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The Reduction of Airborne Lead in Indoor Firing Ranges by Using Modified Ammunition

Law Enforcement Equipment Technology

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

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FOREWORD

The Law Enforcement Standards Laboratory (LESL) of the National Bureau of Standards (NBS) furnishes technical support to the National Institute of Law Enforcement and Criminal Justice (NILECJ) program to strengthen law enforcement and criminal justice in the United States. LESL's function is to conduct research that will assist law enforcement and criminal justice agencies in the selection and procurement of quality equipment.

LESL is (1) subjecting existing equipment to laboratory testing and evaluation and (2) conducting research leading to the development of several series of documents, including national voluntary equipment standards, user guidelines, state-of-the-art surveys and other reports.

This document is a law enforcement equipment report developed by LESL under the sponsorship of NILECJ. Additional reports as well as other documents are being issued under the LESL program in the areas of protective equipment, communications equipment, security systems, weapons, emergency equipment, investigative aids, vehicles and clothing.

Technical comments and suggestions concerning the subject matter of this report are invited from all interested parties. Comments should be addressed to the Law Enforcement Standards Laboratory, National Bureau of Standards, Washington, D.C. 20234.

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CONTENTS

A Reduction of Airborne Lead in Indoor Firing Ranges by Using Modified Ammunition

Abstract

A study was conducted to evaluate the feasibility of decreasing or eliminating airborne lead contamination at firing ranges by modifying the ammunition fired. A 38 Special police revolver was used in the study and firings were conducted in a specially designed container which allowed trapping of particulate effluents from the weapon for subsequent analysis. Under the conditions of the experiment, conventional 38 Special ammunition yielded an average of 5,640 micrograms of lead per round at the position of the shooter. Under identical conditions, experimental ammunition, using jacketed soft-point projectiles and a special non-lead-containing primer composition, yielded an average of 13 micrograms of lead per round. The data indicate a decrease of the particulate lead produced per round by a factor greater than four hundred. The ballistic characteristics of the ammunition were also examined. The manufacture of no-lead primers which will reproduce the interior ballistics of conventionally-primed ammunition appears to be well within the state of the art.

Keywords: Airborne lead; ammunition; firing ranges; law enforcement; lead; lead poisoning.

1. INTRODUCTION

Excessive airborne lead levels at 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 exposure to lead in the workplace.[1,2,3] Instances of lead poisoning on semi-outdoor ranges have also been reported by range personnel. The extent of the problem can be judged by a recent instance[4] in which a newly completed police indoor range facility was forced to close due to excessive lead contamination.

In one approach toward a solution of the problem, a review of ventilation requirements in police ranges has been made.[5] The renovation of all existing police indoor range facilities to comply with stricter ventilation requirements would be extremely expensive, however, and has not yet been shown to be truly effective. It has been suggested that an alternative and possibly better solution might be to reduce the lead contamination at its source, the ammunition itself.[6] The Ballistic Research Laboratories (BRL) was asked by the Law Enforcement Standards Laboratory of the National Bureau of Standards to address this approach. A preliminary report of this and other work has been published.[7]

2. EXPERIMENTAL*

The investigation was performed at the indoor range facilities of the Propulsion Division of the Ballistic Research Laboratories. 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 38 Special Model 10 revolver with a four inch barrel. Ballistic data were obtained on a specially built test fixture and the ammunition used in the study was supplied to BRL's specifications by the Remington Arms Corporation, Bridgeport, Connecticut.

[1] Raised figures indicate literature references on page 22.

* Certain trade names and companies are identified in order to adequately describe the experimental work. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards or the Aberdeen Proving Ground.

The weapon was fired in an air sampling chamber which consisted of an aluminum box with a volume of 0.08 cubic meter (80 liters). The interior was provided with a machine rest for the handgun and a firing solenoid which was actuated by a sequence timer. The lid of the chamber was fitted with a 0.8-micrometer Millipore aerosol filter. A hole was provided in the front for the bullet to exit. A photograph of the chamber is shown in figure 1.

The bullet trap consisted of a 6 mm thick steel plate placed at a 45° angle and located approximately [illegible] meters from the firing chamber. The bullet trap was also fitted with an aerosol filter identical to that used at the gun position. This filter was located 30.5 cm from the expected point of impact.

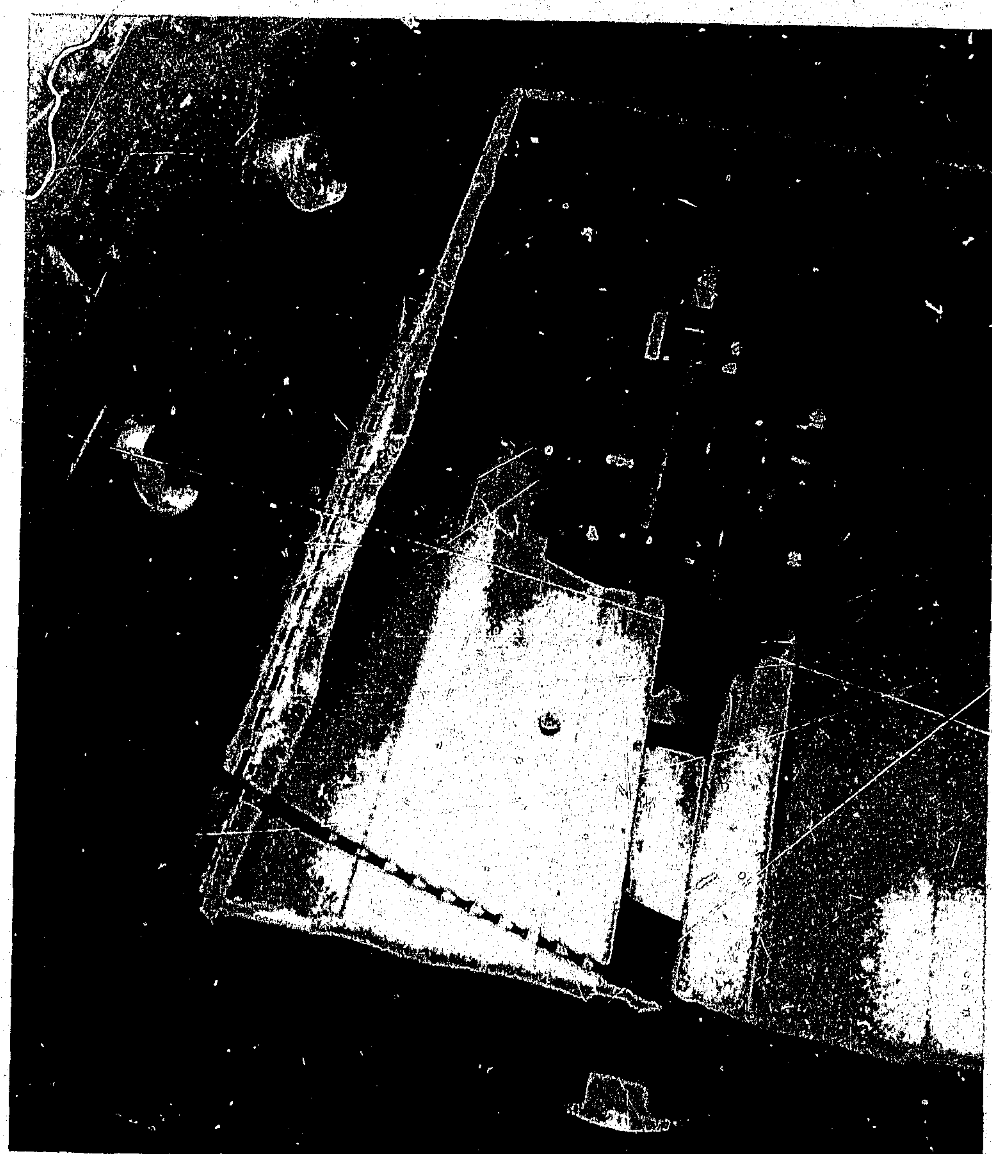

FIGURE 1. *Opened firing box showing revolver, firing solenoid, and sampling filter element.*

Uprange and downrange samples were collected using aerosol monitoring kits sold by the Millipore Corporation, Bedford, Massachusetts. The kits provide 0.8-micrometer filters in a disposable housing and the associated pumping equipment needed for sample collection. Samples were collected at pumping speeds of 10 liters per minute. The pumps were controlled by the sequence timer which also controlled the firing of the gun. Normally the pumps were started eight seconds before firing the gun and stopped two minutes after the gun was fired. A schematic diagram of the test setup is shown in figure 2.

In addition, uprange samples of the particulate effluent of the gun were collected on adhesive coated witness papers located inside the sampling chamber. The location of the witness papers and the gun are shown in figure 3. A cylindrical tube, ~~20 cm in~~ diameter, was slipped over the barrel and cylinder portions of the gun to position witness papers II and III. Sections of these papers and of the Millipore filters were removed and analyzed for particle size and shape with the scanning electron microscope.

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

Two areas of concern within the firing range are in the vicinity of the shooter (uprange) and in the target impact area (downrange). Reducing uprange contamination would involve reducing or eliminating the lead-containing components of 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 backstops for lead bullets or the elimination of lead from the projectiles altogether.

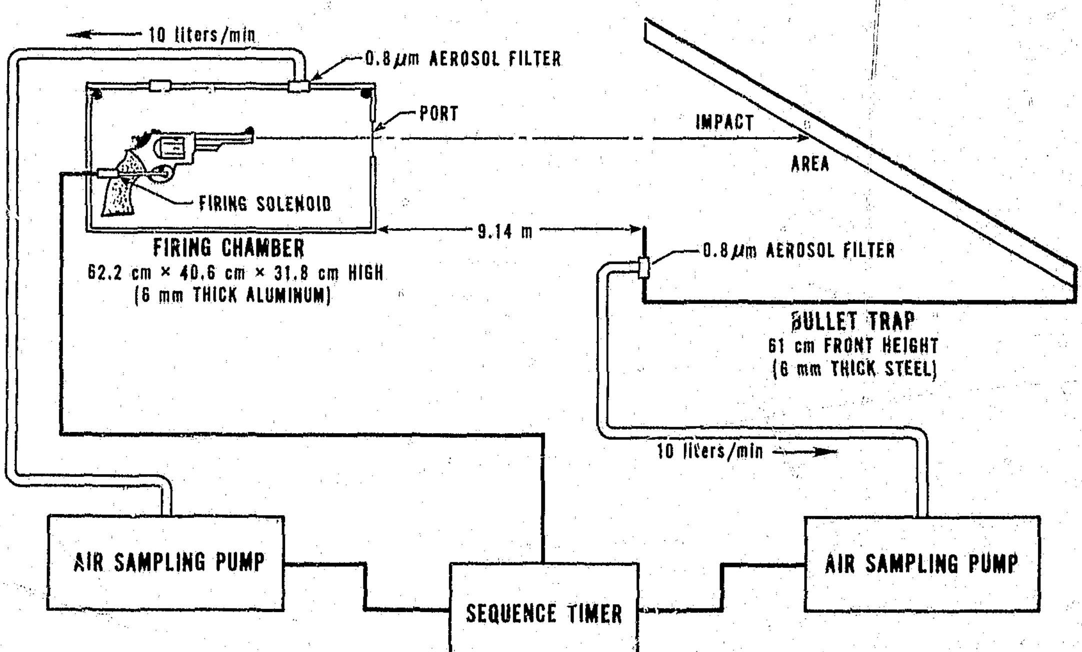

FIGURE 2. *Schematic diagram of air sampling system for obtaining uprange and downrange lead samples.*

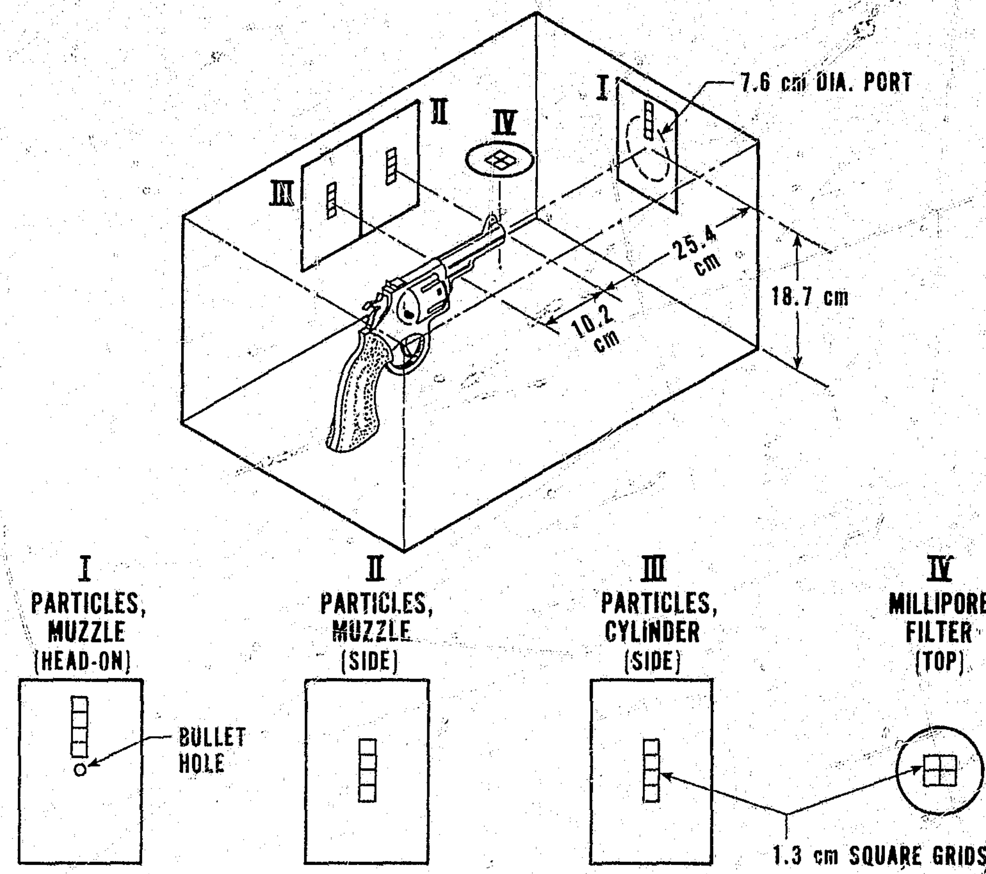

FIGURE 3. *Location of particle sampling areas*

Jacketed lead projectiles are commercially available. For the soft-point type, the base of the projectile as well as its sides are protected by a layer of copper-zinc alloy (86 to 91% Cu); the only exposed lead is that at the nose of the bullet. This type of projectile should prevent formation of lead particles due to the cutting action of the rifling, as well as prevent the formation of lead particles due to the hot gas wash at the base of the projectile. The copper fragments which may be formed would not be nearly as toxic as lead.

Commercial primer compounds for small arms ammunition are generally mixtures of lead styphnate and barium nitrate. Exact compositional data are not generally available from the manufacturers. Examination of a table of compositions of military primer mixes, however, provides a general understanding of the situation. These data are presented in table 1. None of these compositions would be suitable for producing a low- or no-lead primer. In the past, mercury fulminate had been widely used in many priming compositions. This compound, however, would not be a suitable substitute, since one would be replacing one toxic heavy metal with another.

During the early nineteen seventies, the U.S. Army experimented with some no-lead primer compositions as part of its Caseless Ammunition Program.[8] Several promising compositions were tested. Among these were compositions CP-27 (30% mannitol hexanitrate, 70% tetracene), CP-34 (30% diazodinitrophenol, 70% tetracene) and CP-35 (40%

TABLE 1. Military primer compositions

Ingredients	FA70	FA90	PA100	PA101	793	NOL60	NOL130
	Composition (percent by weight)						
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	—	—	—	—	—

diazodinitrophenol, 60% tetracene). Ultimately the Caseless Ammunition Program was terminated and the no-lead primer project stopped with it. The Remington Arms Corporation, however, who had originally developed those primers for the Army, had fired each of the mixes in conventional 30-06 Springfield rounds. In response to BRL's request for information, they provided the data[9] shown in table 2. The performance characteristics of the three no-lead primers were reasonably similar to the standard. Based on discussions with both Frankford Arsenal[10] 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 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.

*TABLE 2. Performance of no-lead primer compositions in the 30-06 Springfield**

Primer	Muzzle Velocity		Maximum Chamber Pressure	
	(m/ sec)	(ft/ sec)	(MPa)	(psi)
Standard	218	2685	356.3	51680
CP-27	814	2671	345.8	50160
CP-34	802	2632	336.5	48800
CP-35	819	2687	362.4	52560

* Data supplied by the Remington Arms Corp.

The apparatus used for interior ballistic evaluation of the ammunition is shown in figure 4. The fixture consists of a 14 cm (5.5 in) long test barrel chambered for 38 Special and fitted with a port, to which a Kistler 607 C4 pressure transducer is attached. A solenoid operated the firing pin assembly. In the firing position, the firing pin is retracted and the breech face is in contact with the cartridge head. The pressure transducer signal is fed into a charge amplifier and recorded on magnetic tape. Muzzle velocities are obtained from several independent chronographs using break-screen triggers located at various distances in front of the barrel.

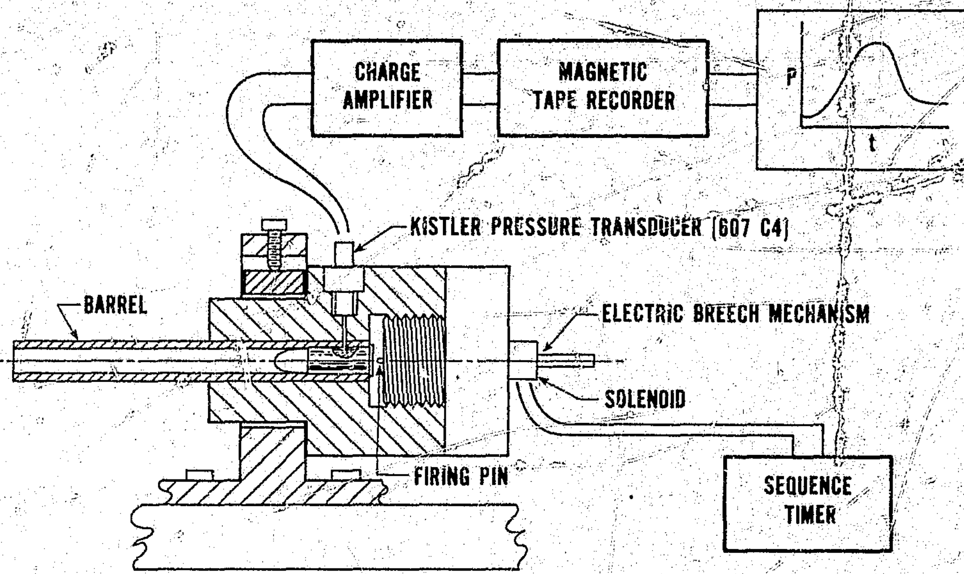

FIGURE 4. *Caliber 38 Mann barrel test fixture for obtaining pressure-time curves.*

The samples and the filter elements on which they collected were dissolved in a HNO_3 - $HClO_4$ solvent. These solutions were analyzed for lead using atomic absorption spectroscopy and for barium by x-ray fluorescence. Data are reported in micrograms of metal per sample.

The ammunition assembled for the study were four different loads:

a. 158 grain lead projectile, standard primer.
b. 158 grain jacketed soft-point projectile, standard primer.
c. 158 grain lead projectile, no-lead (CP-27) primer.
d. 185 grain jacketed soft-point projectile, no-lead (CP-27) primer.

The smokeless powder was the same in all four loads, namely, 0.23 grams (3.6 grains) of HPCl propellant; its chemical composition is:

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

All test rounds were hand-loaded by Remington Arms as part of the contract. Propellant and projectile weights were measured and judged consistent throughout.

3. RESULTS AND DISCUSSION

The use of the four basic loads was expected to provide information on both the relative contribution of primer and projectile to the overall contamination level and on the relative overall improvement possible by the use of the jacketed projectile and the no-lead primer. The sampling technique involved firing the revolver inside an eighty-liter box, and trapping the particulate matter from a twenty-liter air sample onto a filter element and then analyzing the filter element for lead and barium. The twenty-liter air sample size was arrived at empirically. This technique does not trap all the contaminants produced per round, but it did give a reasonably reproducible sample from round to round.

The discussion which follows is divided into five sections. The first concerns the determination of the range of particle sizes of lead given off at various locations about the revolver. The second discusses our measurements of the relative contribution of the primer mix and projectile to the airborne burden of lead particulates produced. The third section presents details of additional measurements on the no-lead primer ammunition and the fourth section discusses measurements of airborne lead downrange at the bullet trap. The discussion concludes with a comparison of the internal ballistic characteristics of the experimental no-lead primer ammunition and conventional ammunition.

3.1 Particle Size and Shape

The objective of this part of the effort was to determine the filter characteristics required to collect the airborne lead particles from the gun. Commercially available aerosol sampling kits use a filter element with an average pore size of 0.8 micrometer; such filters should trap particles down to 0.3 micrometer in diameter. A question that arose was: are the particles which are produced at the gun smaller than those which can be trapped by this filter? Particles deposited in areas in front of and beside the gun as well as those contained in the aerosol filter were examined by scanning electron microscopy (SEM). The range of particle sizes was determined from photographs taken at known magnifications. For this purpose the instrument is calibrated using standard grids and also by measuring standard particles of known size. Particle chemical identification was made using the x-ray output of the SEM.

Figures 5 and 6 are groupings of photomicrographs of particles trapped in front of the gun (see area I, fig. 3). The sample in figure 5 was taken from an area approximately 2 cm from the bullet exit hole. A large particle, approximately 30 μm in diameter, is visible and its shape, as well as many of the others', is highly irregular. Photographs 5B, C and D show these particles at increasing magnification. The smaller particle sizes are more spherical in shape. Particles as small as 0.1 μm are readily distinguishable in figure 5D.

Figure 6 is a grouping of photomicrographs of particles deposited approximately 4 cm from the bullet exit hole (area I, fig. 3). Photograph 6A shows a cluster of large irregular particles along with a scattered multitude of smaller fragments. Photographs 6B, C and D provide enlargements of a portion of this cluster. 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 particles, forward of the barrel, ranged from 0.1 μm to 100 μm. The average particle size decreases as the radial distance from the bullet hole increases. Approximately 5 cm from the bullet exist hole the average particle size falls below the one micrometer size.

There appeared to be little difference in the character of the residues from areas II and III (fig. 3). Figure 7 is a set of photomicrographs of particles trapped in the area to be side of the muzzle (area II). 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 sizes, those from 10 to 50 micrometers in diameter and those from 0.1 to 0.5 micrometer. Print 8A shows the larger, irregularly shaped particles dispersed over the sample. Prints 8C and 8D show the smaller parti-

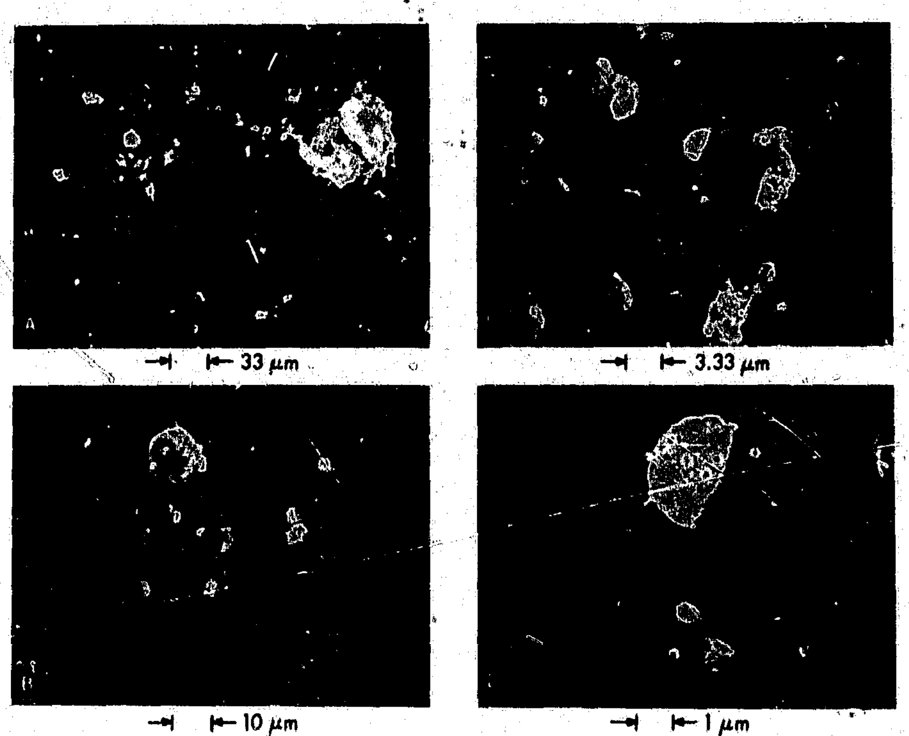

FIGURE 5. *Scanning electron micrographs of particulate matter trapped in front of the gun.* Area approximately 4 cm from bullet exit hole.

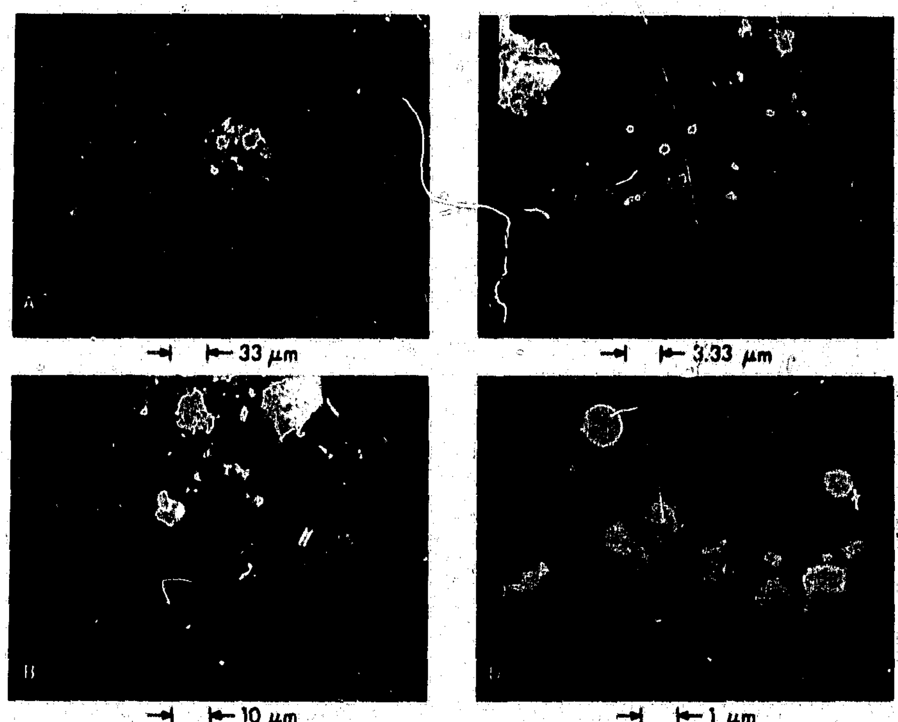

FIGURE 6. *Scanning electron micrographs of particulate matter trapped in front of the gun.* Area approximately 4 cm from bullet exit hole.

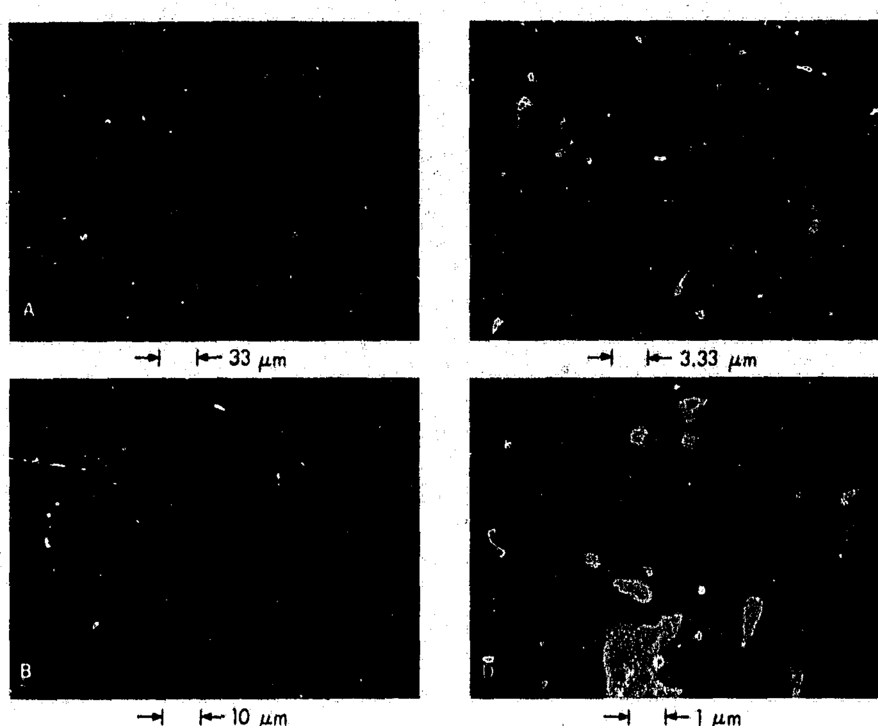

FIGURE 7. *Scanning electron micrographs of particulate matter trapped to the side of the gun muzzle.*

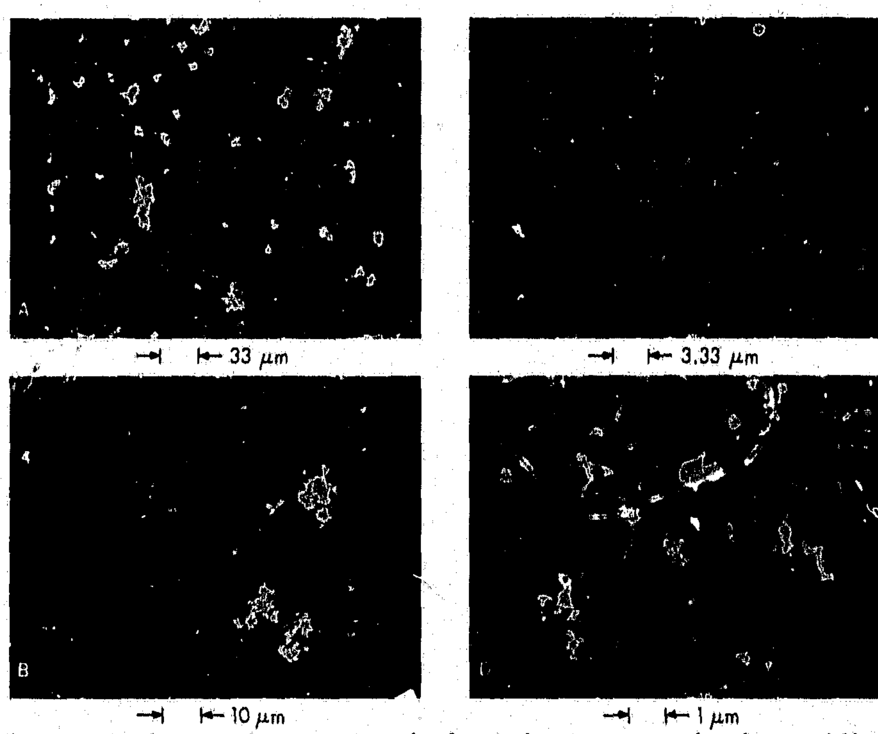

FIGURE 8. *Scanning electron micrographs of particulate matter trapped on the aerosol filter.*

cles. 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.

Illustrations of the particle identification method are given in figures 9 and 10. These figures are scanning electron micrographs 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 are composed of positive signals for lead as obtained by the x-ray microanalysis feature of the SEM. The density of light spots is qualitatively indicative of the amount of lead present. The samples in figure 9 were taken from in front of the muzzle. The globular particle is identified only as lead-bearing by the matching shape in the lead map. Similarly, the large particles in 9B are identified as lead containing species in 9D. It may be that these larger particles have much smaller lead particles deposited on them; it is indeed possible that the larger particles are bits of unburned propellant. Figure 10 similarly shows scanning electron micrographs (10A and B) and their matching lead maps (10C and D) of samples trapped on the 0.8-micrometer filter. Prints 10A and C show a section containing both a large fragment and many smaller ones; prints 10B and D show an enlarged view of the smaller fragments. Note especially that in both x-ray scans the amount of small particulate lead (light spots) is greatly increased over what was found on the sample taken from in front of the muzzle.

Altogether, the particle size distribution of airborne lead-containing residues from firing the gun was found to go from 0.1 micrometer to 100 micrometers. The 0.8-micrometer Millipore filter appeared to be capable of trapping the particles in both the major size ranges observed. The filter was actually capable of retaining particles in the 0.1 micrometer range and possibly smaller ones as well.

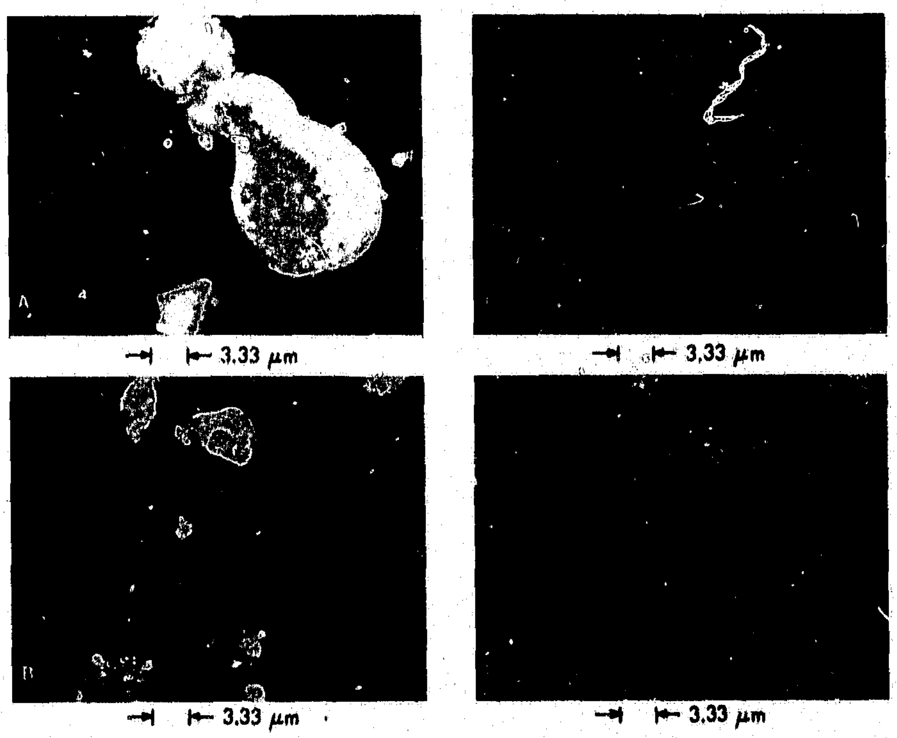

FIGURE 9. *Scanning electron micrographs and matching lead maps from samples trapped in front of the gun muzzle.*

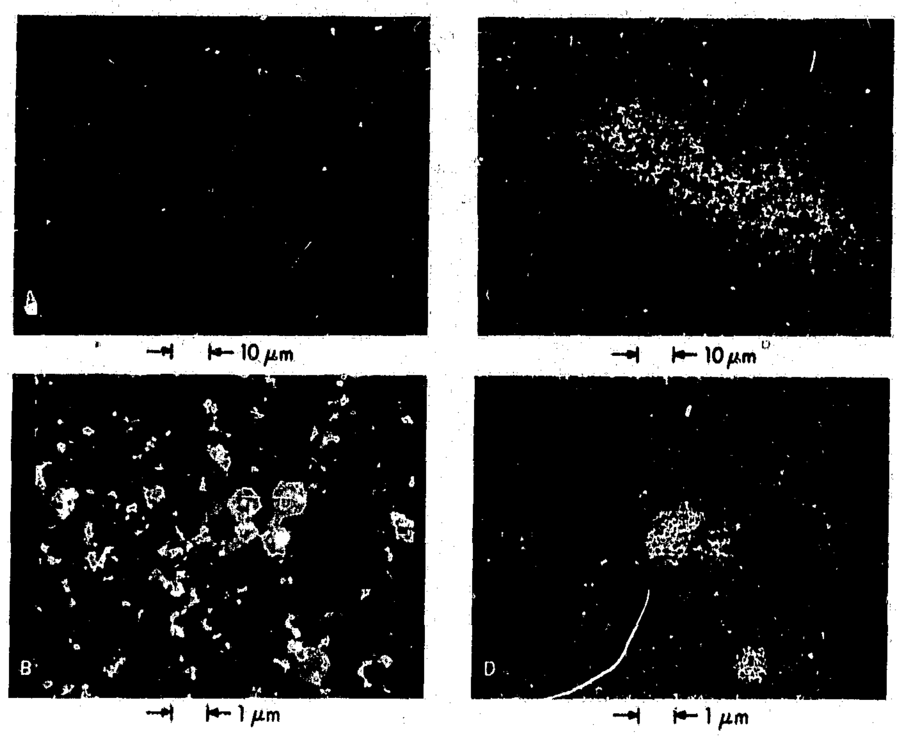

FIGURE 10. *Scanning electron micrographs and matching lead maps from samples trapped on the 0.8 µm filter.*

From these data it appeared that the 0.8 micrometer aerosol filter would be quite adequate for the trapping portion of the experiment.

3.2 Relative Lead Contamination from Primer and Projectile

Firings were carried out using both the lead projectile, conventional primer and the jacketed projectile, conventional primer 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 3 and 4 summarize the data obtained.

A comparison of tables 3 and 4 indicates that the contribution of the projectile predominates over that from all other sources. In fact, the lead levels are fourteen times higher for the lead projectile. The barium levels remain about the same in both cases. This is as expected since barium is a constituent of the primer composition.

It is interesting to note that, under the conditions of the experiment, an average of 0.2 milligram of barium and 5.6 milligrams of lead were trapped per round. Since the experimental procedure did not involve filtering all of the air within the sample chamber, it is clear that even larger amounts of heavy metal contaminants were actually produced. Figure 11 gives a good qualitative indication 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 fig. 11).

TABLE 3. Chemical analyses of uprange samples trapped from lead projectile, conventional primer 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. 5640

* No barium analyses were performed for these samples.

TABLE 4. Chemical analyses of uprange samples trapped from jacketed projectile, conventional primer ammunition

Sample No.	Barium Level (μg/ round)	Lead Level (μg/ round)
1	220	441
2	220	415
3	210	345
4	220	407
	Avg. 218	Avg. 402

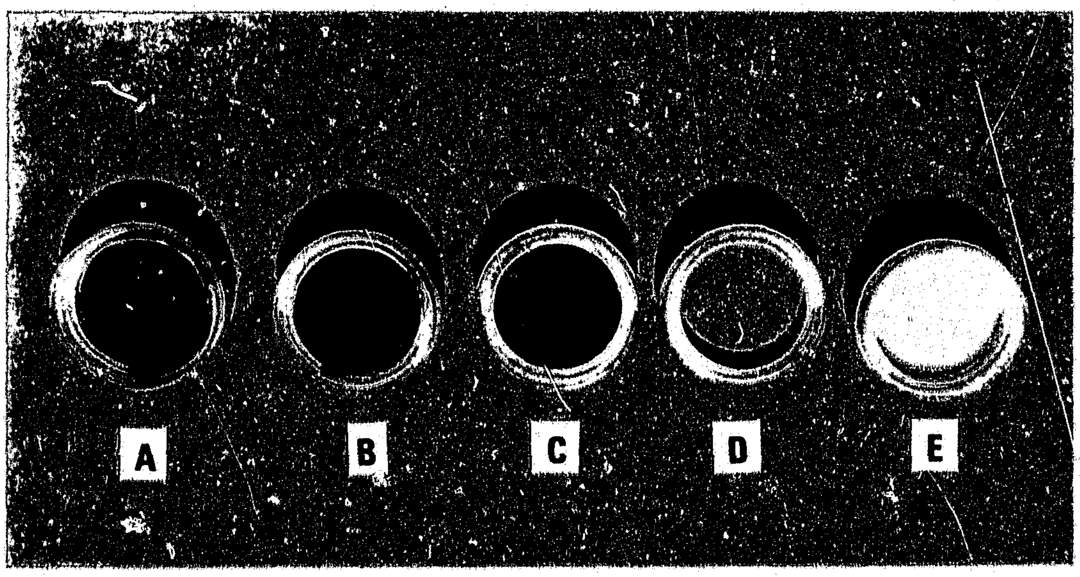

FIGURE 11. *Samples trapped from individual gun firings on 0.8 μm filters.* (A) Lead projectile, conventional primer, (B) Jacketed projectile, conventional primer, (C) Lead projectile, CP-27 primer, (D) Jacketed projectile, CP-27 primer, (E) Blank filter.

3.3 Experimental No-Lead Primer Ammunition

Firing tests were carried out using both lead projectile, no-lead primer and jacketed projectile, no-lead primer 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 show the elimination of essentially all airborne lead.

The results from the first set of firings appear in table 5. The lead level averages 3.38 milligrams per round fired. This value is low compared with the value previously obtained (5.64 mg/round) even if an approximate correction for the primer contribution (0.4 mg/round; table 4) is substracted. It is conceivable that, in the case of the lead projectile-conventional primer ammunition, the larger particulates provide agglomeration sites for the much smaller particles coming from the primer, thus enhancing the trapping efficiency.

TABLE 5. Chemical analyses of uprange samples trapped from lead projectile, CP-27 (no-lead) primer 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

The results from the second set of firings appear in table 6. These data were perplexing at first. Negligible amounts of lead and barium had been expected, yet significant amounts were obtained. This was attributed to cross-contamination from previously-fired rounds. Compare, for example, the barium levels shown in table 5 with those shown in table 6; 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, taking care to thoroughly clean the revolver and the firing chamber. The results are shown in table 7. The barium levels fell to essentially baseline levels as a result of the cleaning procedure. The less-than-10 microgram designation means that some barium was observed, but under the conditions of our experiment, the x-ray fluorescence technique could not provide precise numerical data in this range. The values for lead, however, were again higher than expected. Moreover,

TABLE 6. Chemical analyses of uprange samples trapped from jacketed projectile, CP-27 (no-lead) primer 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

TABLE 7. Chemical analyses of uprange samples trapped from jacketed projectile, CP-27 (no-lead) primer ammunition Series 2

Sample No.	Barium Level (μg/ round)	Lead Level (μg/ round)
1	<10	[illegible]40
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

they showed the same decreasing trend with number of rounds fired as was evident in table 6. It was postulated, therefore, that the lead was coming from the barrel of the weapon and that the copper jacketed projectiles tend to clean the lead contaminants from the bore. Prior to repeating the measurements again, twenty rounds of copper jacketed projectile, no-lead primer ammunition were fired in the weapon; the weapon was then cleaned using normal procedures. The firing box was thoroughly cleaned as before and the experiment repeated. The results are given in table 8.

The data in table 8 show a significant reduction in the amount of trapped lead. Furthermore, the data show only normal scatter, without the decreasing trend noted previously. The background level was also measured, and averaged 5 micrograms; therefore, the net amount of lead trapped per shot was 18 micrograms.

To see if further improvement could be obtained, the noses of several of the jacketed projectiles were machined to 1.5 mm below the lip of the jacket and the recess filled with epoxy. Figure 12 shows both the jacketed soft-point projectile and the modified bullet. These rounds were fired immediately after the series in table 8; the results are given in table 9.

TABLE 8. Chemical analyses of uprange samples trapped from jacketed projectile, CP-27 (no-lead) primer 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

* Outlying value not included in the average.

TABLE 9. Chemical analyses of uprange samples trapped from jacketed projectile, CP-27 (no-lead) primer 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

* Outlying value not included in the average.

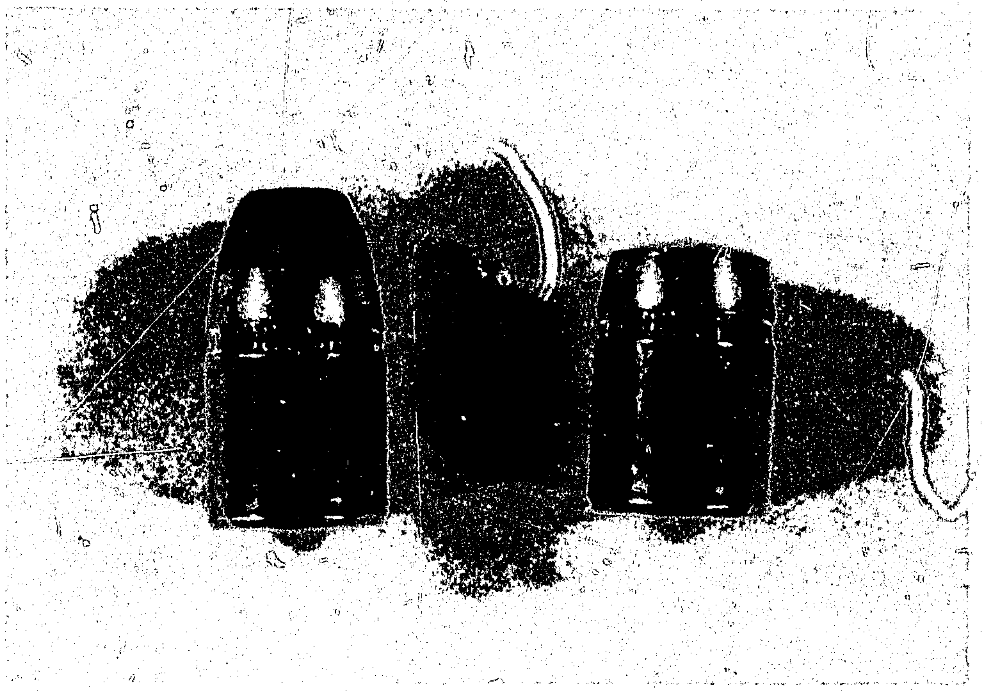

FIGURE 12. *Jacketed soft-point projectile and modified projectile with epoxy-filled nose.*

The data in tables 8 and 9 are essentially in agreement; the net average value for table 9 is 14 micrograms per round when corrected for background.

In a final series of experiments the barrel and cylinder of the weapon were cleaned using six normal nitric acid; no lead fouling was expected to survive the treatment, and indeed, the washings gave positive tests for lead. After cleaning and oiling the weapon and cleaning the sampling chamber, a series of rounds was fired using the standard jacketed projectiles. The results obtained are given in table 10.

TABLE 10. Chemical analyses of uprange samples trapped from jacketed projectile, CP-27 (no-lead) primer ammunition

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

The average background lead level observed during this series was, again, five micrograms. The corrected average is therefore, 13 micrograms per round. Obviously 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 3, which contains the results of firing conventional 38 Special ammunition, the data in table 10 are quite satisfying. On the average, the experiment resulted in a reduction in trapped lead per round by a factor greater than four hundred. On a practical level, under similar conditions, one would have to fire 434 rounds of the low-lead ammunition to produce the amount of lead contamination generated by a single conventional round.

A plausible explanation for the persistence of a low level of lead can be offered. It seems reasonable to assume that the lead is no longer coming from the ammunition but from the surroundings. Background 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 muzzle blast stirred up sufficient lead dust in the vicinity of the sampling chamber to account for the lead levels found in the "clean" firings. And, since BRL's indoor ranges have been in use for many years, lead dust contamination is probably present. It would be interesting to repeat some of the experiments in a completely clean environment.

3.4 Airborne Lead Downrange

The test fixture used to obtain downrange samples has been described earlier. Figure 13 is a photograph of the impact plate, the particle filter and the sampling pump. The projectile, on impacting the steel plate, is expected to produce fragments in a highly irregular fashion. A sampling of downrange air, taken simultaneously with the uprange samples, is shown in table 11. The data are highly scattered, as expected. The amount of lead trapped varies from 61 to 911 micrograms per round and it happens that both the highest and lowest lead levels observed occurred with jacketed bullets. Since no systematic effects were observed, it did not appear profitable to pursue the downrange experiments further.

The question has been raised concerning the possibility that downrange lead particulates could have influenced the uprange values. It seems reasonable to assume that they contributed to the overall lead levels within the range, i.e., the background. However, the distance between the gun box and the impact area was nine meters, and chances are that most of the larger particles would settle out. The diffusion of the smaller particles should result in their dilution to insignificant (background) levels by the time they reached the uprange position.

A comparison of the measured uprange and downrange lead levels indicates that there may be twelve times as much airborne lead produced uprange as downrange. The comparison is admittedly crude, since little attention was given to downrange experiments other than to establish the order of magnitude of the airborne lead; the air sampling arrangement was different as well. However, these measurements do support the findings of earlier measurements[11] made at the National Bureau of Standards. The downrange contamination, in any case, may not be as much 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 target backstops might be the best solution.

FIGURE 13. *Downrange sampling station showing impact area, 0.8 μm filter and sampling pump.*

TABLE 11. Chemical analyses of downrange samples

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

3.5 Internal Ballistics of Experimental Ammunition

The ballistic characteristics of all four types of ammunition were tested in the Mann barrel fixture shown schematically in figure 4. Figure 14 is a photograph of the setup; it clearly 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, and are tabulated in tables 12 through 15.

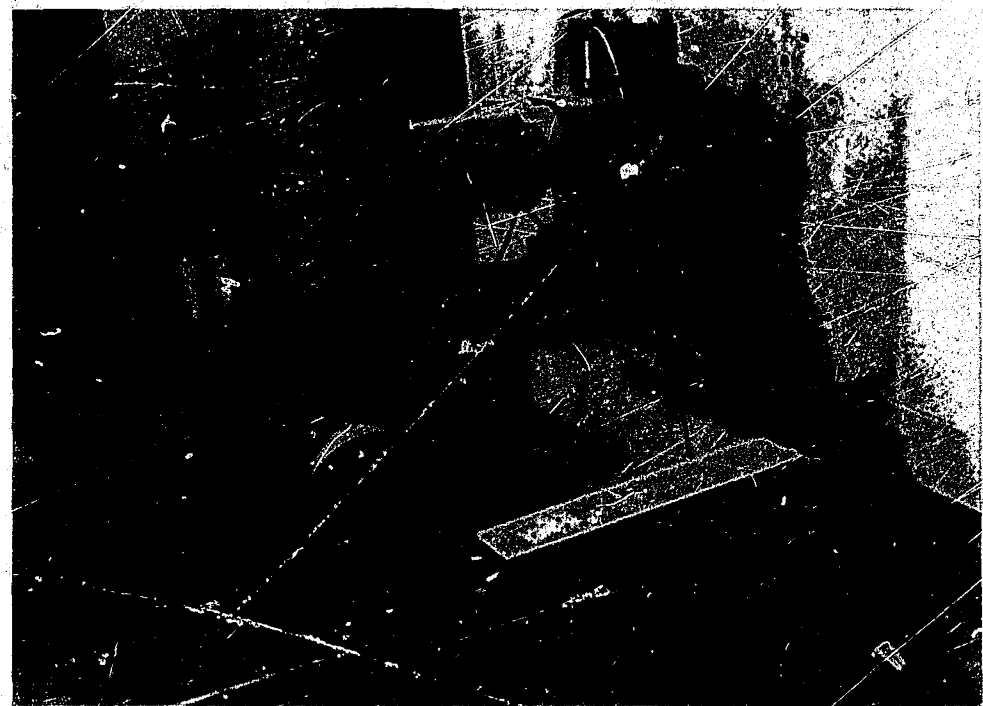

FIGURE 14. *Mann barrel assembly used in determining internal ballistics: Barrel, electric breech unit, pressure transducer and charge amplifier.*

TABLE 12. Muzzle velocities and maximum pressures of conventional primer, lead projectile ammunition

Round No.	ΔT_{ig} (ms)	Muzzle Velocity (m/s)	Muzzle Velocity (ft/s)	Maximum Chamber Pressure (MPa)	Maximum Chamber Pressure (psi)
1	0.081	270.0	886	111.9	16230
2	.128	271.3	890	109.4	15870
3	.128	266.7	875	106.0	15370
4	.081	269.7	885	112.2	16270
5	.163	264.6	868	103.5	15010
6	.140	268.2	880	108.3	15710
7	.145	267.0	876	107.3	15560
8	.093	268.2	880	106.2	15400
9	.058	270.4	887	111.3	16140
10	.151	267.6	878	104.6	15170
Avg.	0.117	268.4	880	108.1	15670
Std. Dev.	.036	2.0	7	3.1	450

These data show that the best internal ballistics were obtained using the conventional primer, lead projectile ammunition. The average velocity for these rounds was 268.4 meters per second, with a low standard deviation (2.0 m/ s). When the jacketed soft-point projectiles were substituted for the lead bullets, the muzzle velocity dropped by 32 meters per second and

TABLE 13. Muzzle velocities and maximum pressures of conventional primer, jacketed projectile ammunition

		Muzzle Velocity		Maximum Chamber Pressure	
Round No.	ΔT_{ig} (ms)	(m/ s)	(ft/ s)	(MPa)	(psi)
1	0.093	244.1	801	106.7	15480
2	.105	231.3	759	106.6	15460
3	.093	233.4	766	118.9	17240
4	.140	244.0	801	109.9	15940
5	.093	227.7	747	112.4	16300
Avg.	0.105	232.1	775	110.9	16080
Std. Dev.	.020	7.5	25	5.1	730

TABLE 14. Muzzle velocities and maximum pressures of no-lead (CP-27) primer, lead projectile ammunition

		Muzzle Velocity		Maximum Chamber Pressure	
Round No.	ΔT_{ig} (ms)	(m/ s)	(ft/ s)	(MPa)	(psi)
1	0.92	252.1	827	82.7	11990
2	.47	268.2	880	108.6	15750
3	.71	268.2	880	107.4	15580
4	1.01	274.9	902	118.6	17200
5	0.30	267.0	876	99.4	14420
6	1.08	241.4	792	73.5	10660
7	2.07	274.0	899	117.1	16980
8	0.33	264.6	868	97.9	14200
9	0.48	263.7	865	98.8	14330
Avg.	0.82	263.8	865	100.4	14570
Std. Dev.	.55	10.7	35	14.9	2160

TABLE 15. Muzzle velocities and maximum pressures of no-lead (CP-27) primer, jacketed projectile

		Muzzle Velocity		Maximum Chamber Pressure	
Round No.	ΔT_{ig} (ms)	(m/ sec)	(ft/ sec)	(MPa)	(psi)
1	0.55	218.2	716	105.3	15270
2	.37	214.0	702	105.2	15260
3	.30	232.6	763	110.0	15950
4	.13	242.6	796	121.9	17680
5	.51	233.5	766	103.6	15030
6	.70	232.6	763	109.4	15870
Avg.	0.43	228.9	751	109.2	15840
Std. Dev.	.20	10.7	35	6.7	970

the standard deviation of the muzzle velocity increased to 7.5 m/s. Although extra propellant could be used to increase the muzzle velocity, the greater inherent scatter from round to round would still be of concern. The poorest ballistics were obtained with the ammunition having the no-lead primer and the jacketed projectile (see table 14).

The data indicate that a significant portion of the nonreproducibility found can be attributed to the no-lead primer and its effect on the ignition behavior of the propellant charge. Tables 12 through 15 give the ignition delay time, ΔT_{ig}, for each of the rounds fired. This time was arrived at by extrapolating the rising portion of the pressure-time curve back to the baseline and then measuring the time interval between this point and the initial pressure rise. Figures 15 and 16 are, respectively, typical traces for the conventional primer and no-lead primer ammunition.

The ammunition with the CP-27 primer consistently showed not only longer ignition delays but a far larger variation in these values. The principal probable causes for this are the reduced sensitivity of the priming mixture and the absence of hot particulate matter in its decomposition products. Reduced sensitivity means that the primer must be struck with greater force in order to function consistently.

Compare the ignition delay data in tables 14 and 15. A large number of misfires occurred while taking the data in table 14. In order to avoid this problem, the voltage on the firing solenoid was increased for the series shown in table 15. With additional force applied to the primer cup, the duration and variability of the ignition delays both decreased.

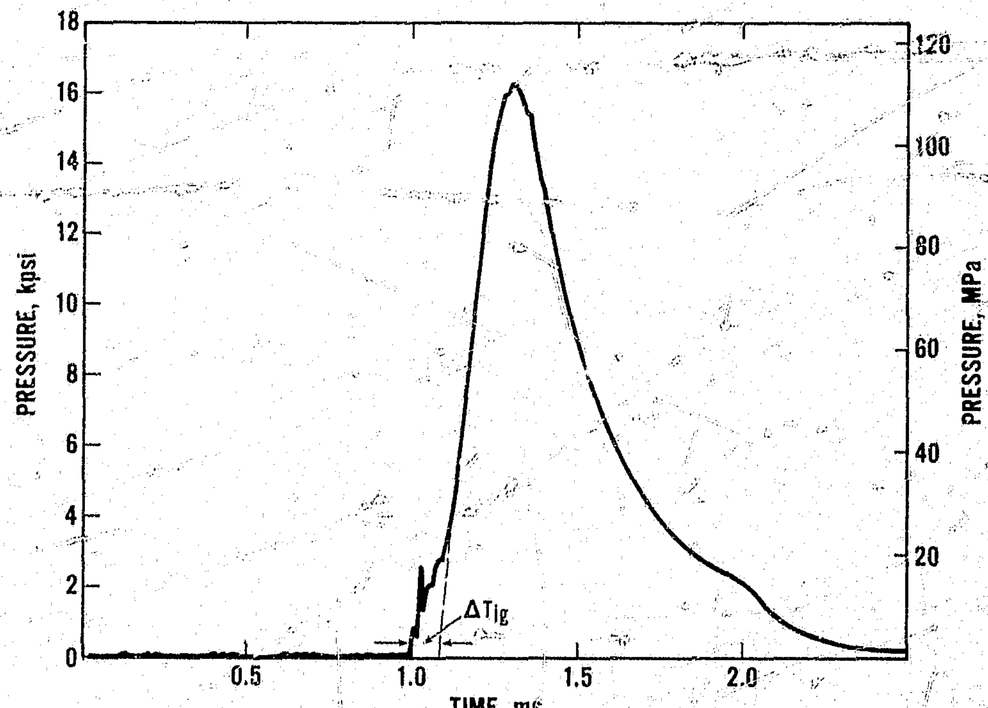

FIGURE 15. *Typical pressure-time record for conventional 38 Special ammunition.* Ignition delay time is indicated.

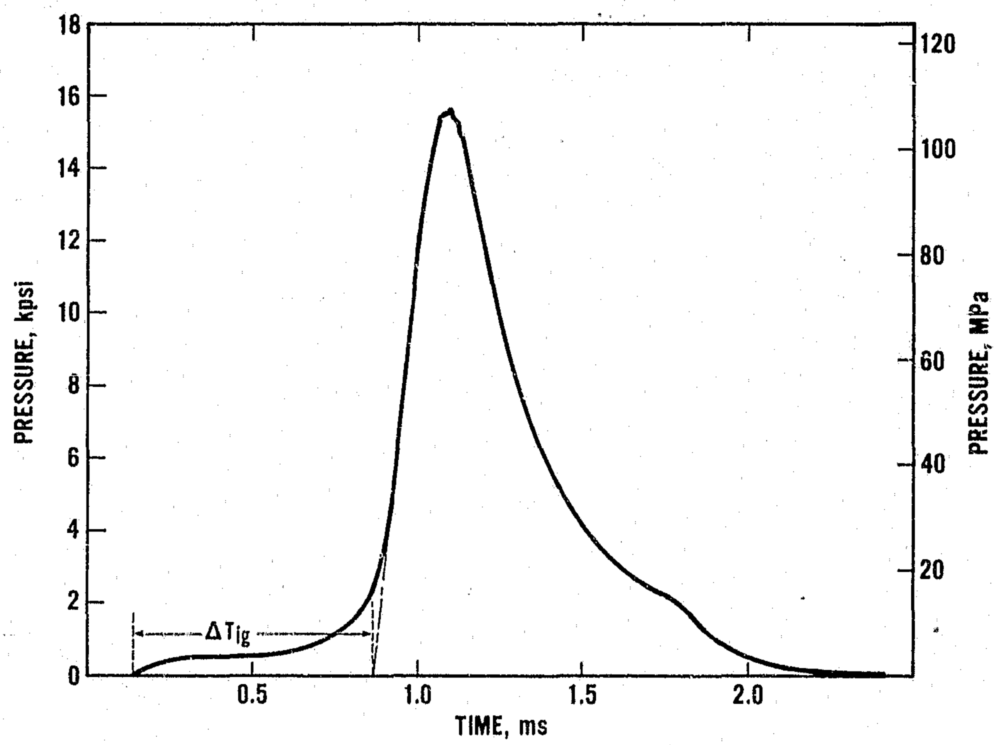

FIGURE 16. *Typical pressure-time record for 38 Special ammunition using CP-27 (no lead) primer.* Ignition delay time is indicated.

4. SUMMARY AND CONCLUSIONS

The concept of substantially reducing uprange lead levels by the use of specially designed ammunition has been validated. In this study, a 430-fold reduction in the amount of airborne lead produced uprange by discharging a 38 Special revolver was realized by the use of a no-lead primer composition (mannitol hexanitrate-tetracene) and a commercially available jacketed soft-point projectile. The use of ammunition loaded with semi-jacketed lead bullets, which are commercially available in high quality, should reduce airborne lead produced at the position of the shooter by a factor of at least 10 and possibly as much as 15.

The ballistic characteristics of the experimental ammunition were examined and compared with conventional 38 Special rounds. The ballistic characteristics of the no-lead primer ammunition are promising, but are not equal to those of conventional rounds.

In order to realize the full potential of this means of achieving reduced lead levels in indoor firing range we recommend the development of an improved primer composition. The objectives are clear; the sensitivity of the mix must be increased and the hot combustion products must include nontoxic particulates. Those knowledgeable in this field indicate that this is feasible. In the interim, we recommend that firearms training rangemasters use ammunition loaded with full base semi-jacketed bullets and conventional primers.

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