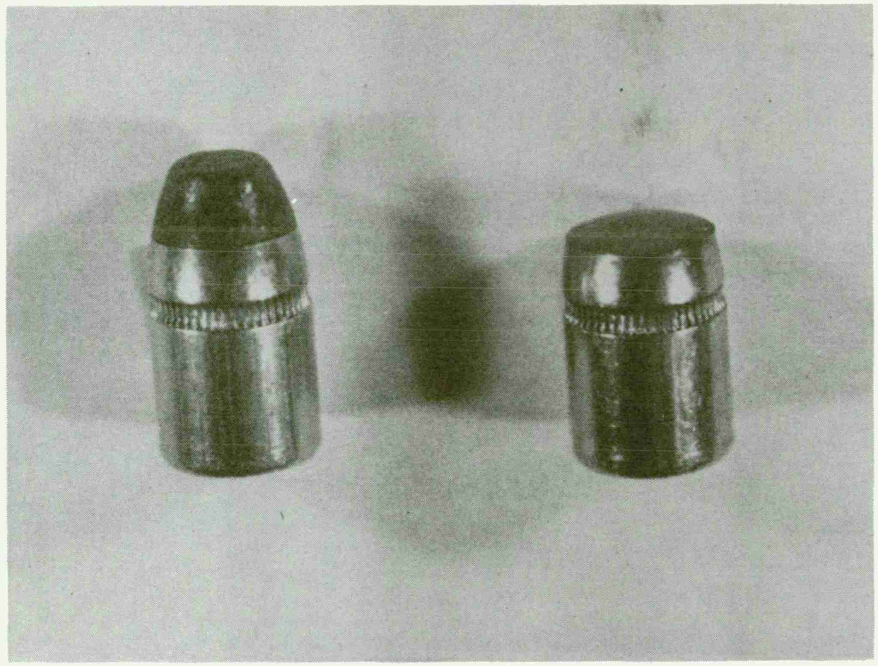

Figure 12. Copper Jacketed Soft Point Projectile and Modified Projectile with Epoxy Coated Tip.

TABLE X. Chemical Analysis, Uprange Samples Trapped from CJBLFP Ammunition. Series 5

Sample No.	Barium Level (μg/round)	Lead Level (μg/round)
1	<10	21
2	<10	22
3	<10	10
4	<10	16
5	<10	19
6	<10	22
7	<10	17
8	<10	21
9	<10	14
10	<10	14
	Avg. <10	Avg. 18
		Std. Dev. 4

The problem of the persistent low level lead contamination observed remains to be treated. From the firings of the ammunition with the lead free primer and the modified projectiles, it appears reasonable that the persistent low level lead contamination is not coming from the ammunition but from the surroundings. The background samples, however, indicated only an average of five micrograms lead per sample. These samples were collected exactly as those from the firings with the exception that the muzzle blast from the weapon was absent. It may be that the blast stirred up sufficient lead dust in the vicinity of the firing box to account for the lead levels found in the "clean" firings. Since BRL's indoor ranges have been in use for many years, lead dust contamination is probably present. It would be quite interesting to repeat some of the experiments in a completely clean environment. Under such conditions the uprange lead contamination should be entirely eliminated.

D. Lead Contamination Effects Downrange

The test fixture used to obtain downrange samples was described in the Experimental section. A photograph of the impact plate along with the particle filter and sampling pump is given in Figure 13. The projectile impacting on the steel plate is expected to produce spall fragments in a highly irregular fashion. A sampling of downrange data (taken simultaneously with the uprange samples) appears in Table XI.

The data are highly scattered as expected. The amount of lead trapped ranges from 61 to 911 μg per round. It turns out that both the highest and lowest lead levels observed occurred with copper jacketed rounds. Since no systematic effects were observed, it did not appear profitable to pursue the downrange data further. The question has been raised concerning the possibility that the downrange lead contamination could

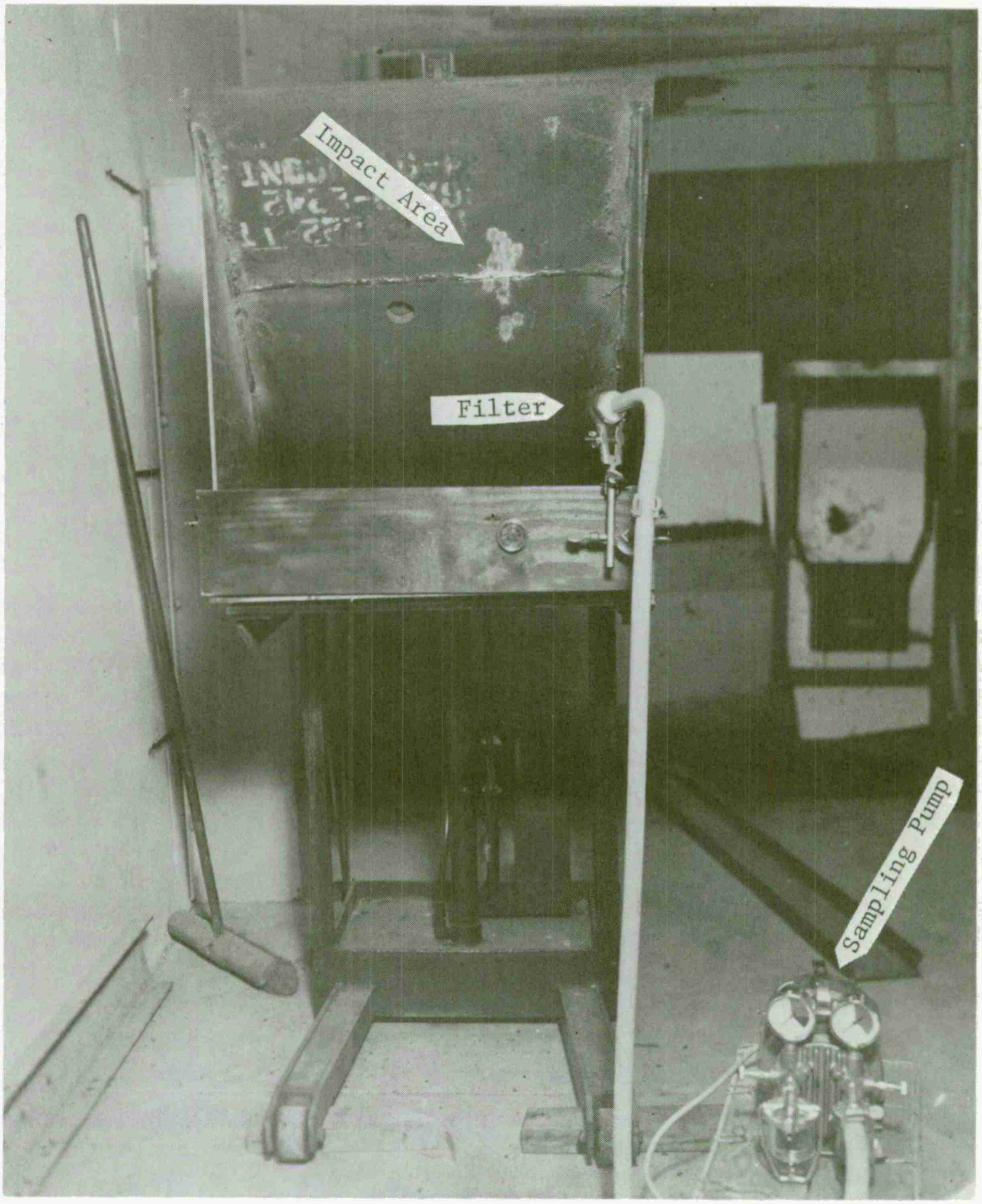

Figure 13. Downrange Sampling Station Impact Area, 0.8μm Filter and Sampling Pump.

TABLE XI. Chemical Analysis, Downrange Samples

Sample	Projectile Type	Lead Level (μg/round)
1	Copper Jacketed	398
2	Copper Jacketed	171
3	Lead	525
4	Lead	826
5	Copper Jacketed	61
6	Copper Jacketed	911
7	Lead	458
8	Lead	390
		Avg. 468
		Std. Dev. 290

have influenced the uprange values. It appears that such an effect would tend to contribute only to the overall lead levels in the range. Since the distance between the firing box and the impact area is nine metres, the chances are that most large particles would settle out. The dispersal of the smaller ones should dilute them to insignificant levels by the time diffusion to the gun takes place.

A comparison of the uprange and downrange lead levels observed (See Tables III and XI) indicates that there was twelve times as much airborne contaminant produced uprange as there was downrange. This may not be strictly true, since the downrange data were very scattered and the trapping arrangements were not strictly alike. The downrange contamination in any case may not be so much of a problem overall since venting arrangements in the impact area are generally good. If lower lead levels are desired in the impact area, without changes in the ventilation system, however, the use of non-lead projectiles or soft targets would be the best solution.

E. Ballistic Characteristics

The ballistic characteristics of all four types of ammunition were tested in a Mann barrel fixture. The schematic is given in Figure 3. A photograph of the setup is given in Figure 14. The photograph shows the barrel assembly, firing solenoid, pressure transducer and charge amplifier. The data taken included both pressure-time traces and muzzle velocities for each type of round. Data on ignition delay times (T_{ign}), muzzle velocities (V_m), and maximum pressure (P_{max}) appear in Tables XII through XV.

As may be seen from Table XII, the best ballistics were obtained using the conventional primer, lead projectile ammunition. The average velocity for these rounds was 268.4 m/s, with a low standard deviation (2.0 m/s). If a copper jacketed projectile is substituted for the lead,

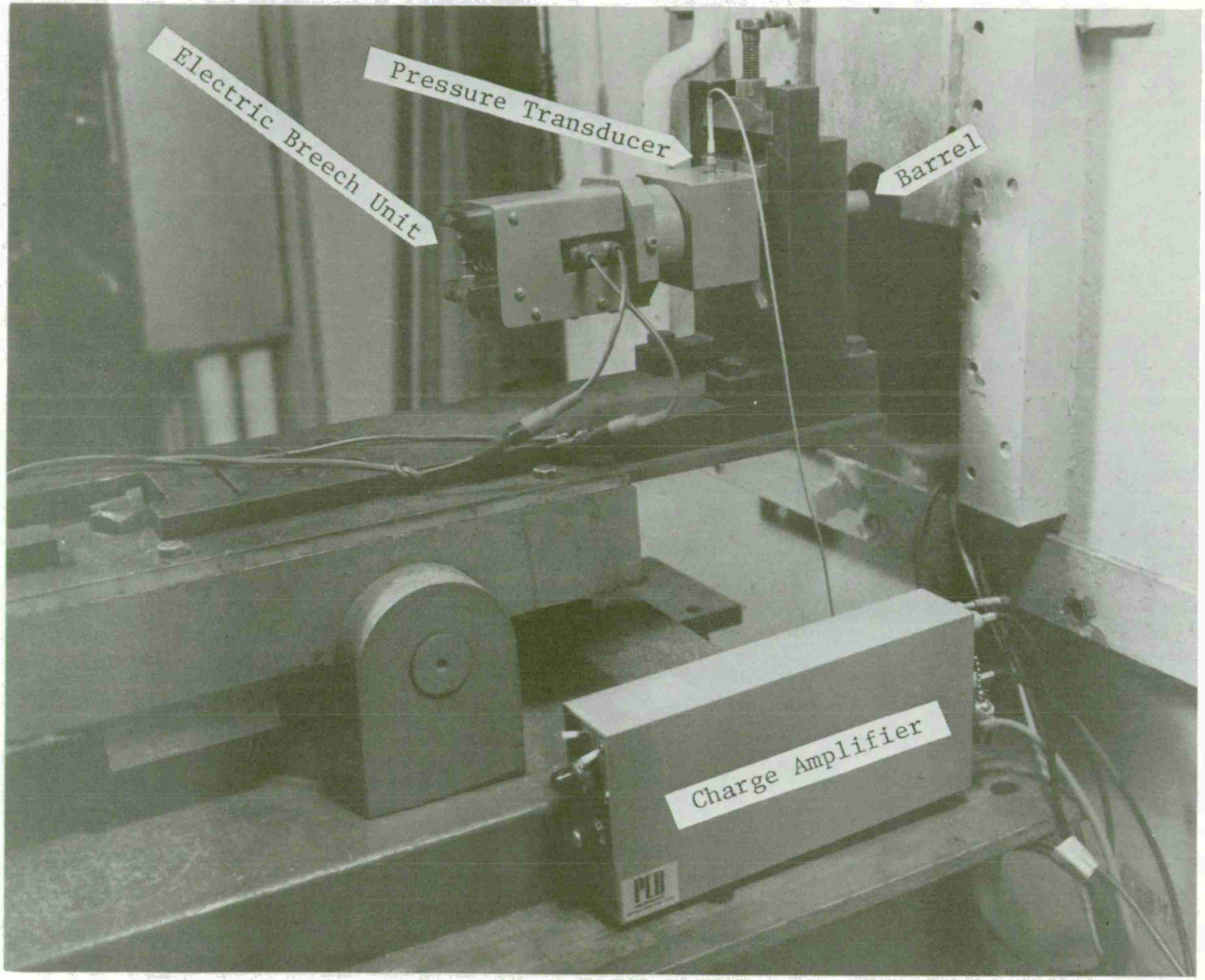

Figure 14. Mann Barrel Assembly for Ballistic Firings Showing Barrel, Electric Breech Unit, Pressure Transducer and Charge Amplifier.

TABLE XII. Muzzle Velocity and Maximum Pressure Data, LBLP Ammunition

Round No.	T_{ign} (ms)	V_m (m/s)	P_{max} (MPa)
1	0.081	270.0	111.9
2	0.128	271.3	109.4
3	0.128	266.7	106.0
4	0.081	269.7	112.2
5	0.163	264.6	103.5
6	0.140	268.2	108.3
7	0.145	267.0	107.3
8	0.093	268.2	106.2
9	0.058	270.4	111.3
10	0.151	267.6	104.6
	Avg. 0.117	Avg. 268.4	Avg. 108.0
	Std. Dev. 0.036	Std. Dev. 2.0	Std. Dev. 3.1

TABLE XIII. Muzzle Velocity and Maximum Pressure Data, CJBLP Ammunition

Round No.	T_{ign} (ms)	V_m (m/s)	P_{max} (MPa)
1	0.093	244.1	106.7
2	0.105	231.3	106.6
3	0.093	233.4	118.9
4	0.140	244.0	109.9
5	0.093	227.7	112.4
	Avg. 0.105	Avg. 236.1	Avg. 110.9
	Std. Dev. 0.020	Std. Dev. 7.5	Std. Dev. 5.1

TABLE XIV. Muzzle Velocity and Maximum Pressure Data, LBLFP Ammunition

Round No.	T_{ign} (ms)	V_m (m/s)	P_{max} (MPa)
1	0.92	252.1	82.7
2	0.47	268.2	108.6
3	0.71	268.2	107.4
4	1.01	274.9	118.6
5	0.30	267.0	99.4
6	1.08	241.4	73.5
7	2.07	274.0	117.1
8	0.33	264.6	97.9
9	0.48	263.7	98.8
	Avg. 0.82	Avg. 263.8	Avg. 100.4
	Std. Dev. 0.55	Std. Dev. 10.7	Std. Dev. 14.9

TABLE XV. Muzzle Velocity and Maximum Pressure Data, CJBLFP Ammunition

Round No.	T_{ign} (ms)	V_m (m/s)	P_{max} (MPa)
1	0.55	218.2	105.3
2	0.37	214.0	105.2
3	0.30	232.6	110.0
4	0.13	242.6	121.9
5	0.51	233.5	103.6
6	0.70	232.6	109.4
Avg.	0.43	228.9	109.2
Std. Dev.	0.20	10.7	6.7

the muzzle velocity drops by 32 m/s and the standard deviation of the muzzle velocity increases to 7.5 m/s. Although extra propellant may be used to bring up the muzzle velocity, the greater inherent scatter from round to round must be reckoned with. The poorest ballistics were obtained from the ammunition having the lead free primer and the jacketed projectile (See Table XV). The average muzzle velocity was lower (228.9 m/s) than for any of the other series. The standard deviation was the same as that obtained in Table XIV (10.7 m/s).

The data indicate that a significant portion of the round-to-round deviation comes from the primer composition. This may be further traced to variations in the ignition behavior of the propellant charge. Tables XII through XV contain data on the ignition delay time (T_{ign}) for each of the rounds fired. The values for the ignition delay times were calculated by extrapolating the rising portion of the pressure-time curve back to the baseline and measuring the time interval between this point and the initial pressure rise. See Figure 15 for typical traces of the conventional primer and lead free primer ammunition. Comparing the average values of the igniton delay time in Tables XII and XIV (0.117 ms vs. 0.82 ms), clearly presents the difference between the performances of the two types of rounds.

The ammunition with the CP-27 primer consistently showed not only longer ignition delay values but a larger variation of these values (compare standard deviations of 0.036 ms in Table XII with 0.55 ms in Table XIV.)

The principal probable causes for this are the reduced sensitivity of the priming mixture and the absence of hot particulate matter in the igniter products. Reduced sensitivity means that the primer must be struck with a larger force to function consistently. Compare, for instance, the data in Tables XIV and XV. A large number of misfires had been observed while taking the data in Table XIV. In order to avoid this problem, the voltage on the firing solenoid was increased for the series in Table XV. With the extra energy on the firing pin, the

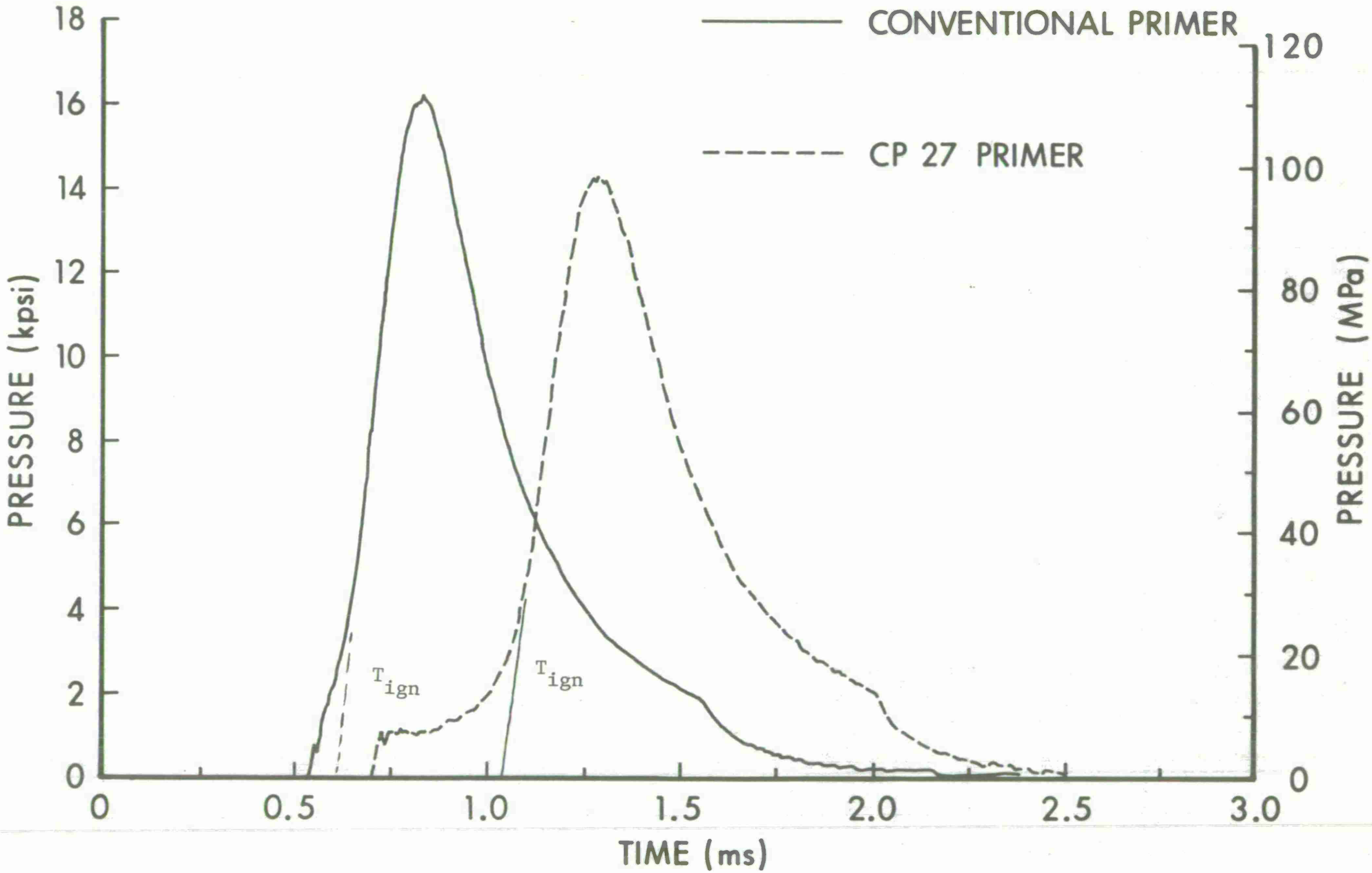

Figure 15. Typical Pressure-Time Records for Conventional Primer Caliber .38 Special Ammunition and CP-27 Primer Ammunition. Ignition Delay Time (T_{ign}) Indicated.

length and variability of the ignition delay both decreased. The absence of hot particulate matter in the decomposition products would tend to produce poorer transfer of energy to the propellant. The pressure-time curves for all the no lead primer rounds are included in the Appendix.

IV. CONCLUSIONS AND RECOMMENDATIONS

It has been shown that a substantial reduction in the aerosol lead contamination from hand guns (by a factor of 430) is feasible by making selected changes in the ammunition fired. It should be possible to achieve this without sacrificing ballistic performance. This aspect of the problem will require further research. It is recommended, therefore, that the law enforcement community undertake further efforts in this regard.

The significance of the findings may not be restricted to law enforcement officers alone since the toxicity hazard is also present to those in the sporting and military communities using indoor ranges. It is possible that even in the case of outdoor ranges, a reduction in lead exposure may be practical by use of modified ammunition. It may be of interest, therefore, to the firearms community at large, to explore the use of low lead contamination ammunition.

ACKNOWLEDGEMENTS

The able assistance of Mr. Nelson McCall and Mr. George Harryman in obtaining the range data and helping with the design of the firing fixture is gratefully acknowledged.

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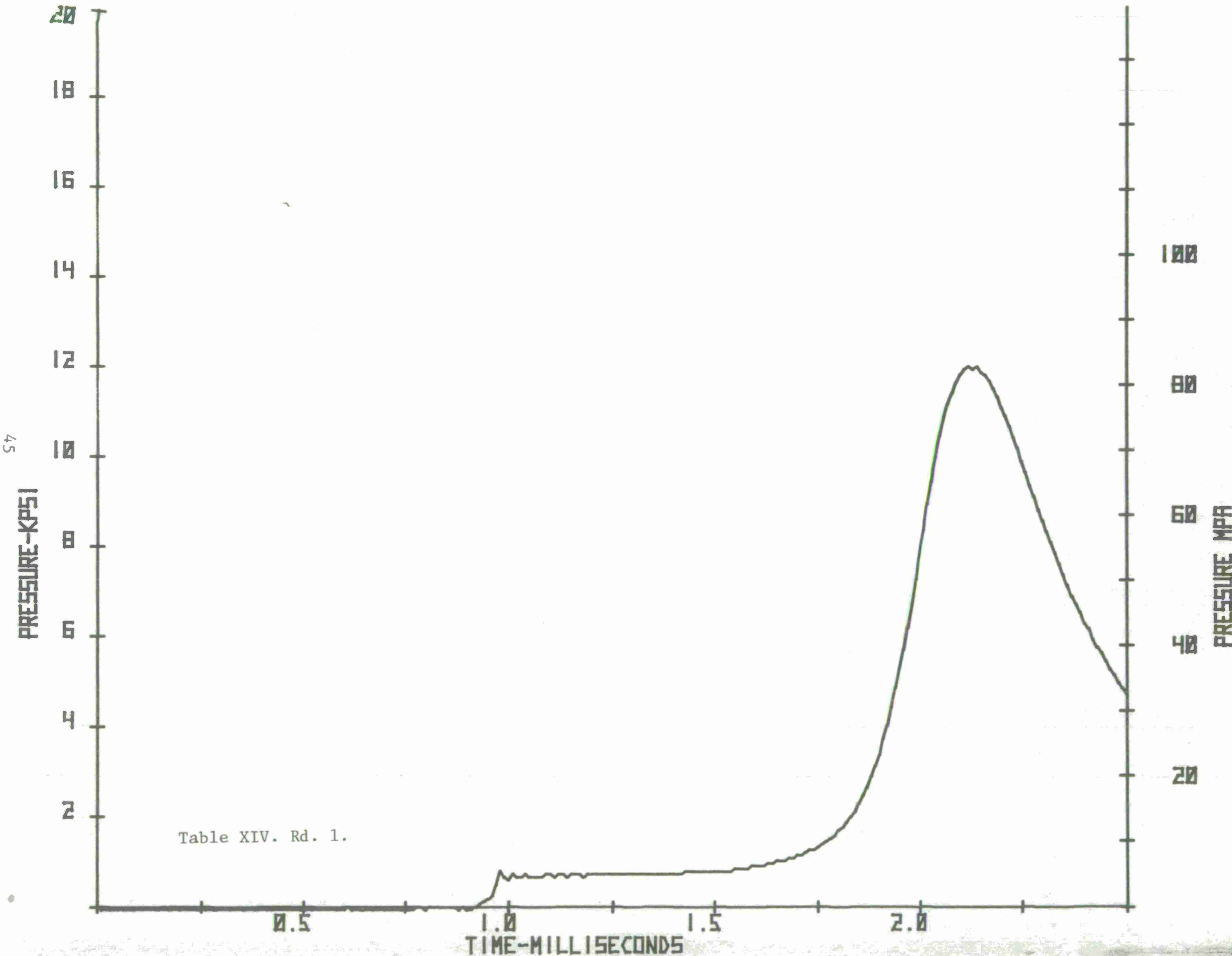
APPENDIX A

PRESSURE-TIME DATA FOR NO LEAD PRIMER AMMUNITION.
(ALL FIRINGS)


20
18
16
14
12
10
8
6
4
2
PRESSURE-KPSI
100
80
60
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20
PRESSURE MPA
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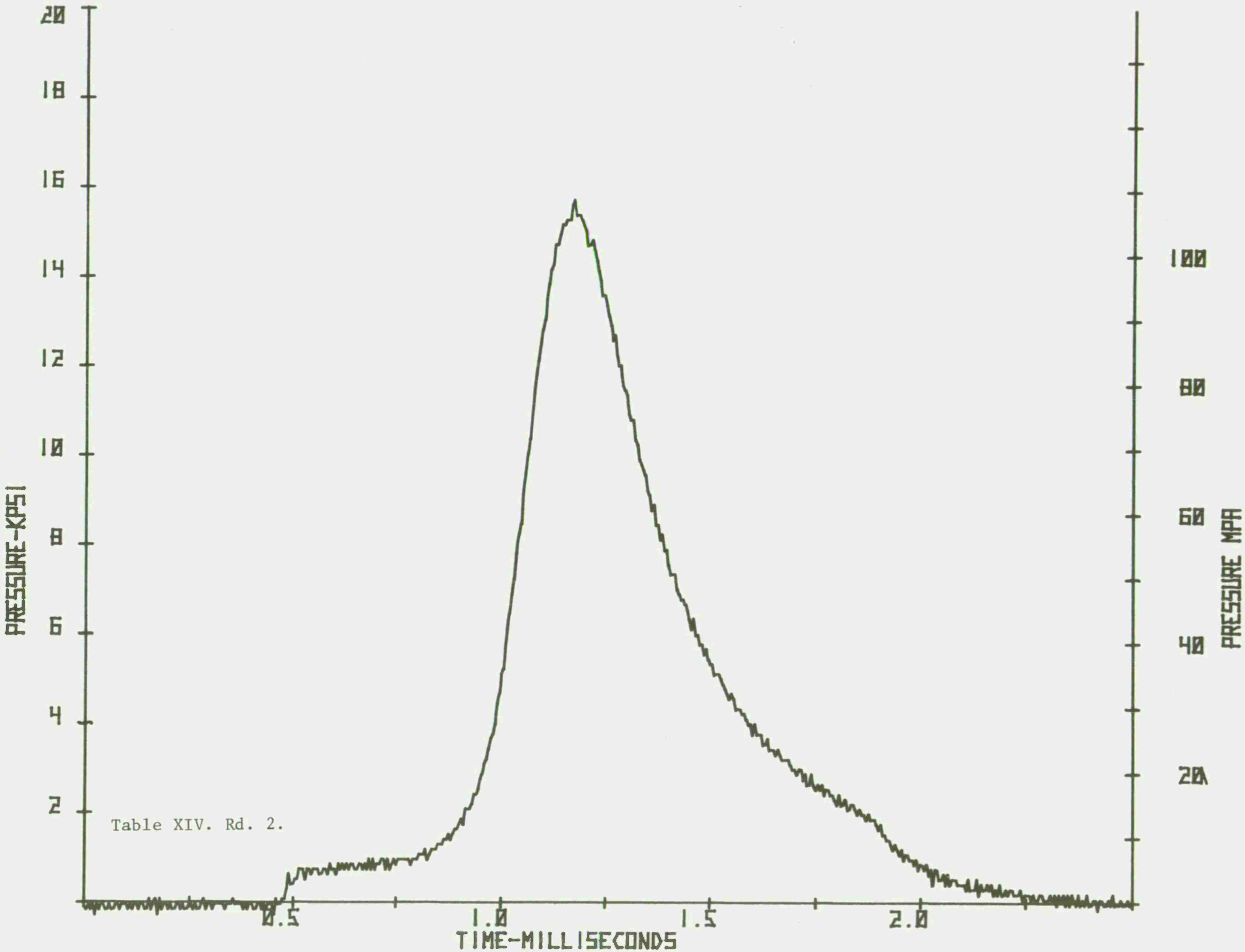
1.0
1.5
2.0
TIME-MILLISECONDS
Table XIV. Rd. 1.



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8
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TIME-MILLISECONDS
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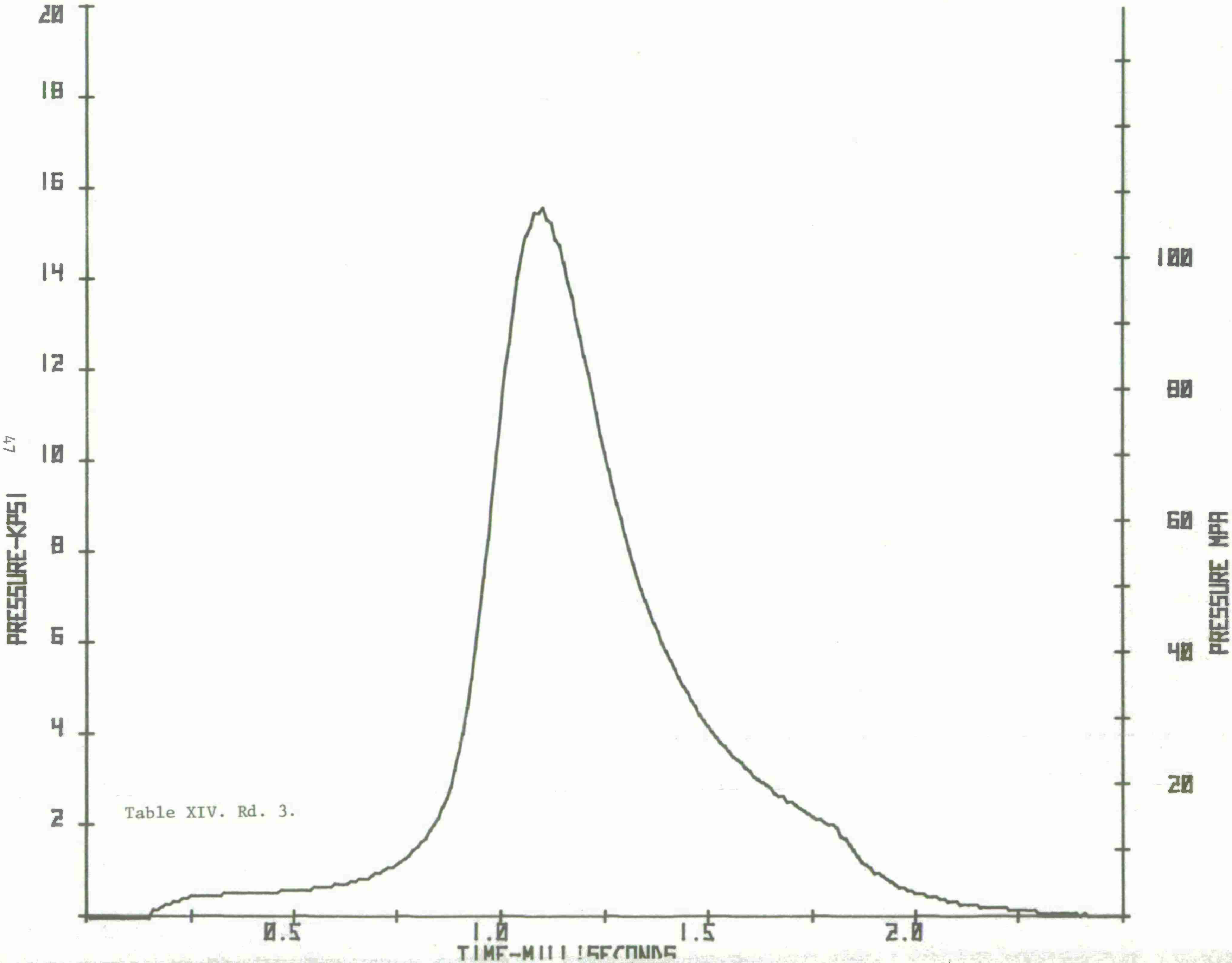
PRESSURE MPA


PRESSURE-KPSI
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18
16
14
12
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8
6
4
2
PRESSURE MPA
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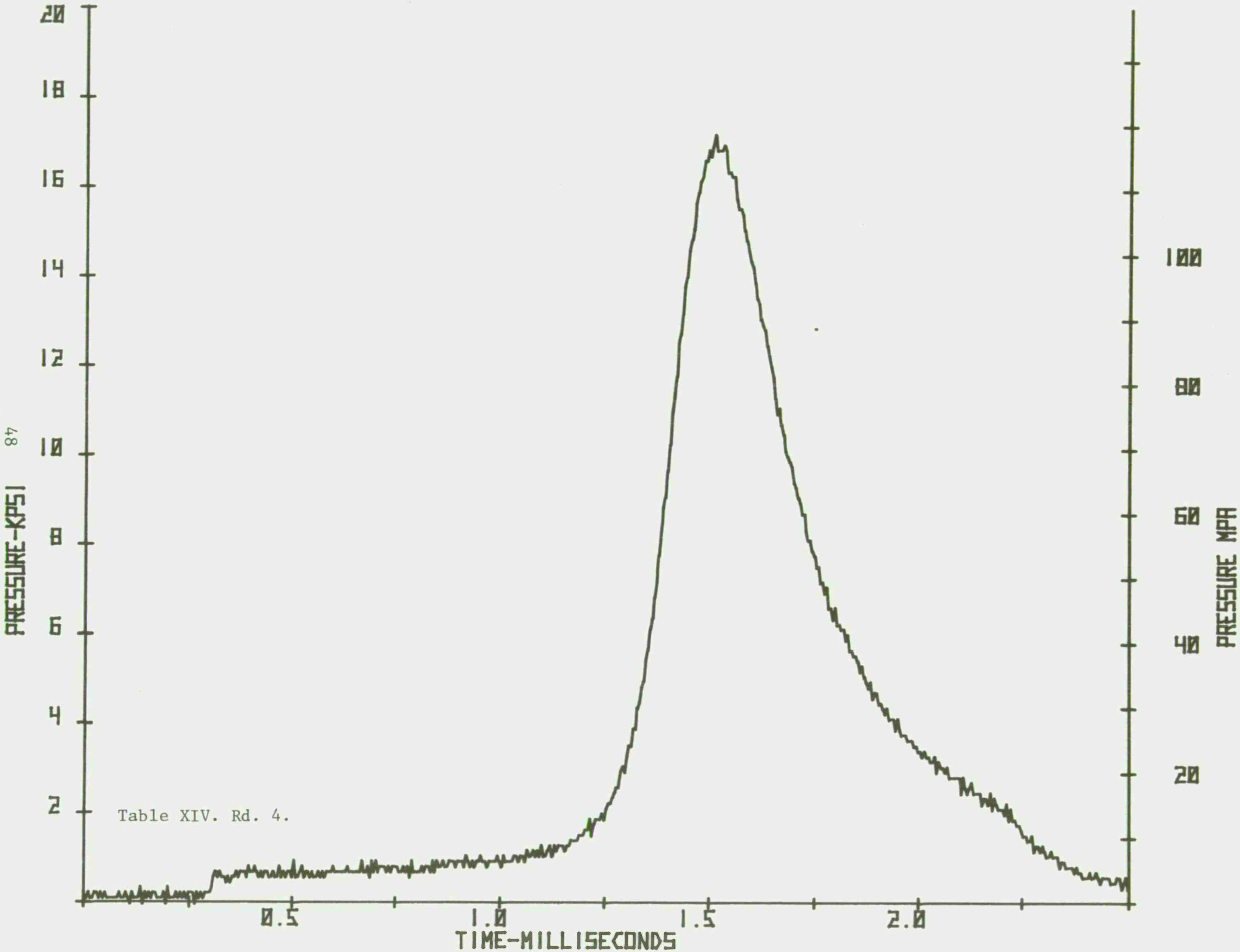
1.5
2.0
TIME-MILLISECONDS
Table XIV. Rd. 3.



PRESSURE-KPSI
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18
16
14
12
10
8
6
4
2
Table XIV. Rd. 4.
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TIME-MILLISECONDS
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60
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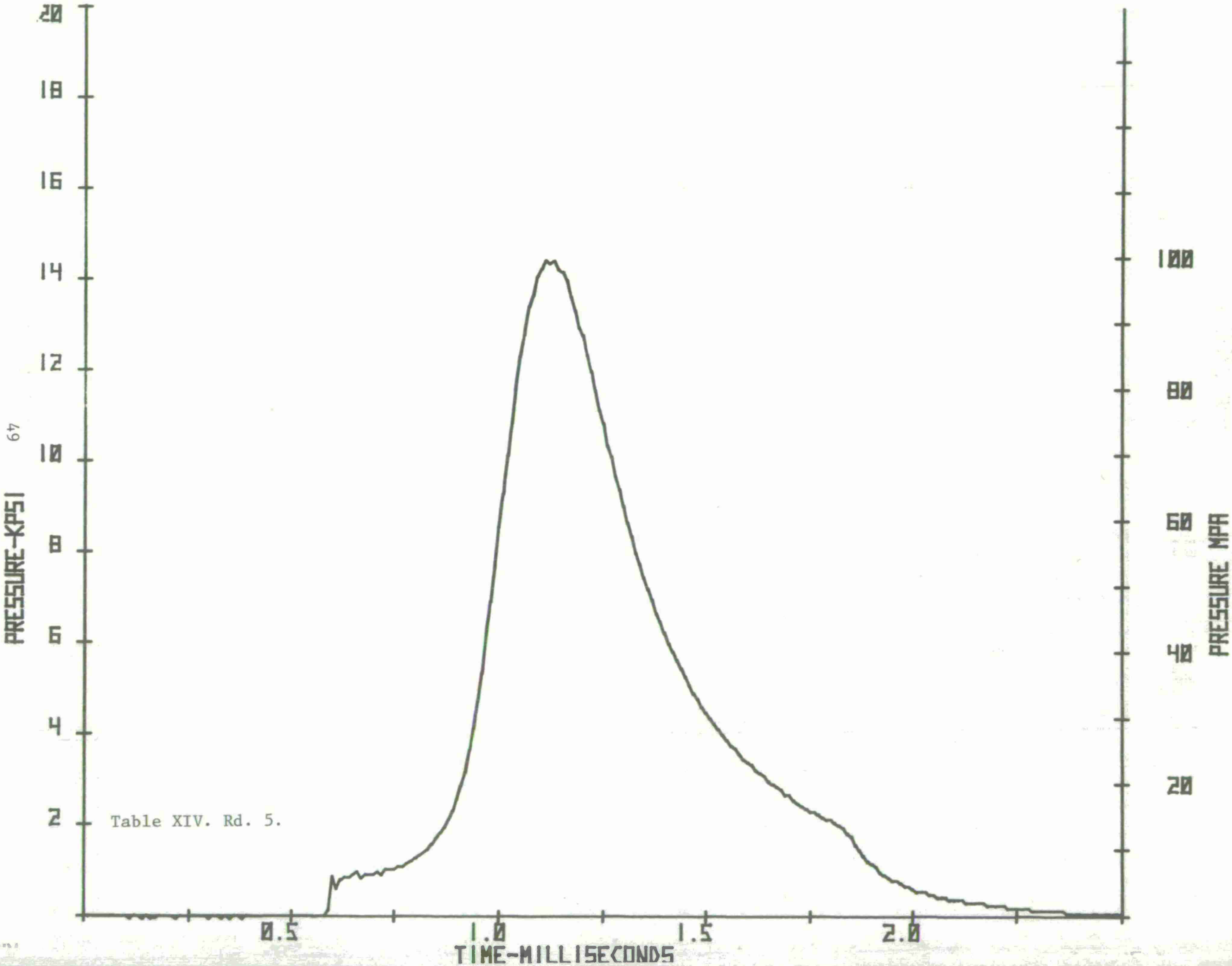
20
PRESSURE MPA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16
14
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8
6
4
2
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TIME-MILLISECONDS
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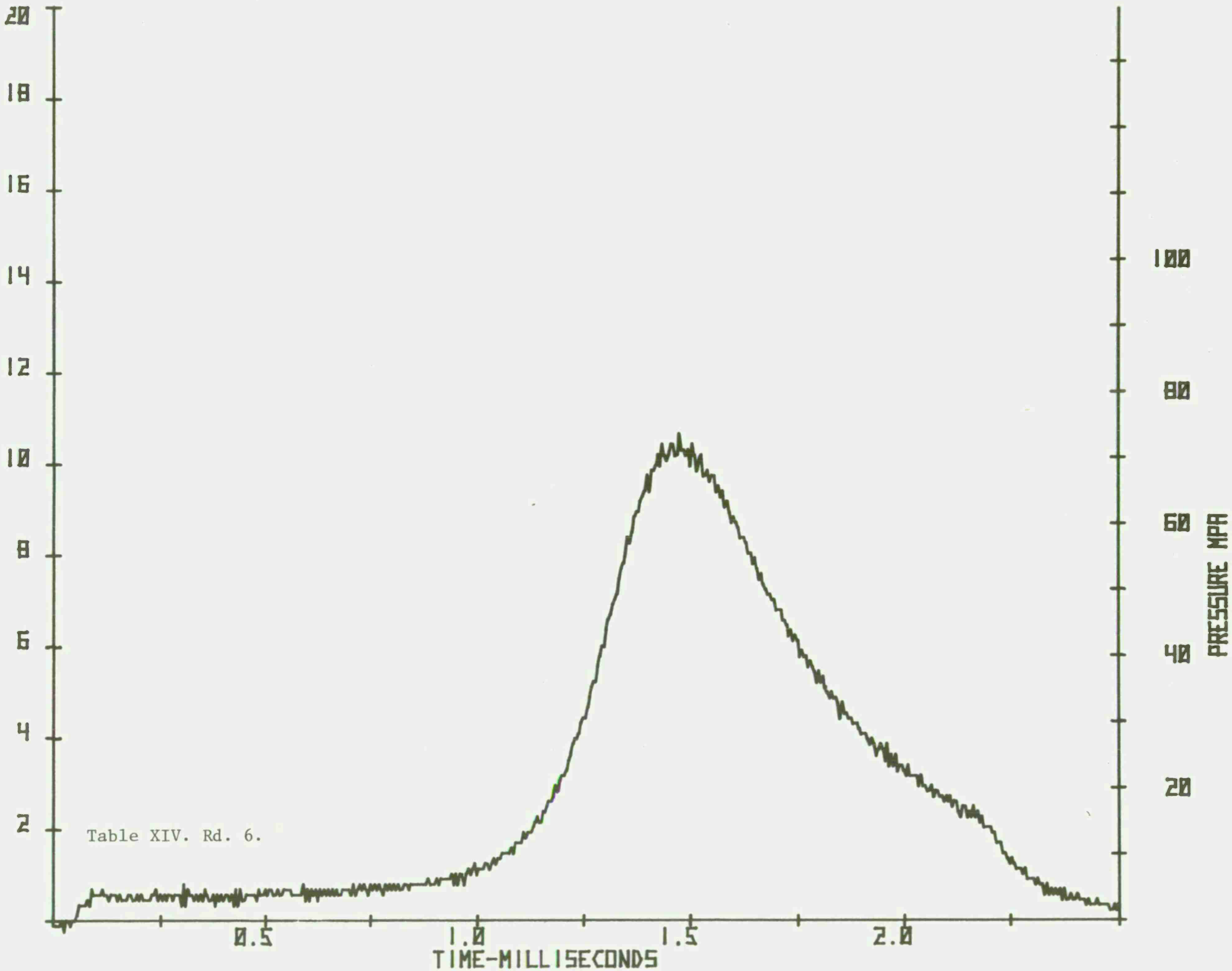
20
PRESSURE MPA



20
18
16
14
12
10
8
6
4
2
PRESSURE-KPSI
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PRESSURE MPA
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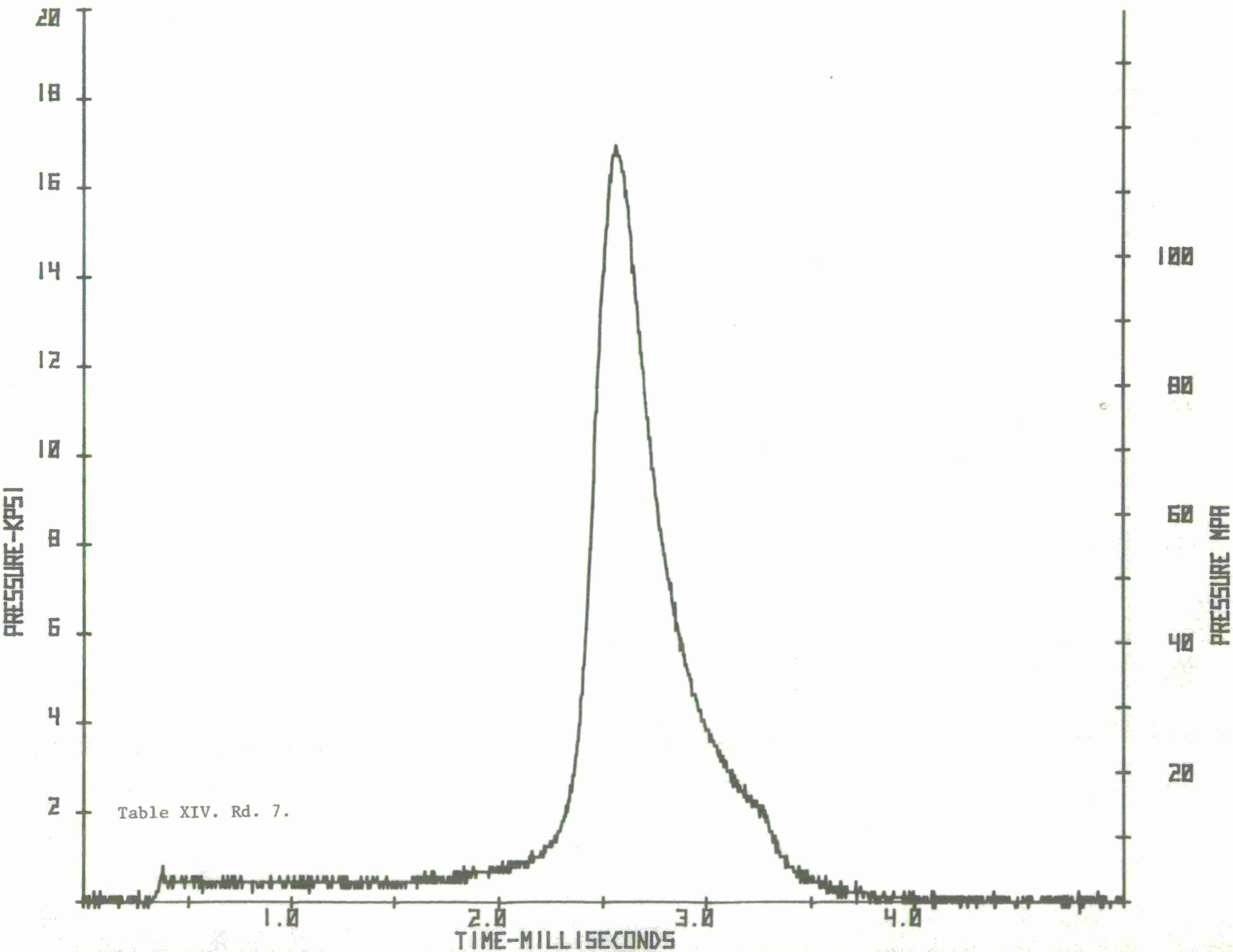
1.5
2.0
TIME-MILLISECONDS
Table XIV. Rd. 6.

50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TIME-MILLISECONDS
PRESSURE MPA
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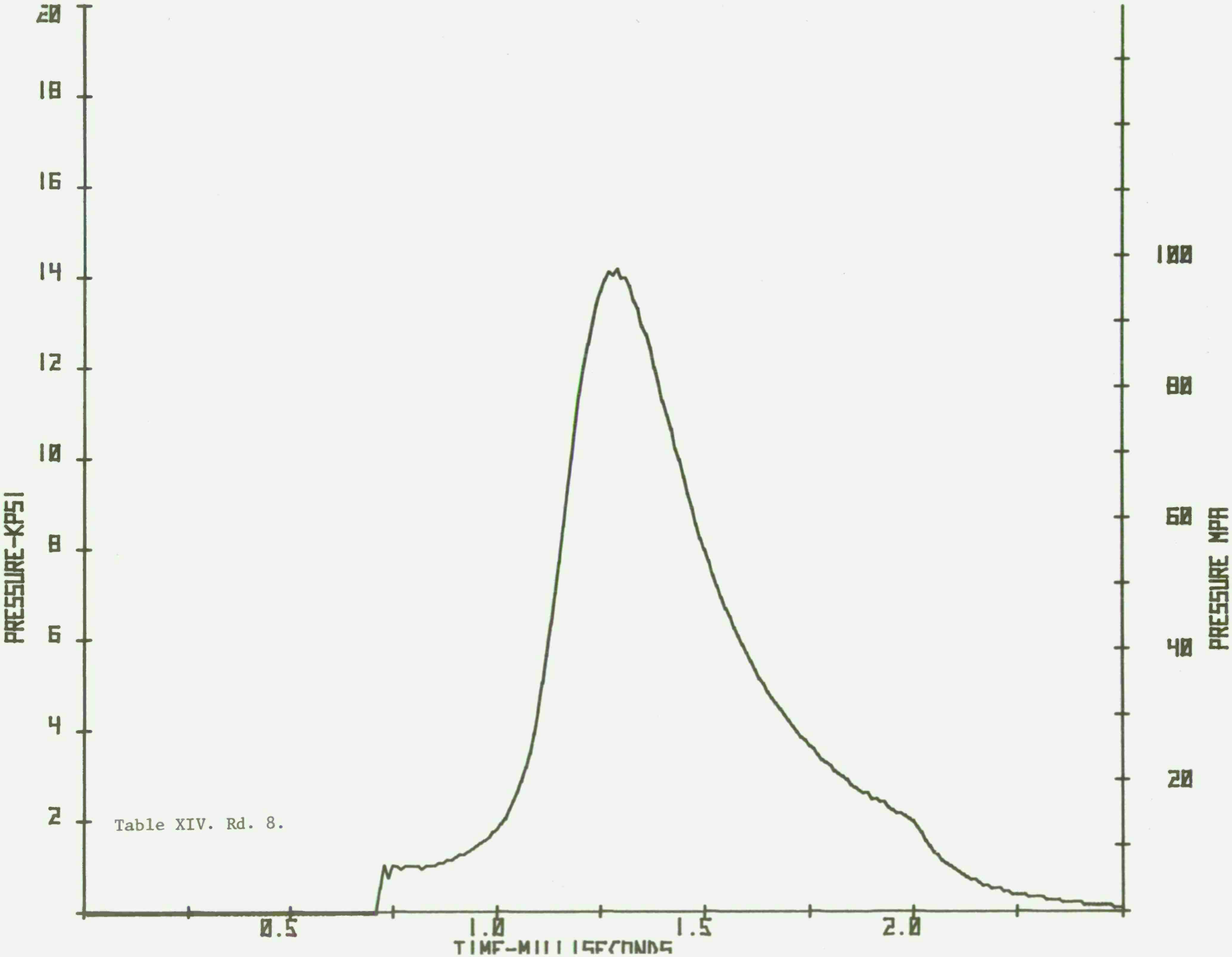
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PRESSURE MPA
TIME-MILLISECONDS
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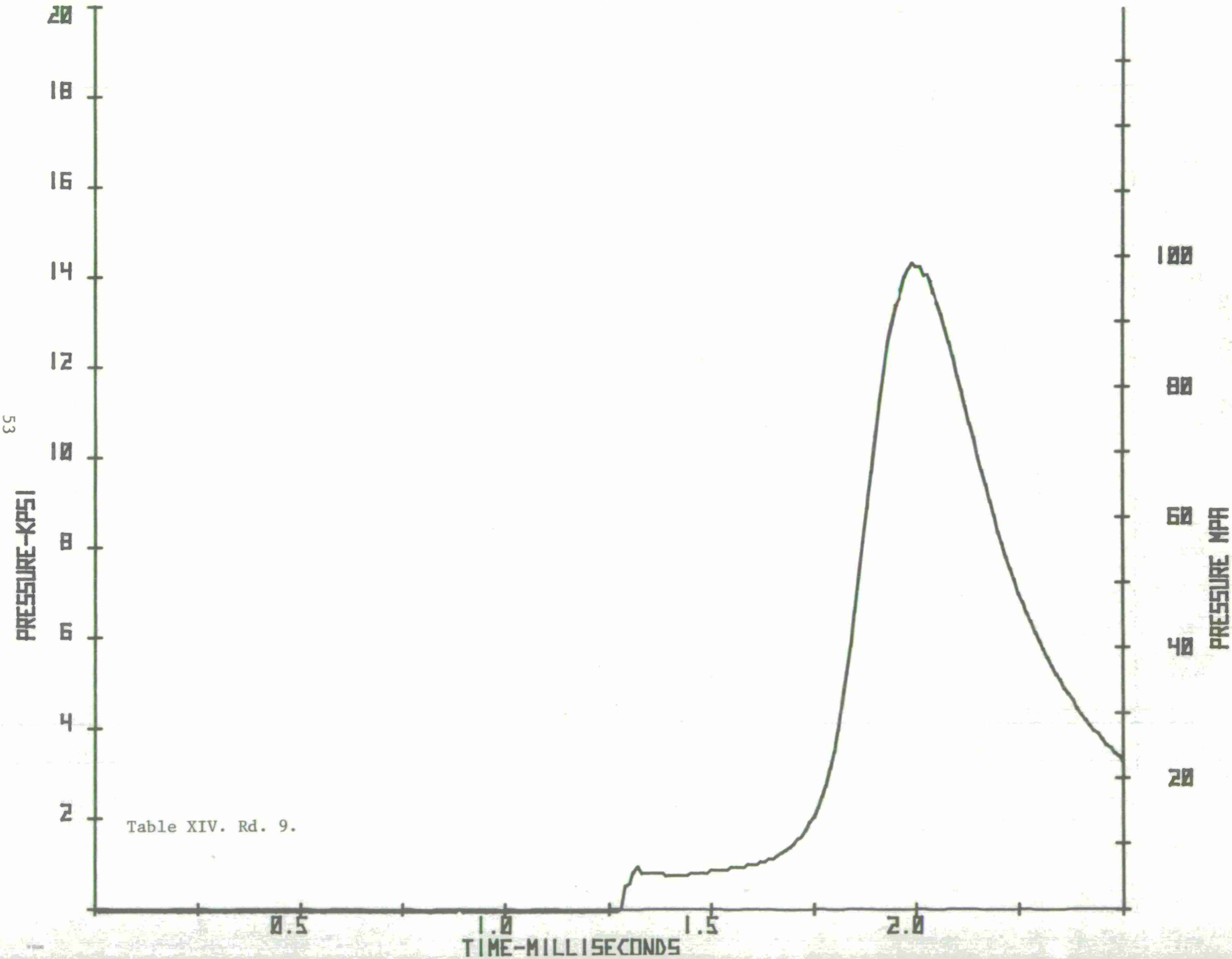
1.5
2.0



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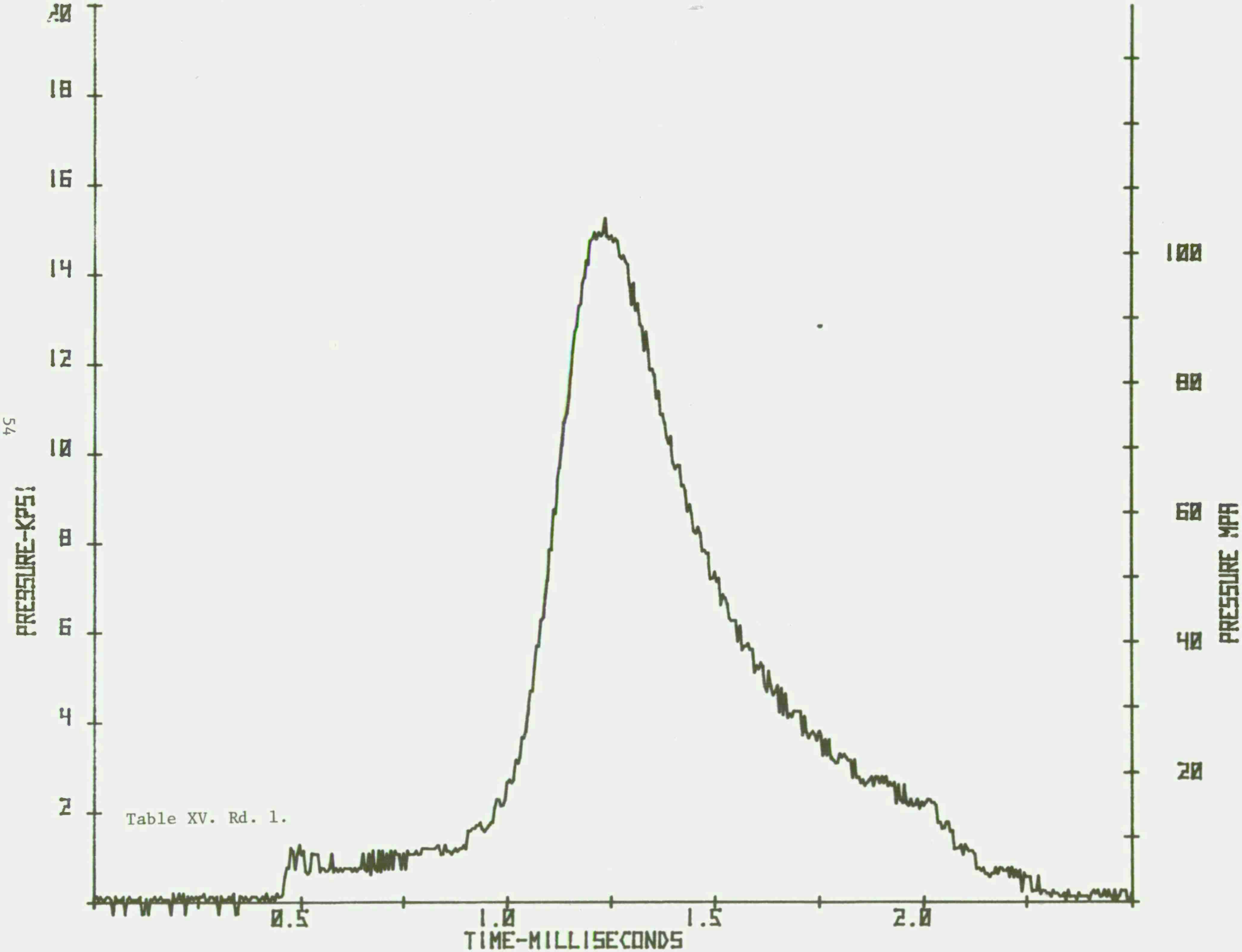
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8
6
4
2
PRESSURE-KPSI
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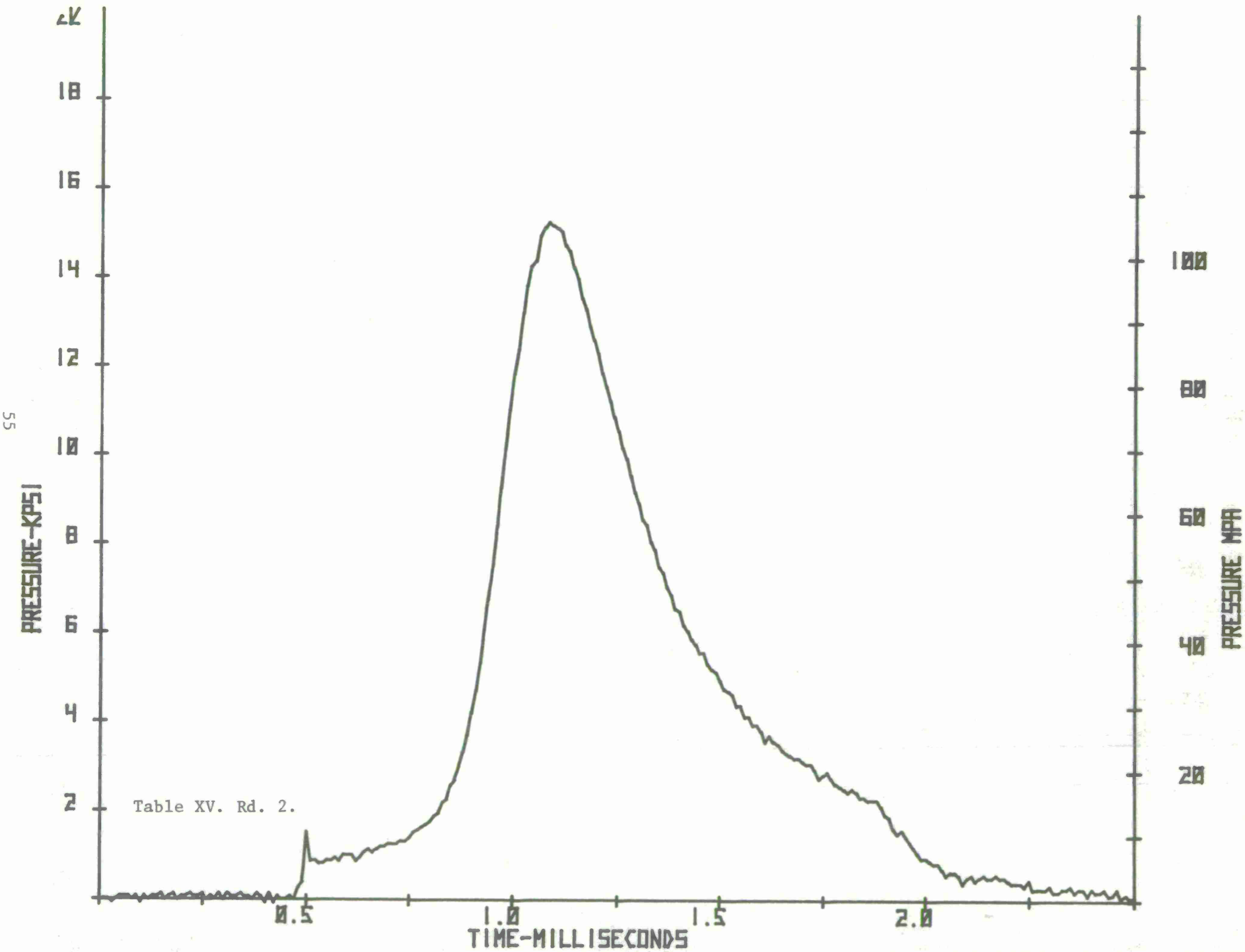
2.0
TIME-MILLISECONDS
100
80
60
40
20
PRESSURE MPA

Table XV. Rd. 1.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6
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10
12
14
16
18
20
PRESSURE MPA
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60
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100
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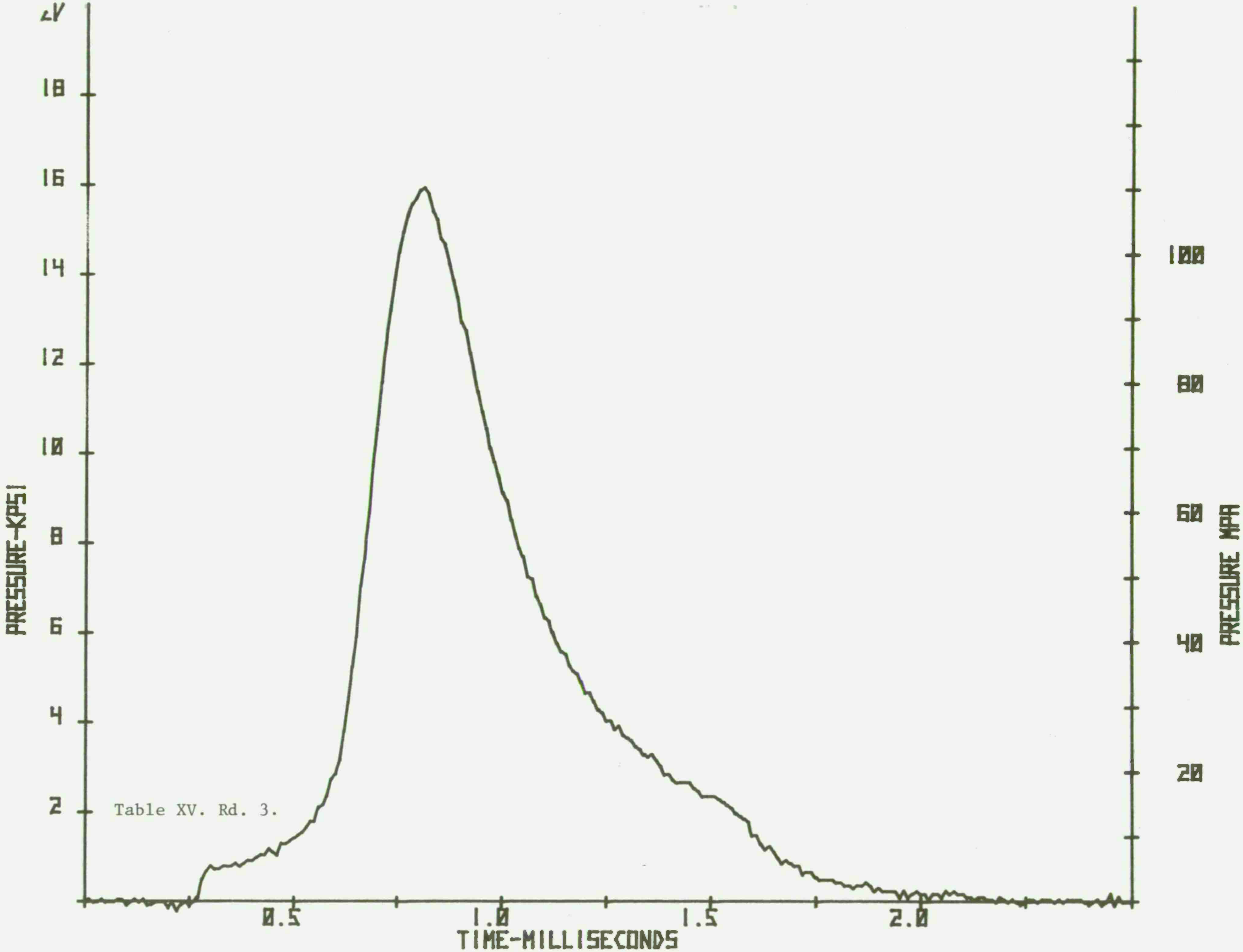
1.0
1.5
2.0
TIME-MILLISECONDS

Table XV. Rd. 2.


PRESSURE-KPSI
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8
10
12
14
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1.5
2.0
TIME-MILLISECONDS
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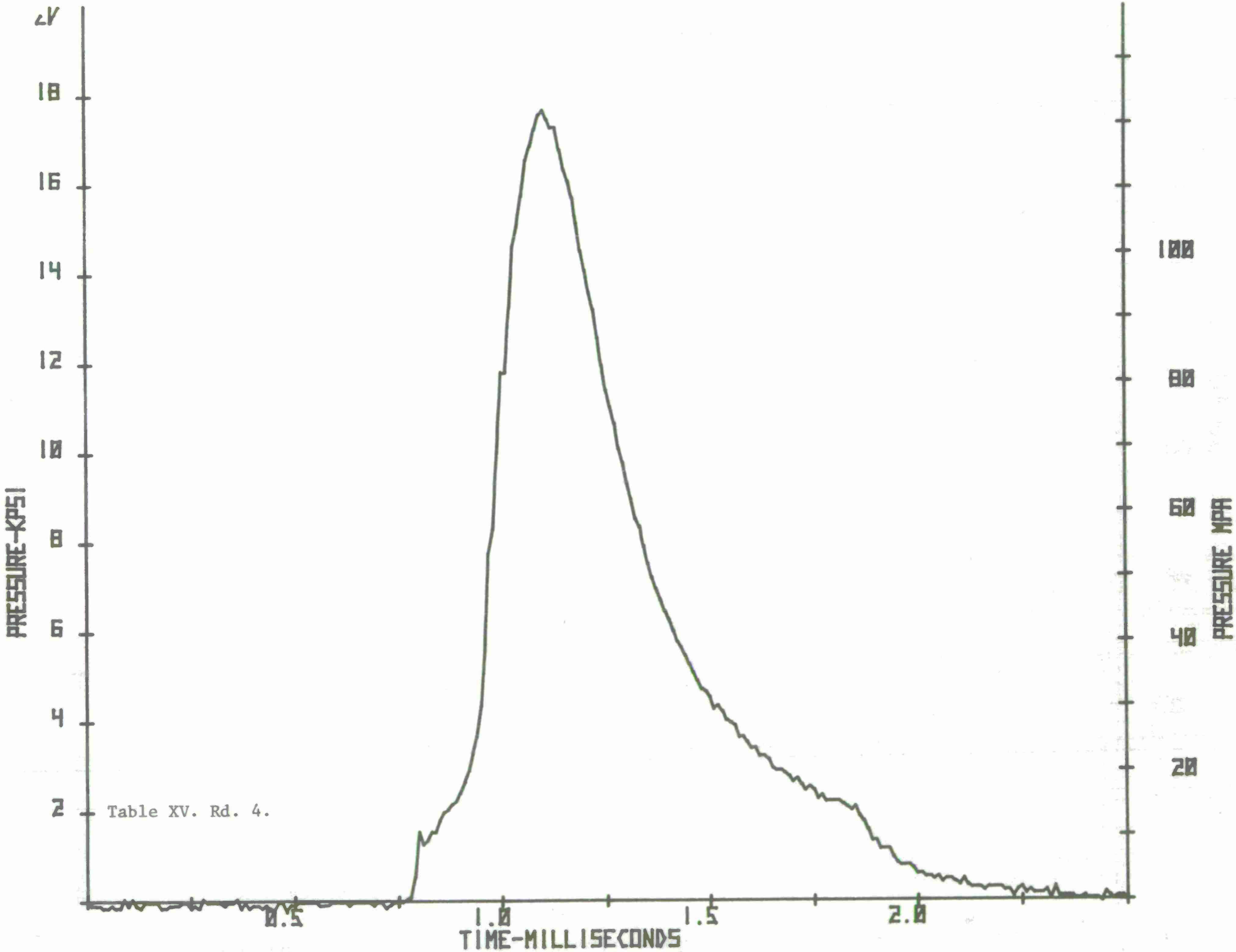

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80
100
TIME-MILLISECONDS
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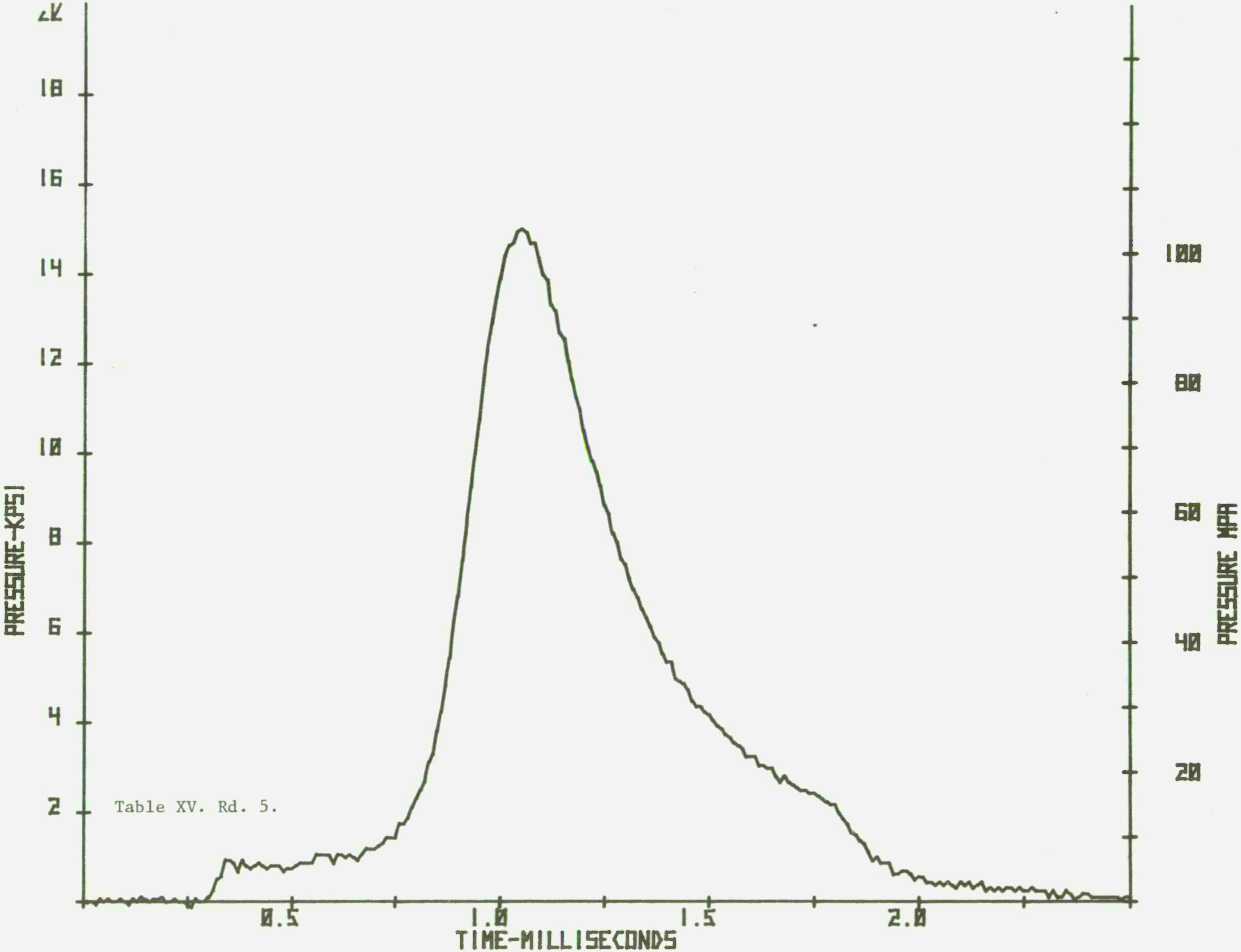
1.0
1.5
2.0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14
12
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8
6
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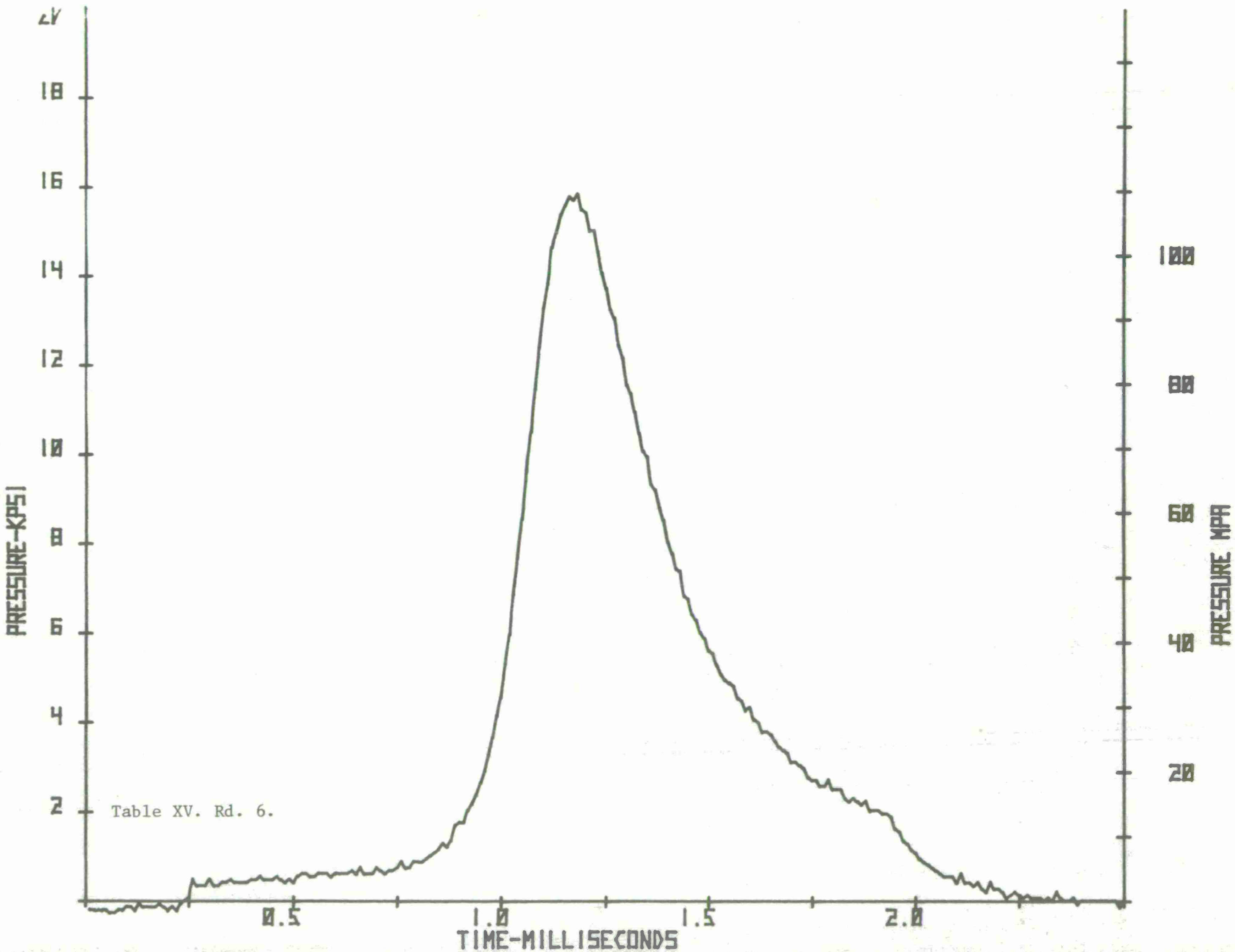
TIME-MILLISECONDS
Table XV. Rd. 5.


PRESSURE-KPSI
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4
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8
10
12
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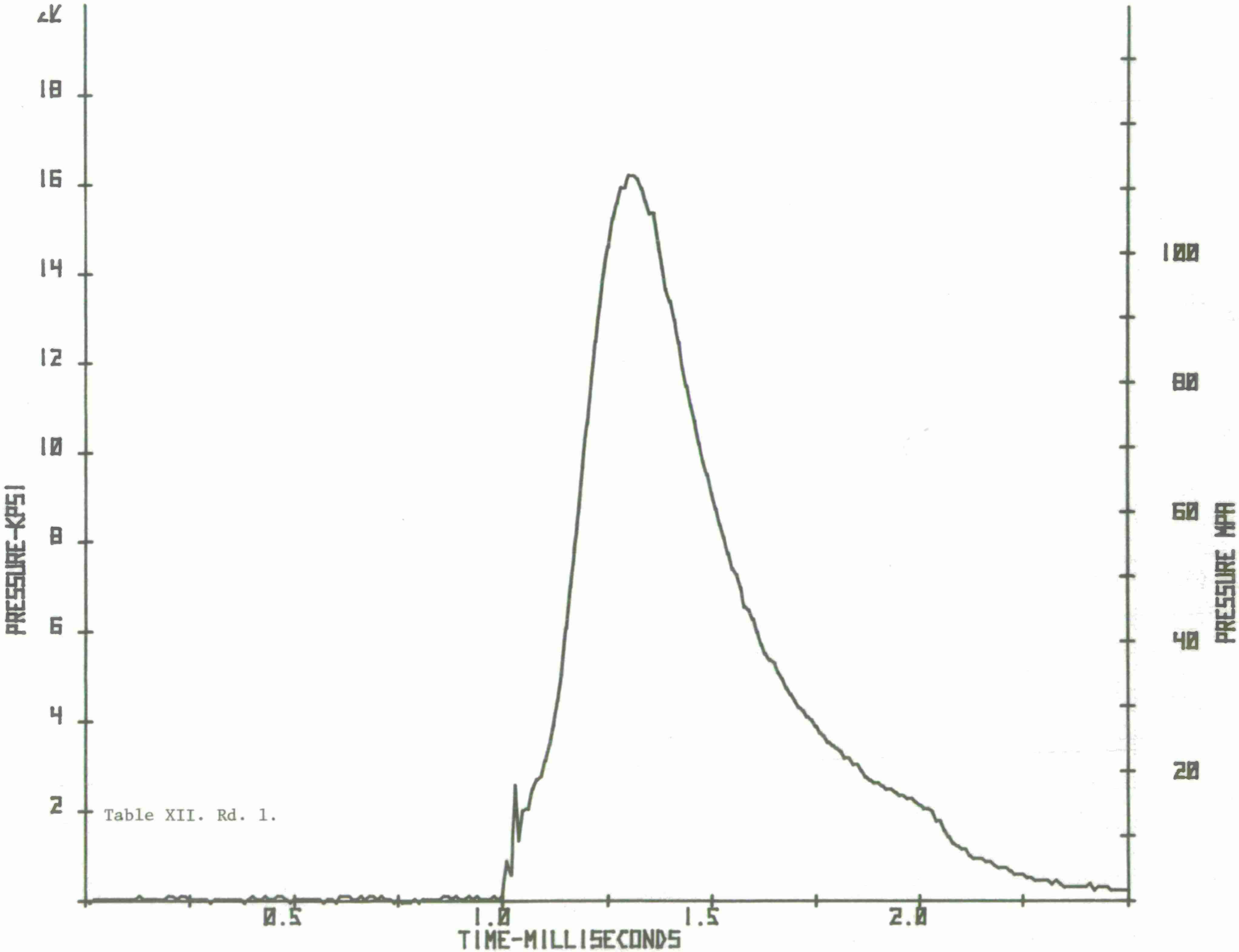
PRESSURE MPA
20
40
60
80
100
0.5
1.0
1.5
2.0
TIME-MILLISECONDS

Table XV. Rd. 6.

APPENDIX B

PRESSURE-TIME DATA FOR CONVENTIONAL PRIMER AMMUNITION. (SELECTED ROUNDS)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16
14
12
10
8
6
4
2
PRESSURE MPA
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60
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2.0
TIME-MILLISECONDS
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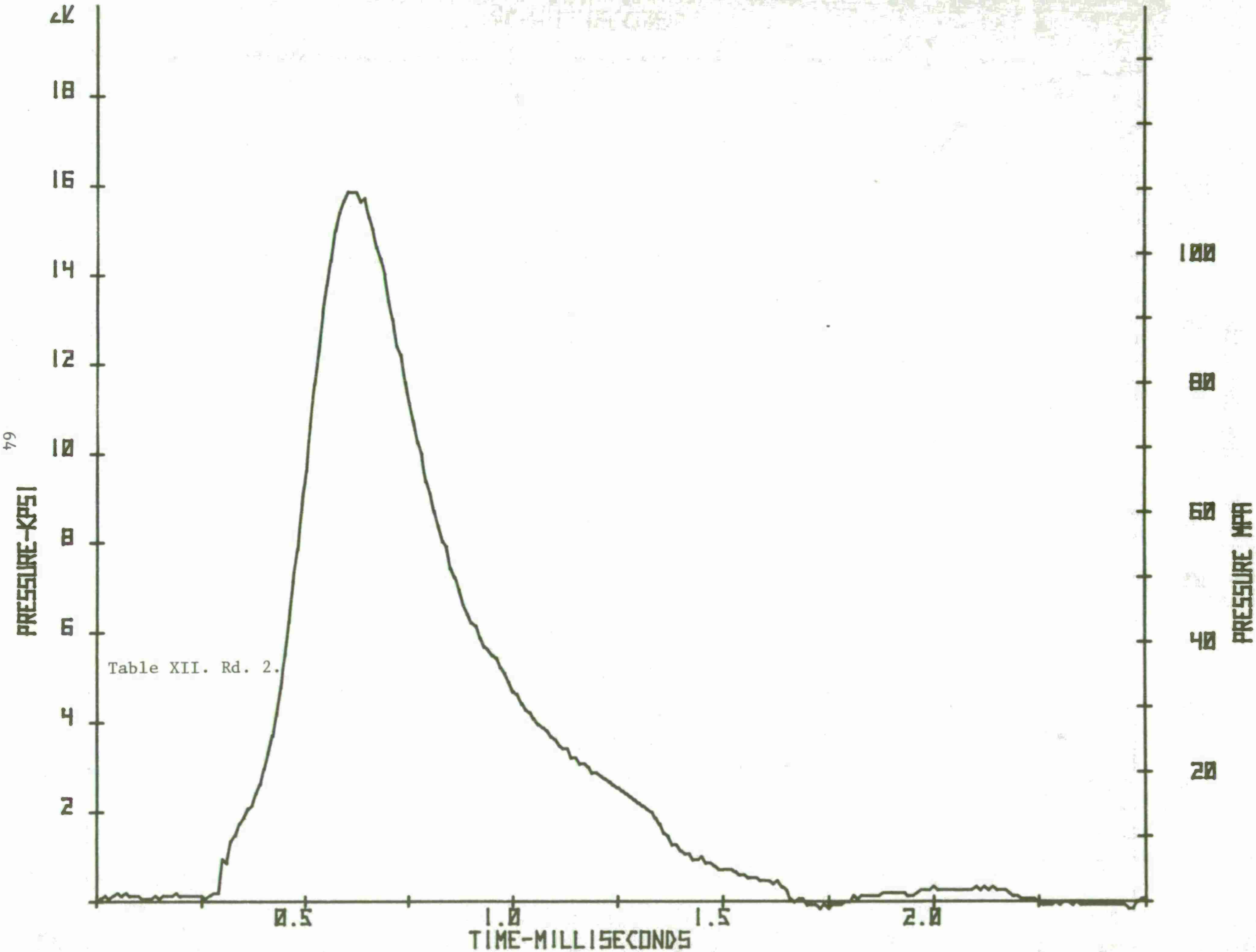

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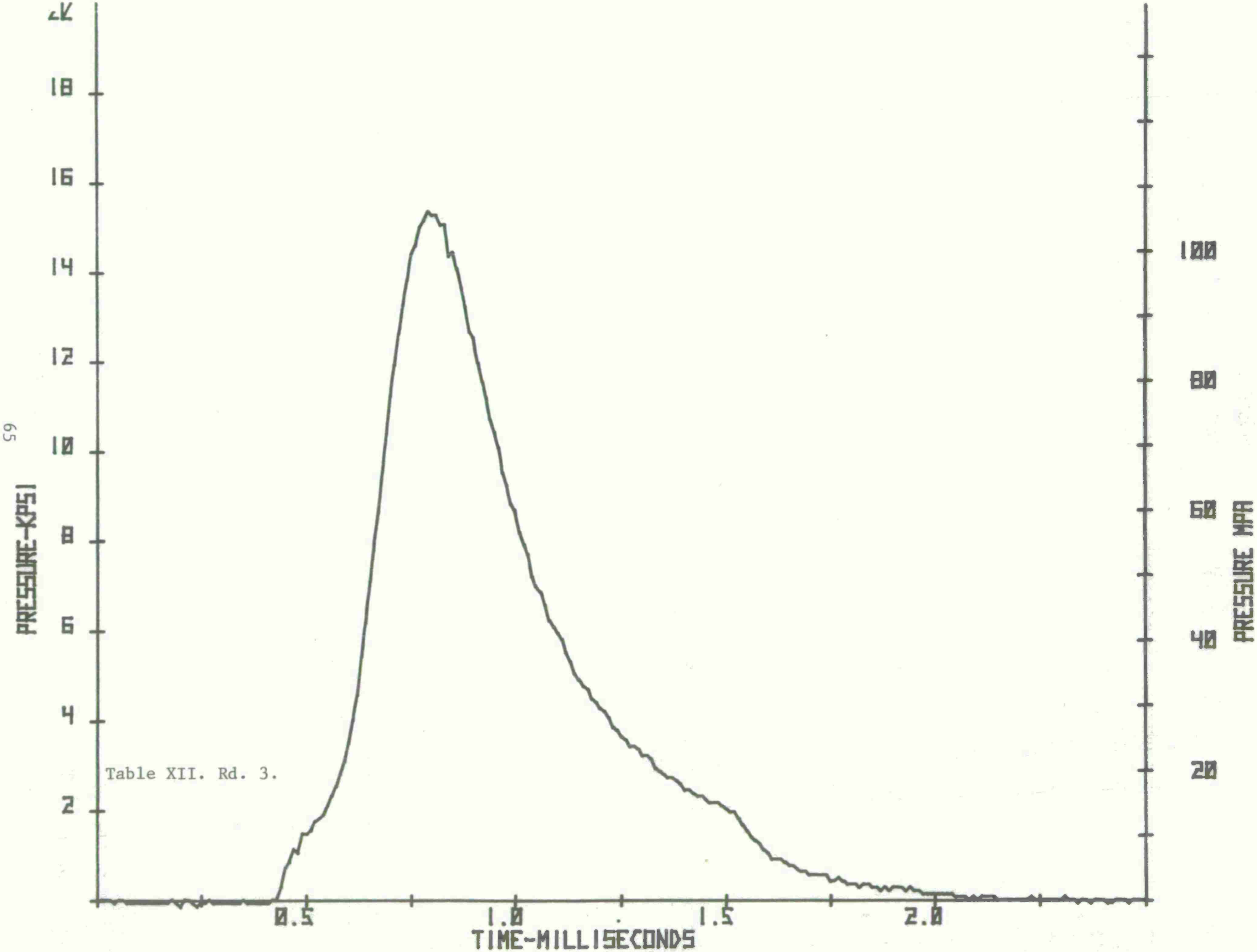
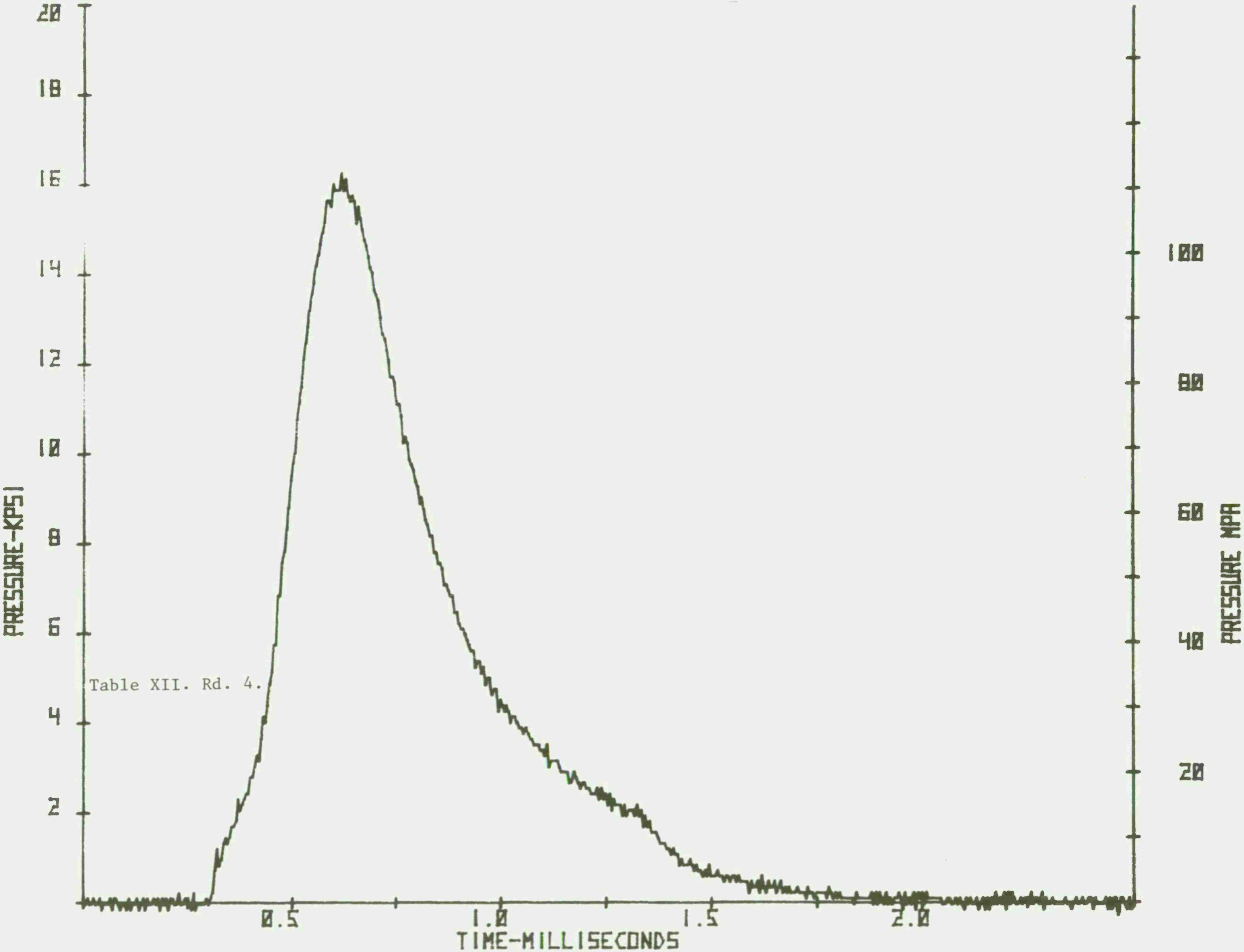


Table XII. Rd. 3.



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