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REPORT R-1936

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M16 RIFLE GAS TUBE FOULING - COMPOSITION, PROPERTIES, AND MEANS OF ELIMINATION

by

LUDWIG STIEFEL
and
BRUCE W. BRODMAN

August 1969

DEPARTMENT OF THE ARMY
FRANKFORD ARSENAL
Philadelphia, Pa. 19137

DISPOSITION INSTRUCTIONS

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AMCMS Code 4810.16.0229.1.03

Pitman-Dunn Research Laboratories
FRANKFORD ARSENAL
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ABSTRACT

Electron microprobe and x-ray diffraction techniques were used to characterize and quantitatively determine the composition of the fouling residue found in the gas tube of the M16A1 rifle. It was found that the residue was composed of a continuous phase of calcium carbonate in which particles of gilding metal and certain metallic primer combustion products were embedded. Organic material was not present in the residue to any significant degree.

Results of atomic absorption analysis of the inorganic constituents of ten propellant lots were correlated with their known fouling characteristics. Those with high $CaCO_3$ content were found to produce gas tube clogging. No relationship was found to exist either between the shape of the pressure-time curves of the ammunition or the deterrent content of the propellants and gas tube fouling. Fouling tests, run with special ammunition to compare ball propellants with high and low calcium carbonate content, confirmed these results. It was shown that when the $CaCO_3$ content is sufficiently low, no significant deposits form in the gas tube or in the barrel.

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INTRODUCTION

During the course of rifle endurance tests, conducted by one of the manufacturers of the M16A1 rifle, a lot of ammunition - RA5317, containing WC 846 propellant - seemed to cause excessive malfunctions while another lot - RA5244, containing WC 846 propellant - produced no such problems.[1]* The source of the excessive malfunctions with lot RA5317 was thought to be constriction of the gas tube due to the presence of fouling deposits. Frankford Arsenal thereupon conducted the following investigations:

1. Establishment of the specific fouling characteristics of three ammunition lots cited by the rifle manufacturer.[1]

2. Evaluation of the effects of restricting the gas tubes.[2]

3. Determination of the degree of residue buildup in the gas tube in terms of different cartridge lots and propellant types.[3]

The most significant findings of these investigations follow.

Deposits were formed in the gas tube of the M16A1 rifle during 6000-round endurance tests. With ball propellant, these deposits collected at the gas tube inlet and rearward for about 1-1/2 to 3 inches. Residues from IMR propellants spread over a greater area, farther down the tube. An ammunition lot loaded with one particular lot of WC 846 propellant (viz., lot 1020) consistently deposited sufficient fouling in the gas tube after firing 4500 to 6500 rounds to prevent proper functioning of the weapon.

The quantity of fouling residue deposited with ammunition containing another WC 846 propellant (viz., lot 873) and with ammunition containing IMR propellants was not sufficient to adversely affect the functioning of the M16A1 rifles.

Constriction of the gas tube, either by artificial means or by actual fouling deposits, results in reduced cyclic rates and, if severe enough, can cause complete weapon stoppage. Figure 1 is a schematic of the M16 rifle showing the location of the gas port and gas tube. When

*See REFERENCES

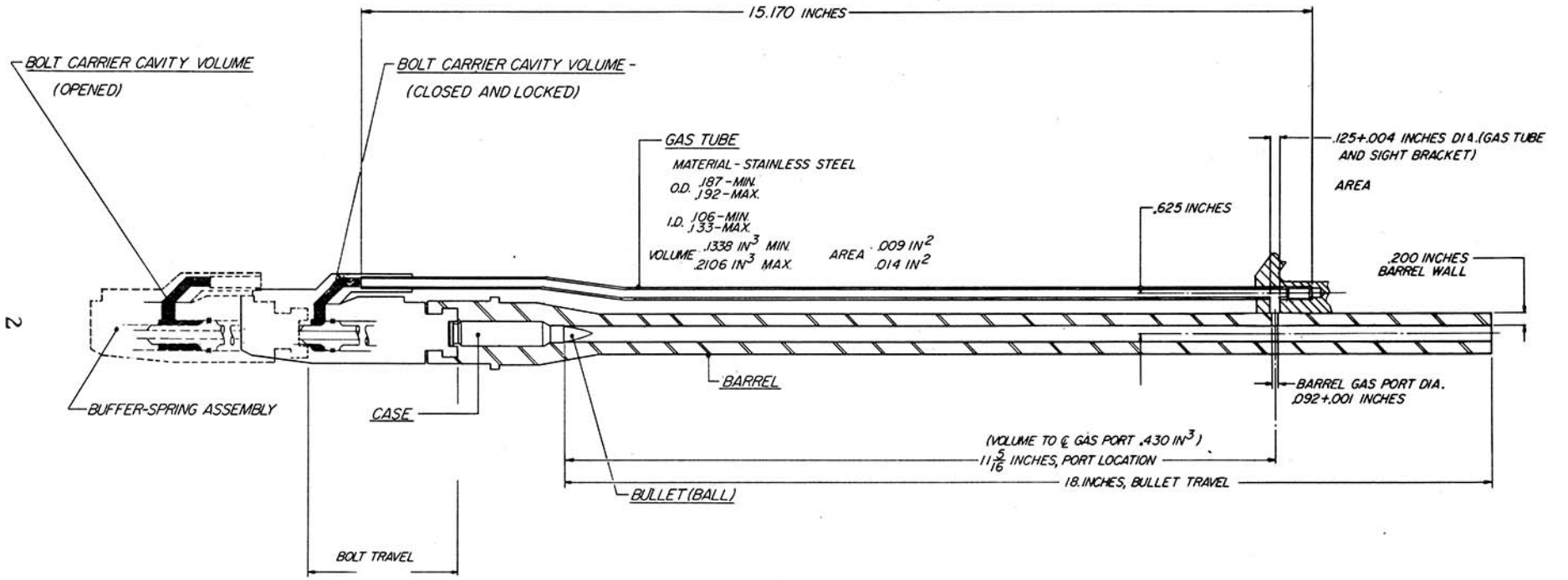


Figure 1. Ballistic schematic, 5.56 mm M16A1 Rifle

a round is fired, the projectile moves forward due to gas pressure produced by the propellant. As the projectile moves past the port, a pulse of gas moves down the gas tube and enters the bolt carrier, causing it to move rearward, allowing extraction and ejection of the empty case. The bolt carrier is propelled forward via a spring-and-buffer system in the rifle stock. The formation of deposits in the gas tube is a serious matter since, in the field, the tube is never cleaned and actually cannot be readily cleaned. The rifleman is not aware of the buildup of residue until the gun malfunctions, at which point the tube must be replaced, a task requiring tools not available to him.

CHARACTERIZATION OF THE FOULING RESIDUE IN THE M16A1 RIFLE

Review of Previous Work

Winchestern Western, a division of Olin Mathieson Chemical Corp., provided this installation with an in-house report[4] describing two 1000-round fouling tests, one with IMR 8208M propellant and one with WC 846 propellant using an AR-15 rifle. The AR-15 was an early version of the present M16A1 rifle. The main differences between the two weapons are that the AR-15 did not have a bolt assist; it did not have a chrome plated chamber; and it did not have the newer spring and buffer system. The objectives of this effort were:

1. Comparison of the quantities of residue collected.

2. Analysis of the residue.

3. Comparison of propellant compositions and the compositions of the residues formed.

An unlubricated AR-15 rifle, which had been cleaned and solvent degreased, was used to fire 1000 rounds of 5.56 mm ball ammunition containing IMR 8208M propellant and 1000 rounds loaded with WC 846 propellant. The residues in various parts of the gun, other

than the gas tube, were collected, weighed, and subjected to chemical analyses. The methods used included infrared spectroscopy, mass spectrometry, emission spectroscopy, elemental analysis, and x-ray diffraction.

Figure 2 shows the estimated composition of the residue produced by firing with both IMR 8208M and WC 846 propellant. Again, this does not involve the residue found in the gas tube. Several important conclusions were drawn from the Winchester work. It can be seen from Figure 2 that about twice as much residue was obtained with WC 846. It can also be seen that the estimated percentages of organics is the same for IMR and ball propellant. In addition, the functional groups found in the infrared region were similar for the IMR and ball residues. There was only a small amount of aliphatic carbon-hydrogen stretching. The major absorptions indicated the presence of NH and/or NH_2 and carbonyl of the $\overset{O}{\overset{\|}{C}}$ - N type. In general, the spectra resemble amides, substituted ureas, etc.

It should be noted that the WC 846 residue contained a large amount of $CaCO_3$ (about 25 percent). Its presence was quantitatively established by an emission spectrographic determination of calcium and by the manometric determination of CO_2. The lot of WC 846 propellant involved contained 0.71 percent $CaCO_3$ by the morpholing method. Also, the WC 846 residue contained more copper than the IMR 8208M residue.

Winchester made a significant observation regarding the physical nature of the residues. The IMR residue was reported as being more easily removed and did not appear to be well bonded to the metal parts. This was not true with the ball propellant residue. It appeared as a baked-on film and was very difficult to remove. In summary, the major findings of this report were:

1. The residue produced by ammunition containing WC 846 propellant contained a large amount of $CaCO_3$.

2. Twice as much residue was produced with WC 846 propellant than with IMR 8208 M.

3. There was no significant amount of unburned propellant or deterrent in either residue.

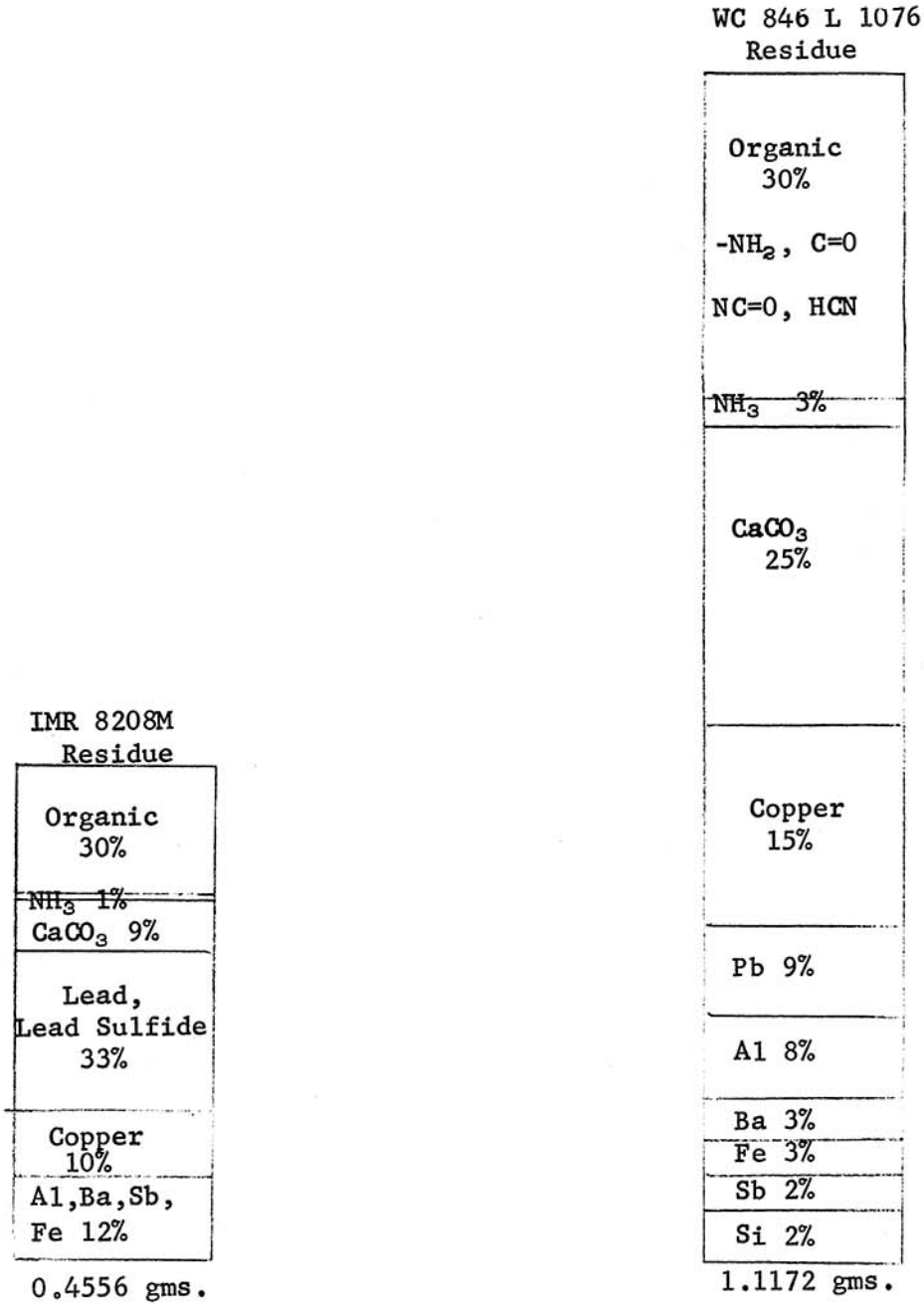


Figure 2. Estimated Residue Constituents, 1000-round Firing Tests, AR-15 Rifle

4. The organic portions of the IMR and ball propellant residues were very similar.

One of the recommendations of this report was to study the fouling characteristics of a ball propellant with a low $CaCO_3$ content. This experiment was described in a later Winchester report.[5] Another 1000-round fouling test was run using WC 846 with $CaCO_3$ content found to be 0.061 percent by atomic absorption and 0.2 percent by the morpholine method. In the ball propellant manufacturing process calcium carbonate is added to the lacquer in the hardening still. As of the time of the Winchester report, the amount of calcium carbonate that was added at the East Alton plant as well as at the Badger plant was one percent of the total material in the still.

Several reasons have been cited for this practice, all of them related to eliminating, as much as possible, the chance that the propellant will contain acidic materials that would decrease its long term storage stability. There was a remote possiblity that some residual acids from the nitration process might have been trapped in the fibrous structure and released when the nitrocellulose was dissolved to form the lacquer. Much of the nitrocellulose used was reclaimed from obsolete propellants which had been in storage for some time. It was thought that acidic decomposition products might have been formed in this material. There was also the possibility that the ethyl acetate solvent might have some acidic decomposition products in it which are not removed in the solvent recovery process.

All of these possibilities are very unlikely, but up to this point the calcium carbonate appeared to cause no harm and provided an additional margin of confidence.

The results of the 1000-round fouling test were as follows:

1. With the low $CaCO_3$ propellant, a 33 percent reduction in the weight of residue on specific gun parts was obtained.

2. The residue was similar to the IMR 8208M residue in its powdery and brittle nature.

3. The chemical composition of the ball propellant residue was more similar to residue produced by IMR propellant.

Some work[3] by emission spectroscopy had been done at Frankford Arsenal to identify the residue present in the gas tube itself. It was estimated that in the residue produced with ammunition containing ball propellant, copper was present at greater than 10 percent, calcium at 5 to 10 percent and lead at 2 to 5 percent. The results are estimates obtained by emission spectroscopy. Copper is known to mask other elements which are present, such as calcium. Furthermore, in order to obtain a sample for this spectroscopic analysis, the fouling residue in the gas tube was extracted with 5 percent HNO_3 and the measurements were made on this extract. It is not known how quantitative the extraction process was. All of these factors tend to make the estimated percentages suspect.

Electron Microprobe and X-ray Diffraction Studies

An extensive investigation was undertaken to characterize the residue in the fouled gas tubes. To do this a gas tube was obtained which had been fouled by 1620 rounds of ball M193 ammunition (lot FC1921) loaded with WC 846 (lot 1100). The $CaCO_3$ content of this propellant was 0.84 percent by atomic absorption and 0.71 percent by the morpholine method.

The gas tube was milled to a depth just exceeding the wall thickness so that the interior of the wall could be observed and photographed. Photographs of the gas tube were taken after it had been cut into 1 inch lengths (labeled A through P, starting at the port end of the gas tube).

Figures 3, 4, and 5 are photomicrographs of the most heavily fouled sections of the gas tube - sections A, B, and C, respectively. The B section contains the residue which is responsible for severely closing the diameter of the gas tube, thus causing reduced gas flow. It can be seen that the A and C sections offer little or no obstruction to the gas flow. All sections cut from this gas tube were submitted to Manlabs, Inc., of Cambridge, Mass., for electron microprobe analysis.

Electron microprobe analysis procedures are employed to provide chemical analyses from specimens as small as a few cubic

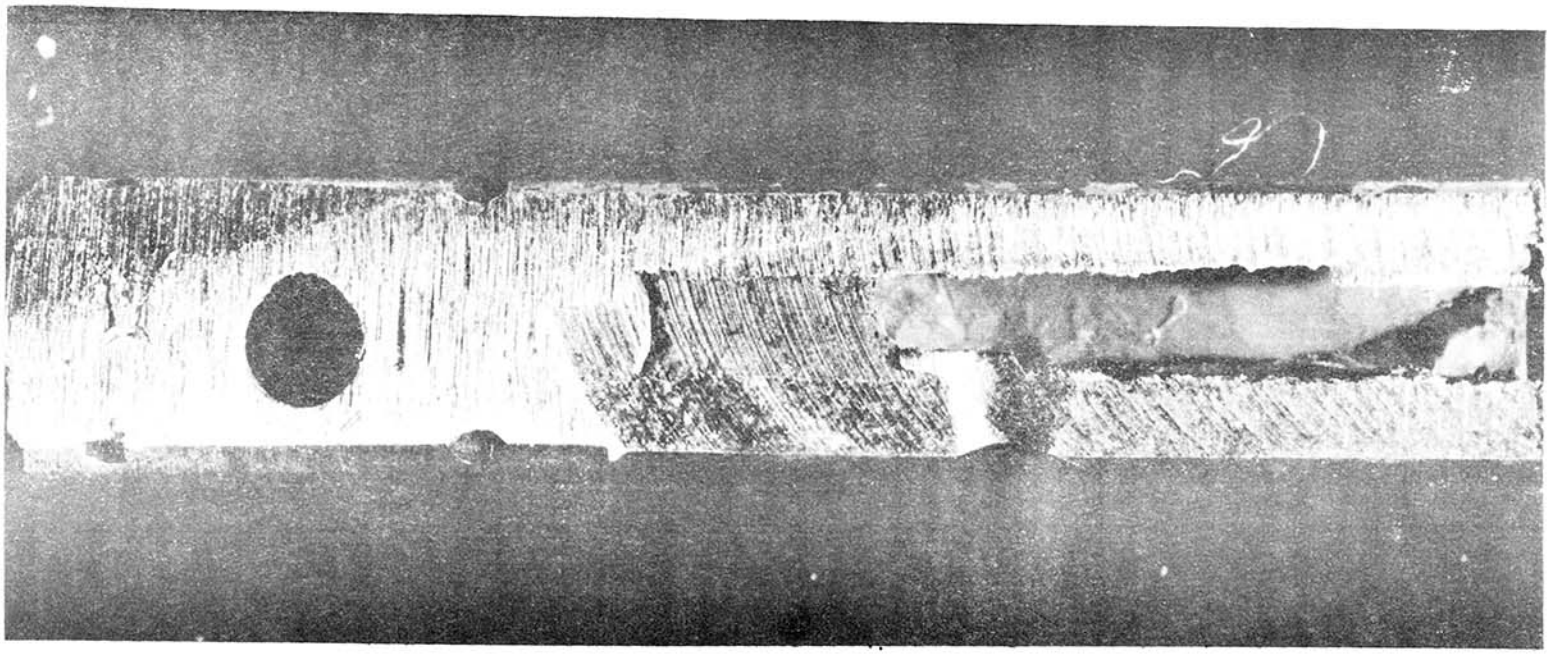


Figure 3. Photomicrograph of Section A of Fouled Gas Tube

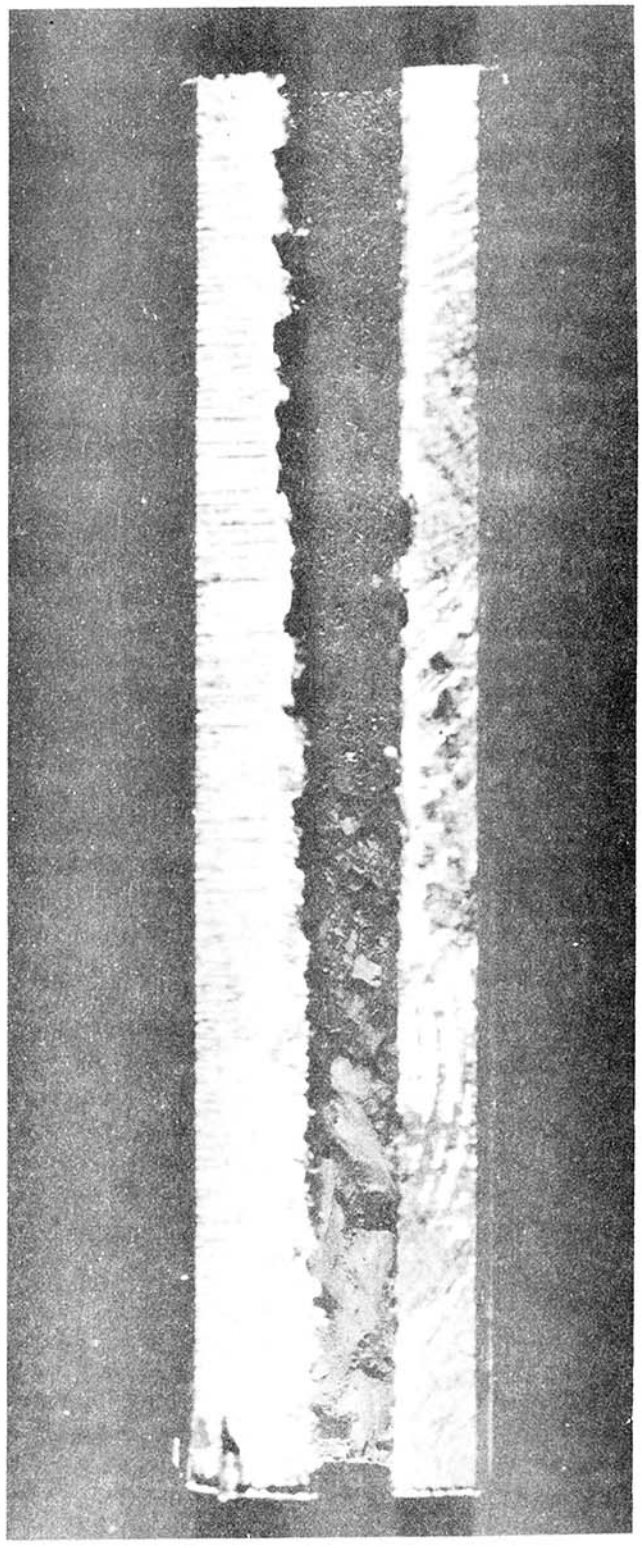


Figure 4. Photomicrograph of Section B of Fouled Gas Tube

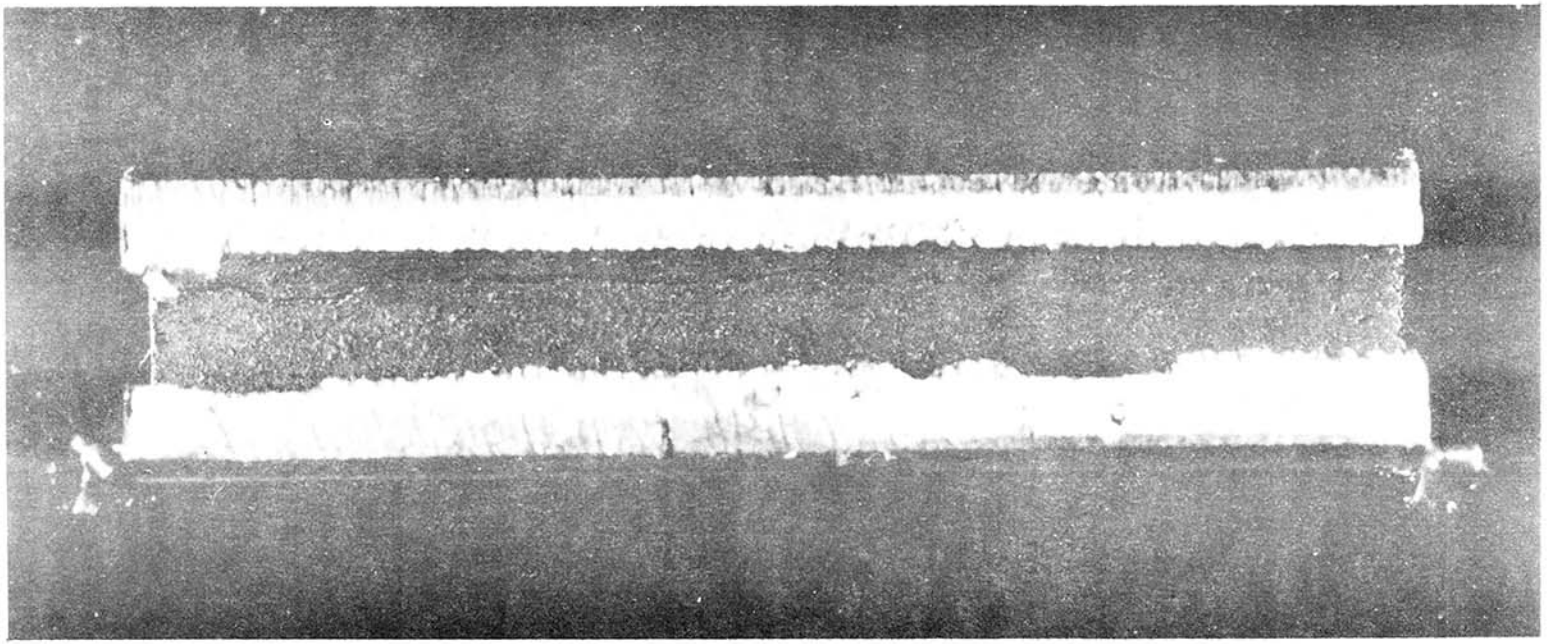


Figure 5. Photomicrograph of Section C of Fouled Gas Tube

microns in volume. For this purpose, a finely focused electron beam is made to impinge onto the specimen area of interest. This beam is located within the surface of a metallographically prepared specimen by means of a 300X light magnification system.

The electrons diffuse into the specimen a short distance, at which point many of them interact with orbital electrons and cause ionizations. This leads to the production of x-rays with wavelengths characteristic of the elements present within the field of electron diffusion. The x-rays so generated are analysed by means of dispersive techniques whereby x-rays of a particular wavelength (λ) are dispersed from a crystalline grating (with a known mean pacing of d) at an angle θ, where $\lambda = 2d \sin \theta$. Knowledge of characteristic wavelengths of the various elements allows one to study the composition of the specimen. The x-ray line intensities, when appropriately corrected for matrix absorption and secondary fluorescence, can be used for quantitative determinations.

A Phillips AMR/3 Electron Probe Microanalyzer was employed in these studies. The apparatus is equipped with two scanning spectrometers which simultaneously analyze for any element between sodium (atomic number 11) and uranium (atomic number 92). One of the spectrometers is equipped with thin windows and a stearate film overlay on the mica analyzing crystal, to extend its analysis range to include the lighter elements, boron (atomic number 5) to sodium (atomic number 11).

Two different data collection procedures were employed:

1. Special Scans - The specimen is held stationary under the electron beam and the spectrometers are scanned over a range of 2 θ values to identify the various elements in the probed sample.

2. Distribution Scans - The spectrometers are set to a specific x-ray line and the specimen is traversed under the beam, presenting a record of x-ray intensity vs distance.

Spectral scans were obtained from central areas in each of the sections C through P. Two scans were made in section A. One, labeled A-a, was obtained adjacent to the hole in the port end of the gas tube and another one, A-b, was taken downstream near the other end of the A section. The scan for section B was obtained from a

sizable chunk of material adhering to the tube wall and located close to the junction with section A. This was the only section containing a large quantity of fouling residue.

However, all of the sections yielded spectral lines for copper, calcium, oxygen, lead, zinc, and carbon. The carbon, it will be seen later, was present in the form of calcium carbonate. No nitrogen was found in the sections. The electron probe minimum detectability limit for nitrogen is several weight percent. It was therefore concluded that high nitrogen organics, such as exist in the bolt carrier, are not present in the gas tube. Other than the elements reported above and nickel, chromium, and manganese, associated with the stainless steel tube, there were no additional elements observed in any of the scans.

Approximate distributions of Cu and Ca as a function of distance along the gas tube are presented in Figures 6 and 7. The x-ray intensities have been normalized and, therefore, are approximately proportional to the amount of each element as a function of distance along the tube. Examination of Figures 6 and 7 shows that the copper concentration peaks in both the A and B sections of the tube, while the calcium concentration peaks in only the B section, which is associated with heavy fouling deposits.

The B section was found to have a high concentration of both Cu and Ca, and it was decided to identify the specific compounds present there by means of Debye-Sherrer x-ray diffraction patterns. Comparison of the observed diffraction line spacings and relative intensities to standard data showed that the residue was mainly composed of $CaCO_3$ and free copper. In summary, it was found that the residue blocking the tube was composed mainly of $CaCO_3$ and Cu, with smaller quantities of Pb and Zn.

To gain an insight into the mechanism of formation and to more quantitatively characterize the residue, another gas tube was examined. This gas tube had been fouled to the point of gun stoppage after it was used for firing 6020 rounds of lot FC1938. Lot FC1938 is loaded with WC 846 propellant, lot 1130 (0.71 percent $CaCO_3$ by the morpholine method and 0.84 percent by atomic absorption).

The tube was sectioned in a different way in order to expose more of the fouling residue and to improve the sample topography which, in turn, would improve the quantitative aspects of the microprobe data. Starting at the port end of the gas tube, short transverse

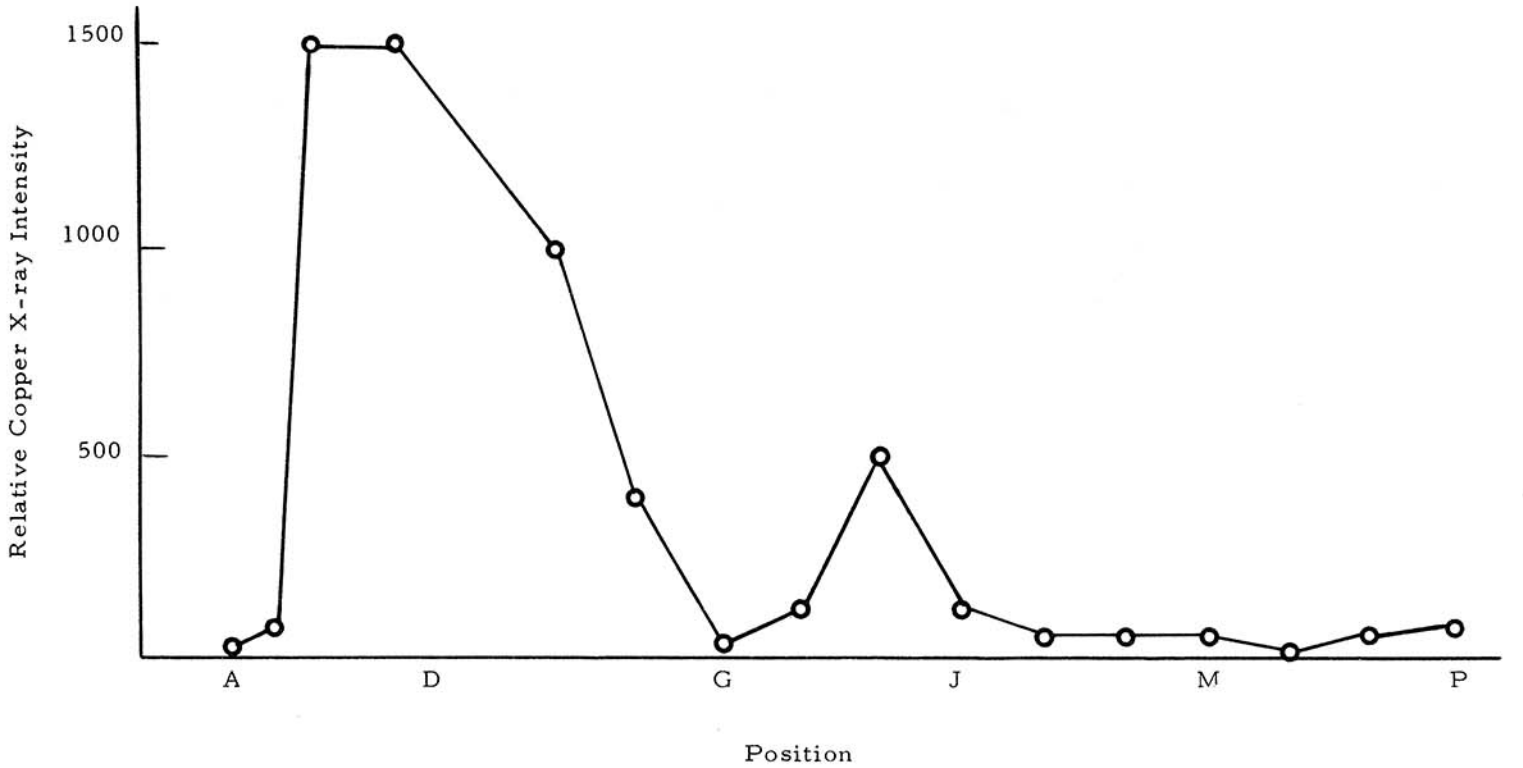


Figure 6. Relative Copper Content vs Distance along the Gas Tube, from Electron Microprobe Distribution Scan

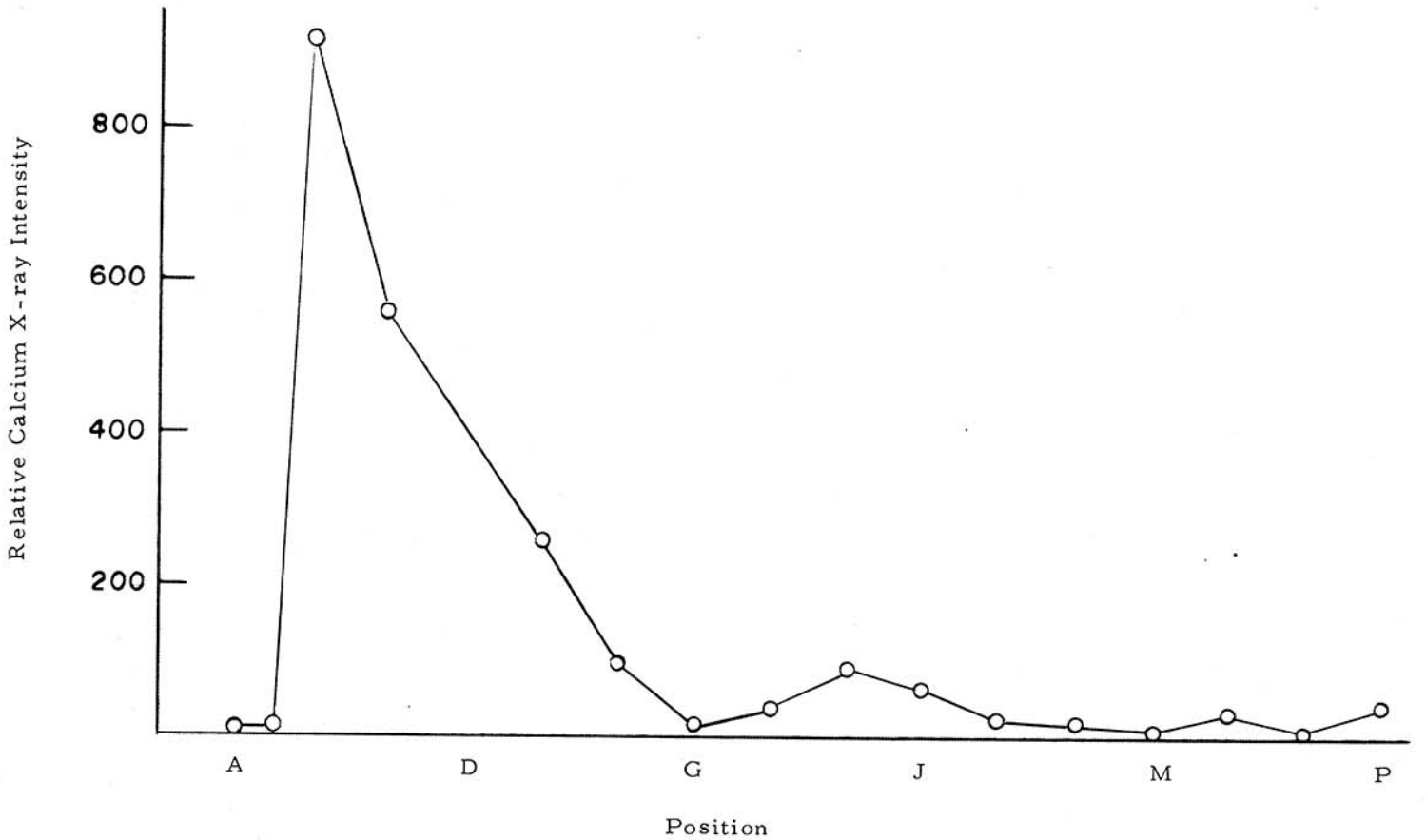


Figure 7. Relative Calcium Content vs Distance along the Gas Tube, from Electron Microprobe Distribution Scan

sections, 3/8 in. long (labeled A through L), were taken at one inch intervals. These sections were metallographically diamond-polished to a 1/4 micron surface finish. Extreme care was taken to preserve the tube-contaminant interface. Eleven of these short sections of the gas tube were submitted to Manlabs, Inc., for microprobe analysis.

Spectral scans were carried out simultaneously on two spectrometers (one of which was equipped with a special analyzing crystal to detect the lighter elements) at several positions of the tube-contaminant interface and, also, within the contaminant. Calcium, copper, zinc, lead, carbon, and oxygen, and also small quantities of iron, chromium, nickel, and manganese were found. The latter elements are undoubtedly from the stainless steel of the tube. These results were obtained by spectral scans of specific areas in sections A, C, F, H, K, and L. A typical spectral scan (section A) is shown in Figure 8 - the abscissa shows the angle of 2θ and the ordinate shows the relative x-ray intensities. The various spectral lines have been indentified and are noted on the chart.

Microprobe distribution scans, traversing the tube section radii in the A, B, and C sections, were carried out for Ca, Cu, Zn, and Pb. A typical distribution scan, in which two divisions on the chart corresponds to 2.5 mils on the specimen, is shown for Section A in Figure 9. Although not precisely in agreement due to difference in the x-ray take off (and variation in absorption), the copper and zinc x-rays are observed to be in good correspondence, thus giving evidence that the copper is present in the form of a brass. Careful measurements carried out on some of the larger copper-colored particles identified them as gilding metal with a zinc content of 7 or 8 percent. X-ray diffraction data were collected from a small piece of the contaminent in Section B. The intensities of x-ray lines were compared with those of known mixtures.

From the microprobe and x-ray diffraction data it was possible to determine the quantitative composition of the residue. The residue found in section A contained 58 percent $CaCO_3$, 35 percent gilding metal (Zn content of 7 or 8 percent), and 7 percent lead. No evidence was obtained in this study indicating that organic material (i, e., unburned propellant or partially decomposed propellant ingredients) were present in the residue to a significant degree.

When the photomicrographs of the metallographically polished specimens (Figures 3, 4, and 5) were compared with the microprobe

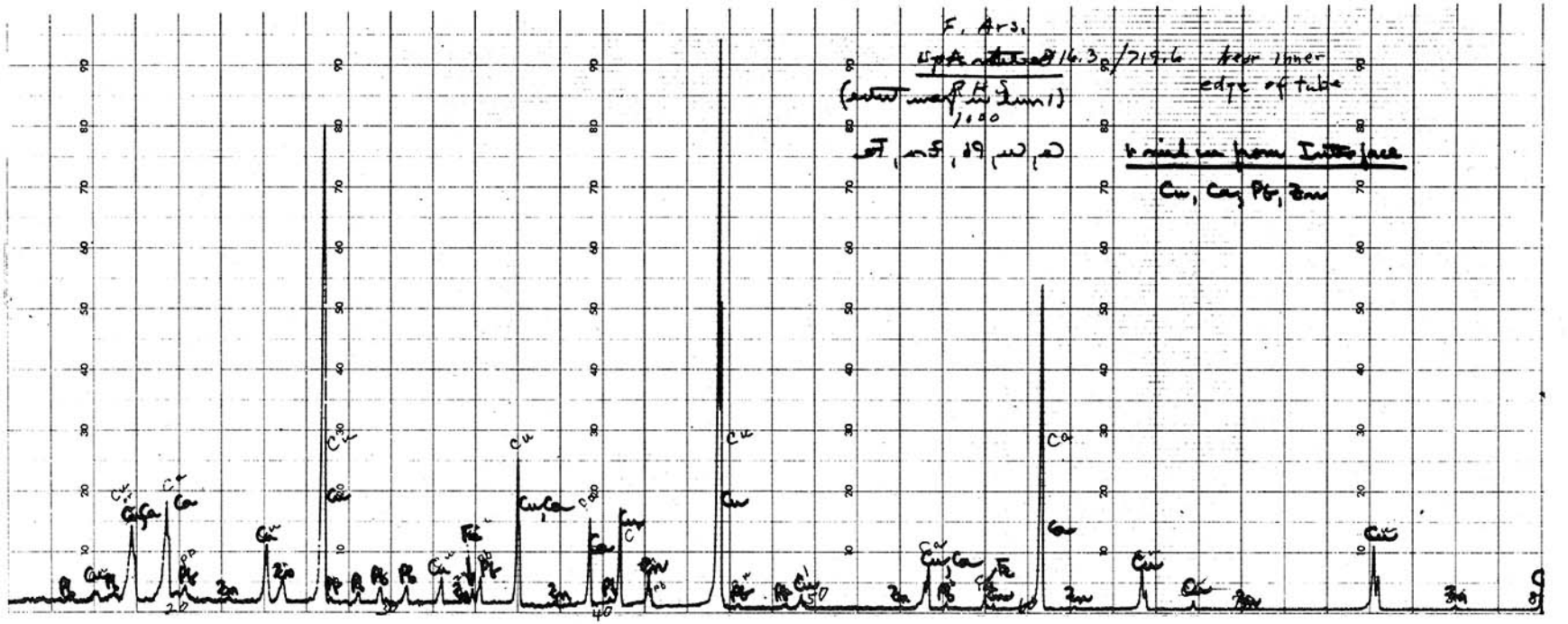


Figure 8. Electron Microprobe Distribution Scan of Tube Section A

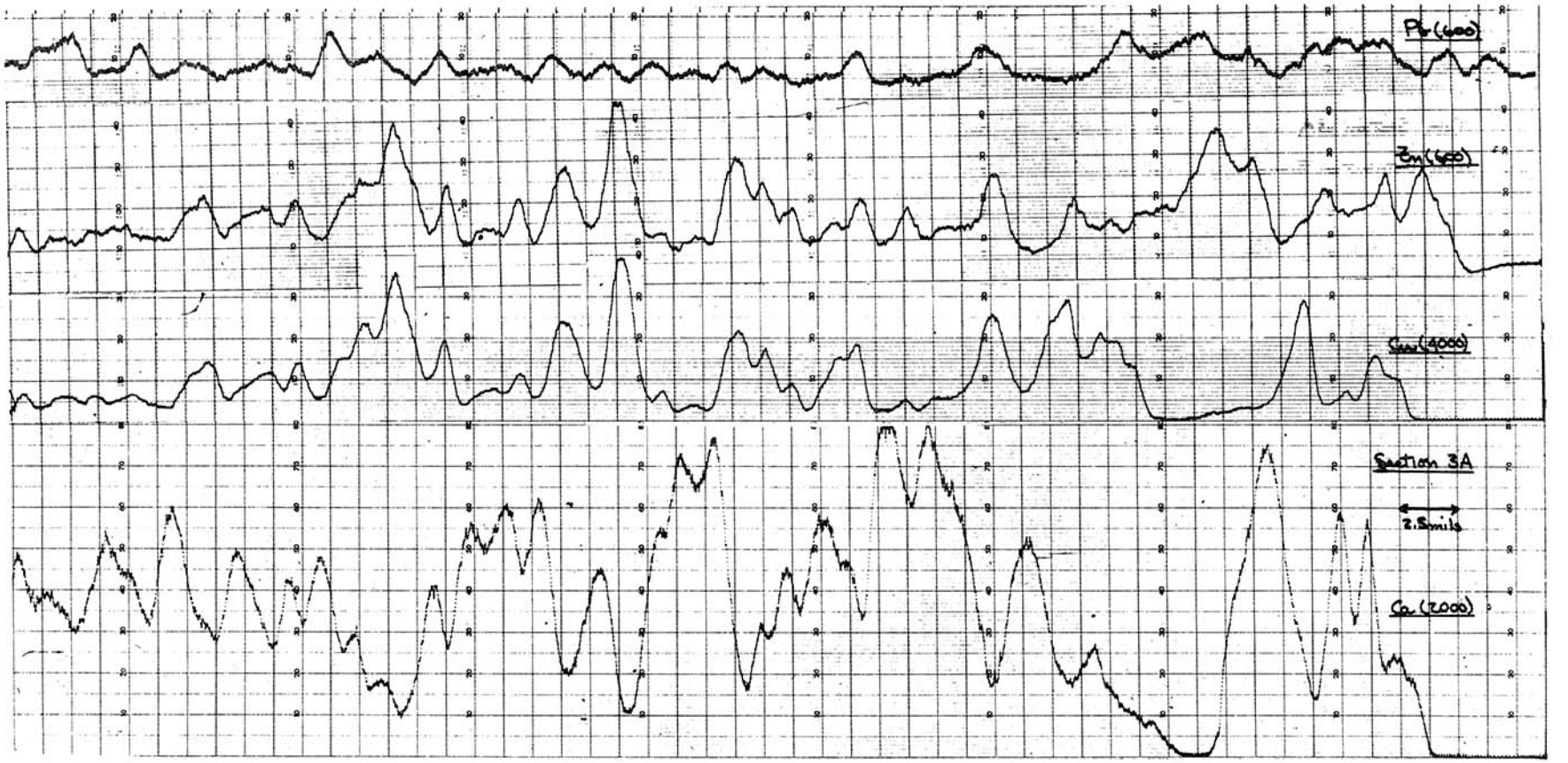


Figure 9. Electron Microprobe Distribution Scans for Lead, Zinc, Copper, and Calcium as a Function of Distance along the A Section

data, it could be seen that $CaCO_3$ was the continuous phase, with pieces of gilding metal (brass containing 95 percent Cu and 5 percent Zn) imbedded in the $CaCO_3$ matrix. In order to obtain a visual conception of the elemental distribution in various areas of the tube, scanning displays were used. In the method employed for this purpose, the electron beam is scanned across an area of the specimen by means of orthogonal deflection coils. The monitored signal (which in this case was a specific x-ray line) was used to modulate the brightness of a cathode ray tube having a sweep synchronous with the electron beam. In this manner a visual representation of the elemental distribution was obtained.

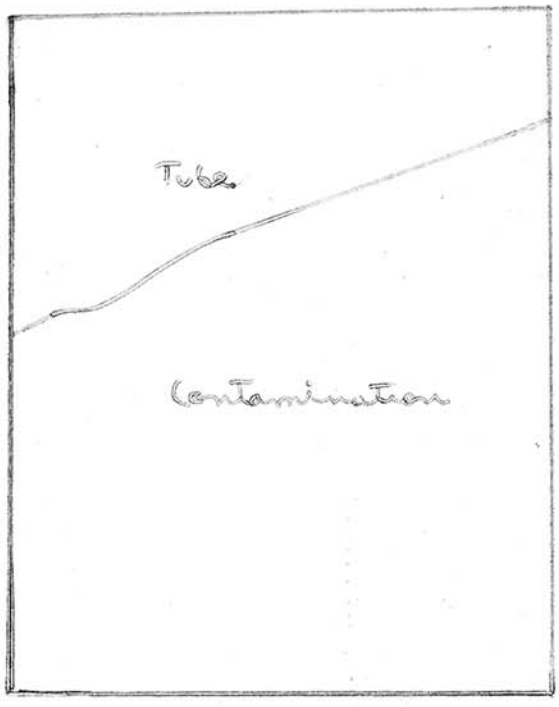
In Figures 10 and 11, we see photographs of scanning displays of copper, zinc, calcium, lead, iron, and chromium for the A section showing the tube wall fouling residue interface. It can be seen that the relative distributions for the specific elements are in good agreement with the quantitative data, and that there was no interdiffusion of fouling residue and tube wall material at the interface.

Based on the foregoing data, a mechanism for gas tube fouling involving M193 ball ammunition loaded with WC 846 ball propellant is here proposed.

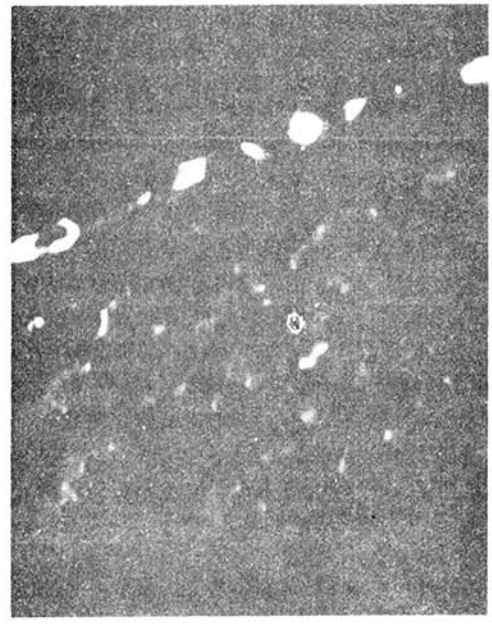
The $CaCO_3$, which is present in the propellant as crystalline inclusions, is probably decomposed when it passes through the propellant flame zone. Part of the calcium recombines with oxides of carbon in the gas tube, depositing molten $CaCO_3$ on the gas tube wall. Gilding metal pieces originating from the bullet jacket are trapped and held in the $CaCO_3$ matrix. Then, more $CaCO_3$ is deposited and more gilding metal is trapped. Considering the proposed mechanism, it can be seen that the amount of gilding metal deposited in the gas tube will depend on the condition of the projectile and barrel. Thus, the quantitative analysis of the gas tube fouling residue given earlier in this report is for one particular gas tube and one particular barrel, used with one specific ammunition sample, and would be expected to vary, within limits, from one rifle and ammunition combination to the next.

The approach to eliminate the gas tube clogging problem which immediately suggests itself is to reduce or eliminate the $CaCO_3$ content in the propellant since it appears that the $CaCO_3$ acts as sort of an adhesive, or binder, which holds the bullet jacket and primer debris.

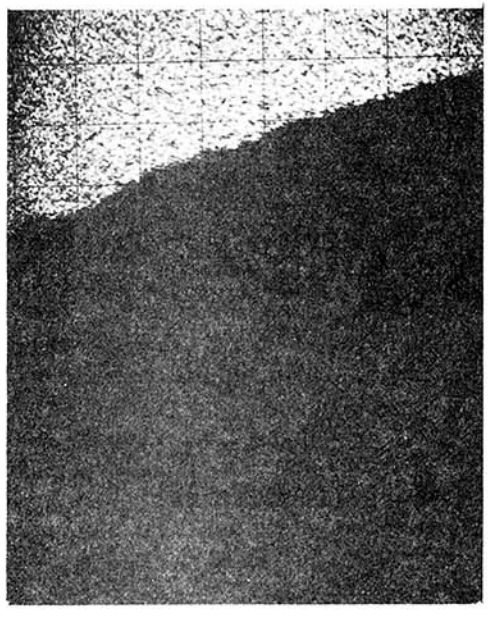
Tube Section 3A Mag: 400X



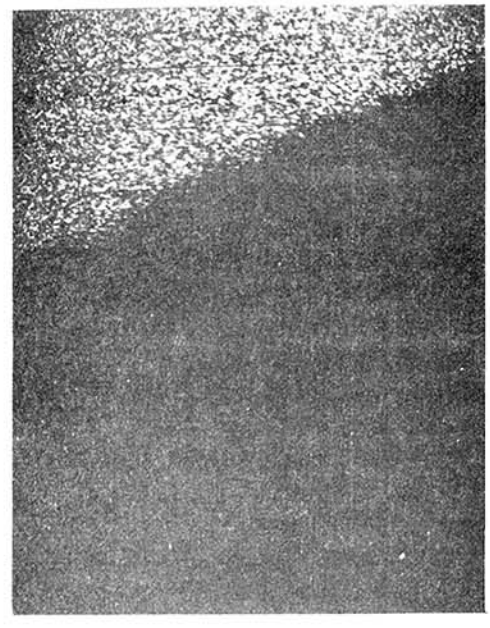
Optical



Specimen Current
(Reference oscilloscope pattern obtained when current is applied to sample)



Iron k_α



Chromium k_α

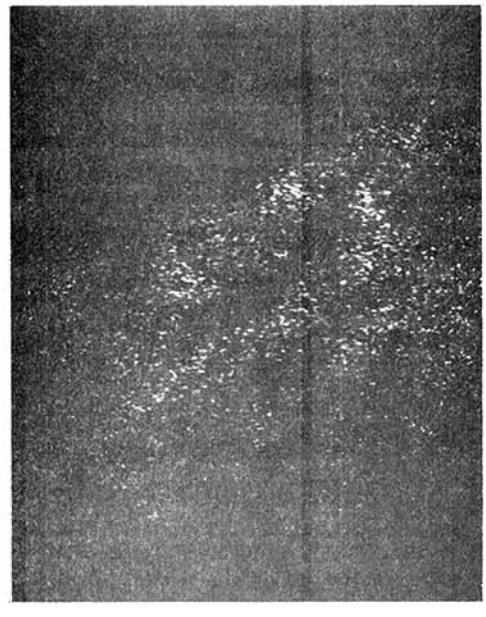
Figure 10. Electron Microprobe Scanning Displays for Iron and Chromium, showing the Tube Wall Fouling Residue Interface

Tube Section 3A Mag: 400X

Copper k_α

Zinc k_α

Calcium k_α



Lead k_α

Figure 11. Electron Microprobe **Scanning Display** for Copper, Zinc, **Calcium,** and Lead, showing **the Tube Wall** Fouling Residue Interface

CHEMICAL ANALYSIS OF PROPELLANTS AND CORRELATION WITH FOULING TEST RESULTS

During an investigation of the effect of various propellant lots on gas tube fouling,[3] it was noted that the "clean" ball propellant (lot 873) contained 0.61 percent $CaCO_3$ while the "dirty" ball propellant (lot 1020) contained 0.76 percent $CaCO_3$. Since the $CaCO_3$ is one of the major constituents of the ball propellant ash and was thus more likely to appear as a solid residue in the rifle, it was decided to conduct further work on this and the other inorganic constituents of the propellant.

Two other ammunition lots came under investigation because they were found to produce severe gas tube fouling in 6000-round rifle endurance tests at Aberdeen Proving Ground (viz., lots FC1921 and FC1938). The propellants from these two ammunition lots and from propellant lots 1020 and 873 were analyzed, with special attention being given to the inorganic constituents. For these analyses the propellant was ashed and the ash was analyzed by emission spectroscopy to determine what elements were present. Then, atomic absorption spectrometry was used for the quantitative determination of those elements present in greatest quantity.

This approach differs considerably from the specification method for the determination of $CaCO_3$.[6,7] In the specification method, a 5.0-gram sample of propellant is dissolved in 50 ml of morpholine. The solution is filtered through a weighed gooch crucible, which is then dried and weighed again. Warm water is poured through the gooch to dissolve any Na_2SO_4. The gooch is dried and weighed, the loss in weight being reported as Na_2SO_4. Then the $CaCO_3$ is washed from the gooch with dilute HCl. The gooch is again dried and weighed and the loss in weight is reported as $CaCO_3$.

The morpholine method is a more laborious method, and it is sensitive to operator skill and experience. Furthermore, the atomic absorption method measures the presence of all of the Ca, while the morpholine method measures only the water-insoluble HCl-soluble calcium salts. The results of these chemical analyses are given in Appendix A. For purposes of completeness, analyses were also run on the primers of the various cartridges. These results are given in Appendix B.

Several other ammunition lots were obtained from U.S. Army Test & Evaluation Command (TECOM), Aberdeen Proving Ground, which had been used in 6000-round rifle endurance tests and for which, therefore, gas tube fouling data were available. The propellants from these ammunition lots were also analyzed using the previously described atomic absorption method. Appendix C contains the results of the complete chemical analyses of these propellants.

The data from the firing tests and from the chemical analyses were then correlated and these results are presented in Table I. The last seven ammunition lots listed were not subjected to the above described analysis. For these, only the acceptance chemical analysis data are given. The dibutyl phthalate content is listed in Table I because it has been suggested that the deterrent played a significant role in gas tube fouling.

The lots are rated as bad (B), good (G), or marginal (M), in terms of gas tube fouling. Those lots listed as bad produced sufficient gas tube fouling to cause weapon stoppage and relatively large increases in gas tube flow meter readings. Those listed as good clearly did not produce an objectionable amount of gas tube clogging.

The marginal lots, for the most part, did not produce excessive malfunctions. They are considered marginal for different reasons. Lot WCC6176 did not produce excessive malfunctions or a large increase in the flow meter reading; yet, it was reported to cause excessive fouling of the flash hider and other weapon parts. Personnel at Aberdeen Proving Ground pointed to the relatively high cyclic rate as a possible contributor to the relatively good performance of this "dirty" lot. Lot TW18228 produced a relatively large increase in flow meter reading (+0.8), but at the end of the test no excessive malfunctioning had occurred.

Ammunition lots FA-1, FA-13, and FA-18 were loaded with the same propellant lot. FA-1 produced no increase in flow rate, but did produce a fairly high rate of malfunctions. FA-13 caused severe gas tube fouling (a large increase in the flow meter reading and gas tube weight) resulting in weapon stoppage at 4000 rounds. Lot FA-18 produced substantial gas tube fouling (sizeable increase in flow meter reading), causing the rifle endurance test to be terminated at 4726 rounds.

TABLE I.
Correlation of DBP and $CaCO_3$ Content with Gas Tube Fouling

CODE: B - Bad
G - Good
M - Marginal

Ammunition Lot No.	Propellant Lot No.	Dibutyl Phthalate (%)	$CaCO_3$ (%) Specification Method[a]	$CaCO_3$ (%) Atomic Absorption	Malfunctions per 1000 rds	Gas Tube Fouling Rating	ΔF (psi)	Rds Fired per Rifle
RA5320	1020	4.33	0.76	0.86	16 (3)[b]	B	1.1[c]	5K
FC1921	1100	4.55	0.71	0.84	2.1 (2)	B	0.5	4.4K
FC1938	1130	4.77	0.97	0.90	3.8 (1)	B	0.7	5K
WCC6176	1136	3.77	0.76	0.86	0.5 (1)	M	0.6	6K
TW18228	44666	-	0.47	0.49	0.5 (1)	M	0.8	6K
RA5244	873	4.33	0.61	0.66	0.3 (3)	G	0.03	10K
FA-1	44977	4.79	0.46	0.61	1.2 (1)	G	0.0	6K
LC12366	45463 45259	4.98	0.44 0.44	0.58	0.0 (1)	G	0.3	6K
TW18301	45476 45524	4.56	0.41 0.33	0.60	0.2 (1)	G	0.1	6K
LC12414	45526 45576	4.99	0.28 0.03	0.39	0.0 (1)	G	0.0	6K
TW18329	45523 45266	4.47	0.48 0.47	0.57	0.2 (1)	G	0.0	6K
LC12387	45463 45259	4.99	0.44 0.86	-	-	M	0.7	5K
FA-13	44977	4.79	0.46	0.61	1.2 (1)	B	1.3	4K
FA-18	44977	4.79	0.46	0.61	1.2 (1)	B	1.3	4.7K
TW18365[d]	45600	4.76	0.23	-	0.0 (1)	G	0.1	6K
LC12453[d]	45596	4.83	0.11	-	0.0 (1)	G	0.1	6K
RA5394[d]	1215	3.50	0.36	-	0.0 (1)	G	0.4	6K
LC12499[d]	45608	5.68	0.13	0.19	0.2 (2)	G	0.1	6K
LC12473[d]	45582	5.34	0.21	-	0.0 (1)	G	0.1	6K

[a]Morpholine method.

[b]Figure in parentheses represents the number of rifles used.

[c]Change in flow meter readings.

[d]These ammunition lots contain propellant made since June 1968.

It is evident from the Table that a high $CaCO_3$ content strongly correlates with gas tube fouling. In fact, to date no ammunition lot loaded with propellant with low quantities of $CaCO_3$ (<0.40 percent) has been found which has caused excessive gas tube fouling. The existence of the marginal lots and the varying performance of propellant lot 44977 in ammunition lots FA-1, FA-13, and FA-18 lead to the conclusion that variables in the ammunition metal parts affect the severity of the fouling produced by a given lot. This has been substantiated by other experimental work at Frankford Arsenal.*

Obviously, since the gas tube residue consists primarily of gilding metal particles and metallic primer residues embedded in a $CaCO_3$ matrix, the source of the gilding metal (i.e., the bullet jacket) is a facet in the fouling picture, as are gun-ammunition interactions that cause the production of small gilding metal particles during the firing cycle. No correlation of gas tube fouling with dibutyl phthalate (DBP) content is evident.

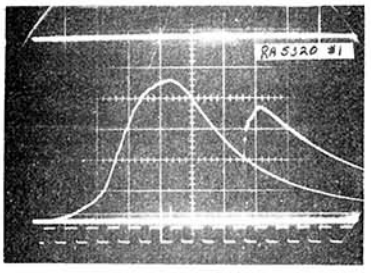
The relative number of "good" and "bad" lots listed in Table I is of no significance since all of the "bad" lots that had come to the attention of Frankford Arsenal are listed while only an arbitary small number of "good" lots were selected for inclusion in the Table.

In June 1968, the amount of $CaCO_3$ added to the material in the hardening still was reduced from 1.0 percent to 0.25 percent at Badger Ordnance Works and from 1.0 percent to 0.50 percent at the Olin Mathieson Plant at East Alton, Ill. The last five lots of ammunition listed in Table I contain propellant made since June 1968.

PRESSURE-TIME STUDIES

Pressure-time curves produced by "good" ammunition lots were compared to pressure-time curves of lots found to be "bad" in terms of gas tube fouling. Figure 12 shows typical curves obtained with

*A. J. Grandy, unpublished data, Frankford Arsenal



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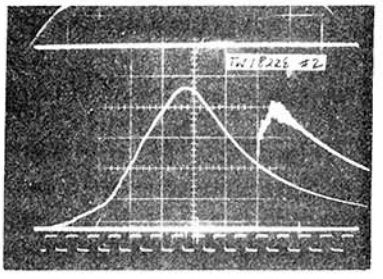

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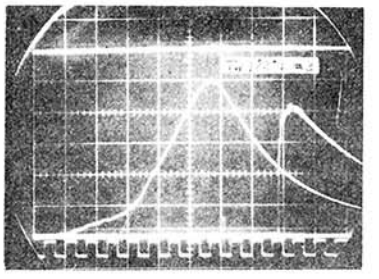

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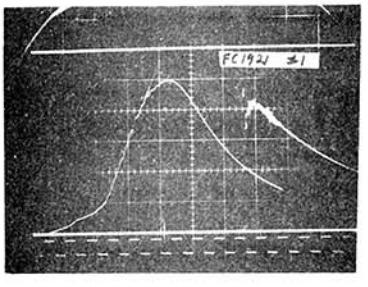

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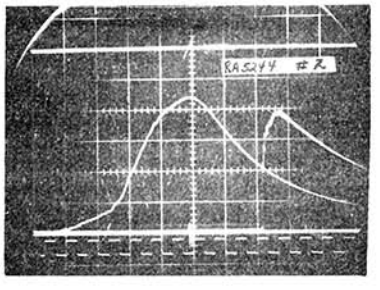

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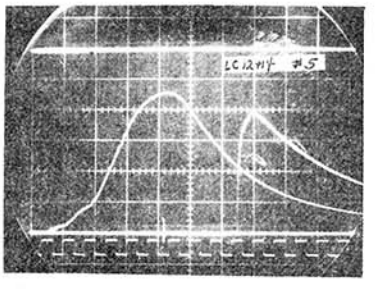

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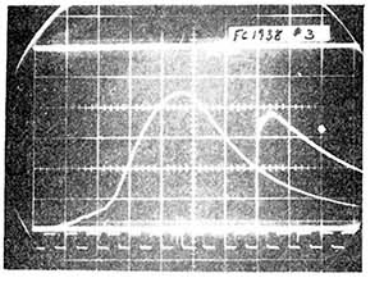

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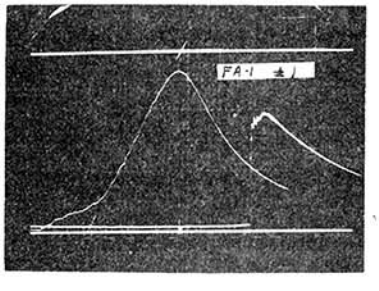

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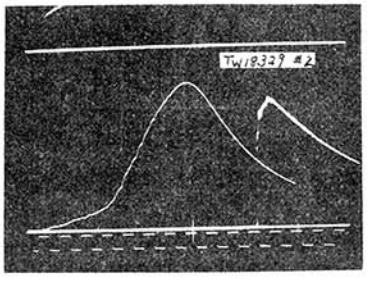

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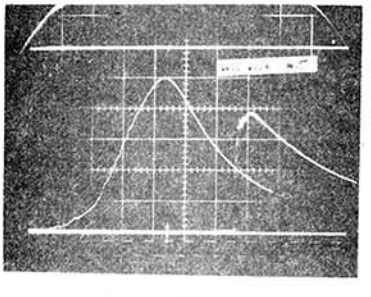

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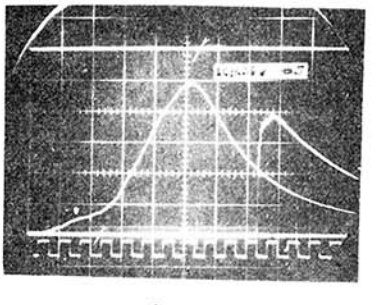

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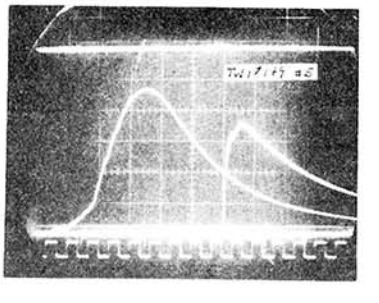

G

Code: B = bad; G = good; M = marginal.

Figure 12. Pressure-Time Studies of 5.56 mm Ammunition Lots with Known Fouling Characteristics

each of the twelve lots of ammunition studied. It is clear that the general shapes of the curves do not correlate with the gas tube fouling rating indicated with each curve.

Table II gives the measurements obtained from these curves It is clear that there is no correlation between gas tube fouling and the following: peak chamber pressure, peak port pressure, propellant ignition time, barrel time, time to port pressure, and time to peak pressure.

FOULING TESTS WITH SPECIAL PROPELLANTS

In order to confirm the findings of this effort - namely, that the $CaCO_3$ in the propellant is a major constituent of the fouling residues in the tube and that its absence in the propellant prevents the occurrence of gas tube fouling - two extensive fouling tests were conducted.

In the first test, ammuntion loaded with ball propellant containing a deliberately added large amount of calcium carbonate was evaluated and the results were then compared to those obtained from the second test in which ball propellant with a low $CaCO_3$ level was used. The chemical compositons of the two propellants, lot X2842 (high $CaCO_3$ content) and BAJ45608 (low $CaCO_3$ content), are given in Table III. The two propellants were loaded into 5.56 mm ball M193 Frankford Arsenal components, the ammunition loaded with lot X2842 being designated ammunition lot FAP 564 and that containing lot BAJ45608 being designated ammunition lot FAP 565.

Charge establishment and other ballistic data for the two lots are given in Table IV.

It can be seen that the charge in lot FAP 564 produces a velocity of 3164 fps at 15 feet, which is below the specification requirement (3250 ± 40 fps at 15 ft). The charge of 28.2 grains was the maximum charge of X2842 propellant that could be machine-loaded into the case. This deviation is not considered to have an effect

TABLE II.
Data from Pressure-Time Studies

NOTE: Data are averages of 3 to 5 shots.

Ammunition Lot No.	Chamber Pressure Curve						Port Pressure Curve		
	Time (msec)			dp/dt x 10^8 (psi/sec)	Pressure (kpsi)		Time to Port Pressure (msec)	Peak Port Pressure (kpsi)	Gas Tube Fouling Rating
	Propellant Ignition	To Peak Pressure	Barrel		Peak	Muzzle			
RA5320	0.16	0.48	0.91	2.1	46.3	13.6	0.82	12.3	B
FC1921	0.19	0.52	1.00	2.3	49.4	13.4	0.83	13.5	B
FC1938	0.20	0.55	1.01	1.8	46.3	13.6	0.83	12.6	B
WCC6176	0.14	0.50	0.99	1.6	50.4	13.3	0.81	12.9	M
TW18228	0.26	0.59	1.10	1.2	46.6	13.3	0.90	12.9	M
RA5244	0.16	0.51	1.01	1.7	45.0	13.6	0.83	12.6	G
FA-1	0.22	0.61	1.09	1.4	50.3	13.3	0.91	12.3	G
LC12366	0.26	0.61	1.09	1.4	49.7	13.3	0.91	12.9	G
TW18301	0.28	0.60	-	1.2	48.0	14.1	1.00	15.1	G
LC12414	0.14	0.49	1.01	1.7	46.3	13.9	0.81	13.7	G
TW18329	0.22	0.62	1.11	1.4	47.5	13.8	0.92	13.5	G
TW18149	0.14	0.43	0.94	2.2	46.8	12.0	0.78	11.8	G

TABLE III.
Chemical Composition of Propellant Lots X2842 and BAJ45608

	% Component	
	X2842	BAJ45608
Nitrogen in NC	13.16	13.16
Nitroglycerine	9.11	10.52
Dinitrotoluene	0.66	0.06
Diphenylamine	0.94	0.98
Dibutylphthalate	4.89	5.68
Total volatiles	1.21	1.23
Moisture	0.83	-
Residual solvent	0.38	0.60
Moisture and volatiles	0.87	1.06
Calcium carbonate	1.02[a]	0.13[a]
	1.15[b]	0.19[b]
Sodium sulfate	0.28[a]	0.09[a]
	0.055[b]	0.027[b]
Graphite	0.21	0.12
Nitrocellulose (by difference)	81.68	81.19

[a]By Specification (morpholine) method.

[b]By atomic absorption spectrometry.

TABLE IV.
Ballistic Data for Ammunition Lots FAP 564 and FAP 565

	FAP 564	FAP 565
Propellant	X2842	BAJ45608
Charge weight (gr)	28.2	27.6
Pressure, copper (kpsi)		
Peak chamber	47.9	45.1
Peak port	14.8	15.5
Velocity at 15 ft (fps)	3164	3254

on the gas tube fouling results since the residue which clogged the tube contained no significant amount of organic material which could be traced to unburned propellant or partially decomposed propellant material.

The two ammunition lots were each fired in three different rifles in order to avoid any bias that might be caused by the unusual performance of one rifle. The test procedure followed in these firings was basically the "Rifle Endurance Test" as described in Appendix G of SAPD-253F.[8] The specific steps in the test procedure are outlined here.

1. The M16A1 rifles used were in the best possible condition, being equipped with chromed chambers and new type buffers, and with a new, unused gas tube. In these tests, two of the three rifles used with each propellant lot were equipped with previously used barrels and one weapon from both groups was fitted with a completely new barrel.

2. At the start of the test, the gas tubes were weighed and radiographs were taken of the rifle with gas tube attached. Special efforts were made to examine not only the gas tube, but also the channel leading from the bore through the sight bracket to the gas tube. In order to accomplish this, two radiographs were taken, one focused on the forward portion of the gas tube while the other one was exposed to show the channel coming from the bore.

The barrel was gaged at the beginning of the test and a flow measurement was taken, using the Frankford Arsenal flow meter.[3] Firing then commenced according to the following sequence:

1. Twenty rounds automatic - in bursts of approximately five rounds each.

2. Twenty rounds automatic - in one burst.

3. Twenty rounds semiautomatic - at a rate of ten to thirty rounds per minute.

4. Twenty rounds automatic - in bursts of approximately five rounds each.

5. Twenty rounds semiautomatic - at a rate of ten to thirty rounds per minute.

Cyclic rate was recorded during each fully automatic burst. The barrel was then cooled to the point where it was possible to hold it with the bare hand. This sequence was followed until 1000 rounds had been fired. At all times the rifle was kept mounted in the tests stand (i.e., it was not fired while being held in the hand, as per SAPD 253F).

Flow meter readings, Precisionaire gage measurements, and x-ray pictures were taken after evey 1000 rounds. The rifle was also cleaned and lubricated every 1000 rounds, strictly in accordance with the specification procedure. This involved the use of a lubricant specified in MIL-C-46000 and cleaning solvent specified in MIL-C-372.

A motion picture was taken of muzzle flash for a 100-round cycle with each propellant lot to monitor any difference in flash that might occur as a result of the reduction of calcium carbonate. No significant difference was detected between the flash produced by the low $CaCO_3$ propellant as compared to the high one. It is difficult to reproduce radiographs for publication in a completely satisfactory manner because while one can observe the location of the deposits, the intensities of the exposures at the beginning and end of the 6000-round tests are not reproducible. This is primarily because, with the equipment used, it was impossible to properly compensate for day-to-day changes in strength of the x-ray film developer while the test was in progress. Figure 13 shows radiographs of the port area of rifle No. 861763 used with ammunition lot FAP 764 taken at the beginning and at the end (after 5700 rds) of the test.

As was expected, ammunition lot FAP 564, containing the high $CaCO_3$ propellant X2842, produced significant deposits in the gas tubes of all three rifles. The radiographs from all three rifles also indicated increasing amounts of deposits in the gas tubes with each 1000 rounds fired. As had been observed previously, the deposits formed only in the forward end of the gas tube. Deposits were also found in the sight bracket channel leading from the port to the gas tube. The ammunition loaded with the low $CaCO_3$ propellant (lot FAP 565) produced no deposits visible in the radiographs in either the gas tube or the channel in the sight bracket, and produced little or no increases in flow rate measurements (Table V). The deposits formed in the gas tube when firing with lot FAP 564 consistently caused substantial increases in flow meter readings.

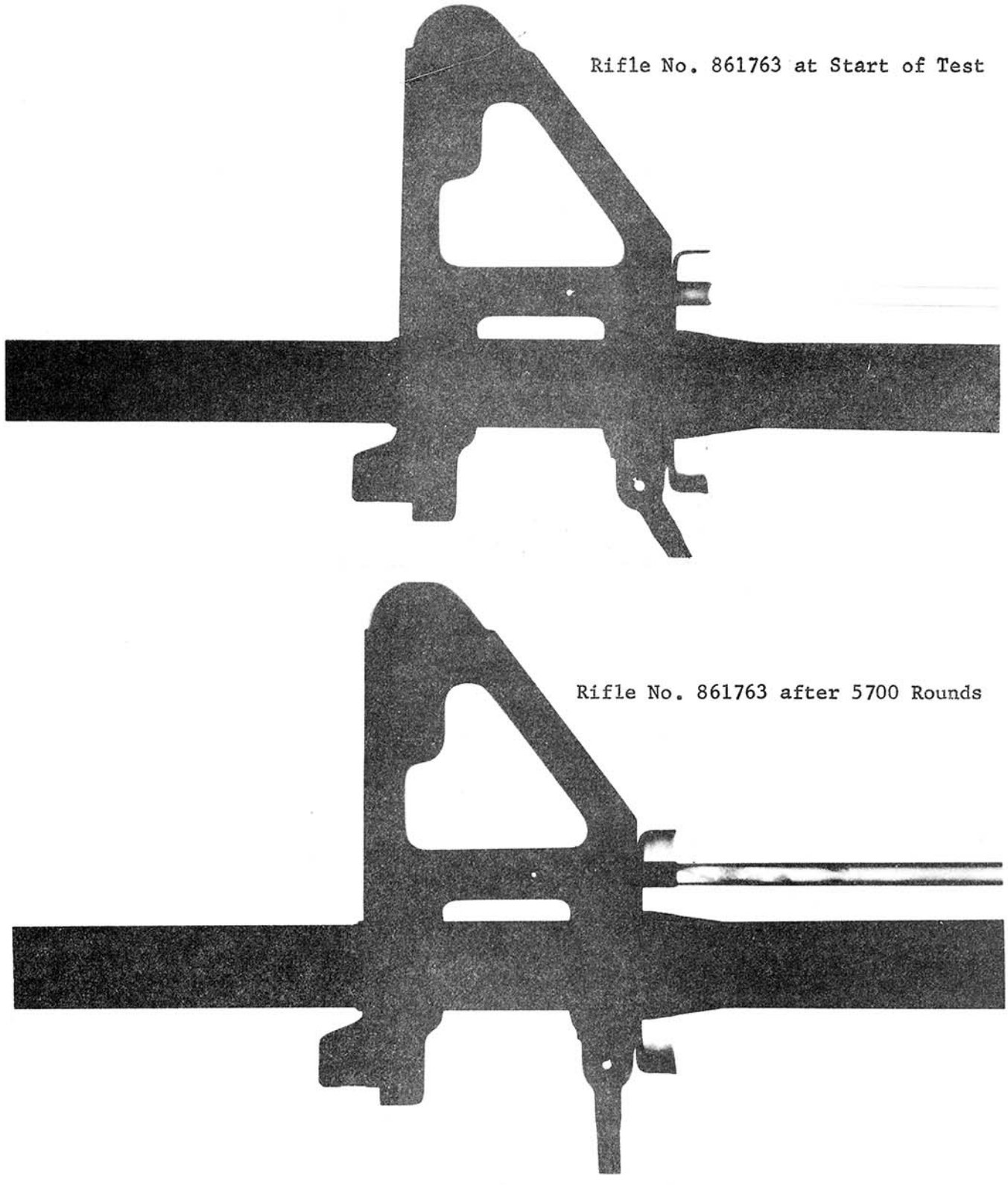

Figure 13. X-ray picture of Front Sight Region of Rifle No. 861763 at Start of Test and after 5700 Rounds

TABLE V.

Flow Meter Readings for Ammunition Lots FAP 564 and FAP 565

Rifle No.	0	1000	2000	3000	4000	5000	6000	ΔF.M.[a]
				Ammunition Lot FAP 564				
861763C	1.43	1.63	1.66	1.76	1.66	1.64	1.66	+0.23
823422	1.47	1.66	1.75	1.80	1.92	1.92	2.04	+0.57
167512[b]	1.73	1.64	1.79	1.70	1.86	1.93	2.05	+0.32
				Ammunition Lot FAP 565				
823422N	1.64	1.57	1.59	1.58	1.55	1.54	1.54	-0.10
859740	1.57	1.56	1.56	1.57	1.58	1.63	1.61	+0.04
861763CN[b]	1.63	1.47	-	1.47	1.48	1.49	1.49	-0.14

[a]Change in flow meter reading

[b]New barrel; others reconditioned, with approximately 1000 rounds fired previously.

The changes in gas tube weights observed with both lots are given in Table VI. The high calcium carbonate propellant gave consistent increases in gas tube weight. The low calcium carbonate lot produced varying results, all of them considerably lower than the other lot. Two of the gas tubes fired with FAP 565 gained weight and one lost weight. The gains in weight with FAP 565 are probably due to deposits formed in the cavity of the tube which is forward of the port. The cavity fills up, but the deposit does not interfere with the flow of gas to the breech. There are no deposits visible in the portion of the gas tube that conveys the gas to the bolt carrier. Rifle No. 861763CN showed a loss in weight of the gas tube. It is likely that this loss is due to removal of a chip or burr in the tube. This is substantiated from the flow meter reading where there was a drop from 1.63 to 1.47 in the first 1000 rounds. Cyclic rate measurements were taken during every 100-round cycle. Averages for 1000-round intervals are given in Table VII. There seems to be no relationship between the gas tube fouling results and the cyclic rate measurements.

TABLE VI.
Change in Weight of Gas Tubes

Rifle No.	Weight (gm) Original	Final	Change
	Ammunition Lot FAP 564 (High $CaCO_3$)		
861763C	26.6788	27.1958[a]	+0.5170
823422	27.1322	27.7004	+0.5680
167512	27.9736	28.6286	+0.6550
	Ammunition Lot FAP 565 (Low $CaCO_3$)		
859740	28.2586	28.5872	+0.3286
861763CN	27.5472	27.1000	-0.4472
823422N	27.8040	27.9742	+0.1702

[a]After 5700 rounds; others after 6000 rounds.

TABLE VII.
Average Cyclic Rate Values for 1000-round Intervals

Rifle No.	Cyclic Rate (rd/min) for Round Intervals of					
	Start	0 to 1000	1000 to 2000	2000 to 3000	3000 to 4000	4000 to 5000	5000 to 6000
Ammunition Lot FAP 564 (High $CaCO_3$)							
823422							
Avg cyclic rate	931	898	876	844	884	881	856
Extreme variation	-	61	43	53	38	57	52
861763C							
Avg cyclic rate	898	884	890	902	863	881	874
Extreme variation	-	28	57	51	134	75	48
167512							
Avg cyclic rate	946	917	866	871	933	912	910
Extreme variation	-	86	77	53	27	43	36
Ammunition Lot FAP 565 (Low $CaCO_3$)							
823422 N							
Avg cyclic rate	901	865	833	877	891	906	895
Extreme variation	-	88	105	61	31	32	36
859740							
Avg cyclic rate	784	803	810	834	841	856	851
Extreme variation	-	36	69	60	92	42	46
861763CN							
Avg cyclic rate	851	877	929	916	924	929	943
Extreme variation	-	68	30	27	19	34	35

Lot FAP 764 with the high $CaCO_3$ propellant, while producing deposits in the tubes, did not produce excessive malfunctions during the 6000-round firings. Some lots, such as FC1938, produced sufficient gas tube clogging to cause complete gun stoppage before 6000 rounds could be fired.

Apparently, if the $CaCO_3$ is present in sufficient quantity to form a deposit, the actual degree of clogging is also a function of the projectile. It was found, for example, that the cannelures of the projectiles used in lots FC1938 and FC1921 were badly made and that these lots also had relatively high bullet pull values. *

The rifle bores were gaged with a Precisionaire instrument at the beginning of the test and after every 1000 rounds thereafter. Bore gaging records for the barrels, taken at the beginning and at the end of the test, are given in Appendix D.

With lot FAP 564 (with the high calcium carbonate level), heavy barrel fouling was encountered with all three rifles. After firing only 1000 rounds, the muzzle end of each barrel was so heavily fouled that the gage spindle would not enter the barrel. The ammunition with the low calcium carbonate levels produced very little barrel fouling. Some erosion was evident near the breech end of the barrels after the 6000-round test. This also probably occurred with lot FAP 564 but could not be measured because of the heavy fouling deposits.

The amount of erosion is small and is not expected to affect the accuracy of the rifle.

Additional comments on the functioning of the rifles, number of malfunctions encountered, fouling in the flash suppressor, and misfires are presented in Appendix E for each rifle. These are included for purposes of completeness, but they are not directly applicable to the objective of this study.

*A. J. Grandy, unpublished data, Frankford Arsenal.

CONCLUSIONS

1. Gas tube clogging in the M16A1 rifle when firing ball ammunition loaded with ball propellant is due to calcium carbonate which deposits in a localized area of the gas tube and traps metallic debris.

2. The deposits causing the clogging consisted of gilding metal and primer product particles embedded in a calcium carbonate matrix.

3. Ball propellants containing little or no calcium carbonate did not produce localized deposits that could clog the gas tubes.

4. When using ball propellant in ball ammunition, the fouling deposits in the gas tubes did not contain a significant amount of either unburned propellant or partially decomposed organic propellant material.

5. There is no correlation between the shape of the p-t curve and gas tube fouling.

6. There is no correlation between deterrent (DBP) content and gas tubing fouling.

7. In the firing tests conducted during this study, the propellant with little calcium carbonate produced substantially less barrel fouling than the propellant with the high calcium carbonate content.

RECOMMENDATIONS

It is recommended that

1. The calcium carbonate content of propellants used in ammunition for the M16A1 rifle be kept below 0.25 percent.

2. Studies be conducted aimed at total elimination of the calcium carbonate while retaining the required long term storage stability.

3. The electron microprobe techniques be applied to studies of barrel erosion and fouling.

REFERENCES

1. C. L. Fulton, C. E. Shindler, and F. J. Shinaly, "Special Tests of 5.56 mm Ammunition," Frankford Arsenal Report R-1883 (page 49), February 1968.

2. Op cit (page 50)

3. R. E. Donnard, "Investigation of Gas Tube Fouling Characteristics of M193 Ball Cartridges in M16A1 Rifle," Frankford Arsenal Report R-1895, Rev I, August 1968.

4. A. H. Milford, "Function and Fouling Tests of AR-15 Rifle No. 201548; Analysis of Residue N.B. 1006671," Interoffice Memorandum, Olin Corporation, 22 February 1968.

5. A. H. Milford, "Analysis of Fouling Residue: Firing Tests and Low Calcium Carbonate Ball Powder X-2797; Project MAF #4392," Interoffice Memorandum, Olin Corporation, 28 June 1968.

6. Military Standard MIL-STD-286A, "Propellants, Solid: Sampling, Examination, and Testing," 18 August 1961.

7. J. B. Apatoff and G. Norwitz, "Determination of Potassium, Sodium, Calcium, and Barium in Nitrocellulose-base Propellants by Atomic Absorption," Frankford Arsenal Test Report T69-1-1, February 1969.

8. Small Arms Purchase Description, "Rifles, 5.56 mm: M16 and M16A1," SAPD-253F, 22 November 1968.

APPENDIX A

RESULTS OF CHEMICAL ANALYSIS OF PROPELLANTS

	% Component			
	FC1921	FC1938	RA5244	RA5320
Sodium sulfate	0.050	0.042	0.076	0.041
Calcium carbonate	0.84	0.90	0.66	0.86
Iron	0.008	0.020	0.014	0.010
Magnesium	<0.005	<0.005	<0.005	<0.005
Aluminum	<0.005	0.013	0.008	<0.005
Silicon	Trace	0.071	<0.005	<0.005
Barium	Trace	Trace	Trace	0.072
Lithium	ND[a]	ND[a]	<0.005	ND
Antimony	ND	ND	Trace	ND
Tungsten	ND	ND	Trace	ND
Solvent extractable	16.59	16.99	15.95	16.64
Nitroglycerine	9.84	10.34	9.81	10.27
Dibutyl phthalate	4.55	4.77	4.33	4.33
Diphenylamine	0.88	0.84	0.85	0.96
Nitrogen (in N. C.)	12.82	12.76	12.82	12.79
Titanous chloride reducibles	0.78	0.78	0.46	0.54
Graphite	0.13	0.22	0.26	0.19
Total volatiles	1.01	0.93	1.02	0.91
Heat test at 120° C	60 min	70 min	60 min	70 min
Salmon pink explosion	5 hr +	5 hr +	5 hr +	5 hr +

[a]None detected.

APPENDIX B

RESULTS OF CHEMICAL ANALYSIS OF PRIMERS

	% Component			
	K-75 Primer		Remington 92 Primer	
	FC1921	FC1938	RA5244	RA5320
Lead styphnate	38.7[a]	39.0[a]	37.3[b]	38.8[b]
Barium nitrate	39.5	40.1	60.5	59.4
Nitrocellulose	7.0	6.3		
Tetracene	2.2	2.5	1.8	1.5
Antimony sulfide	12.6	12.1	0.4	0.3

[a]Basic
[b]Normal

APPENDIX C

CHEMICAL COMPOSITION OF PROPELLANTS TESTED IN TECOM RIFLE ENDURANCE TESTS

	% Component					
	FA-1	LC 12414	LC 12366	TW18329	TW18301	WCC6176
Sodium sulfate	0.044	0.42	0.43	0.054	0.045	0.055
Calcium carbonate	0.61	0.39	0.58	0.57	0.60	0.86
Iron	0.059	0.019	0.062	0.027	0.033	0.018
Magnesium	<0.01	Trace	Trace	Trace	Trace	Trace
Aluminum	0.032	0.012	0.023	0.053	0.042	0.039
Silicon	0.017	0.014	0.016	0.021	0.020	0.019
Barium	Trace	Trace	Trace	Trace	Trace	Trace
Tin	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Copper	Trace	Trace	Trace	Trace	Trace	Trace
Zinc	Trace	Trace	Trace	Trace	Trace	Trace
Potassium	Trace	Trace	Trace	Trace	Trace	Trace
Solvent extractables	16.73	16.57	16.79	16.31	16.60	16.30
Nitroglycerin	10.00	10.36	10.12	10.14	10.17	10.23
Dibutylphthalate	4.79	4.99	4.98	4.47	4.56	3.77
Diphenylamine	0.87	0.89	0.86	0.97	1.02	0.96
Titanous chloride reducibles	0.50	0.0	0.55	0.48	0.55	0.84
Nitrogen (in NC)	13.10	13.09	13.07	12.78	13.07	12.89
Nitrocellulose	82.99	83.23	82.67	83.12	82.85	82.98
Graphite	0.20	0.10	0.18	0.18	0.23	0.27
Total volatiles	0.78	1.03	0.82	1.27	0.82	0.87
Moisture and volatiles	0.83	0.90	0.88	0.96	0.84	0.86
N-Nitroso diphenylamine	0.79	0.38	0.56	0.53	0.80	0.74
2-Nitro diphenylamine	0.06	0.08	0.10	0.05	0.01	0.04
Actual diphenylamine	0.11	0.40	0.64	0.52	0.25	0.39
Total as diphenylamine	0.83	0.78	1.08	1.01	0.93	0.94
Ash	0.13	0.12	0.18	0.11	0.12	0.20
Heat test at 120° C salmon pink	60 min	85 min	60 min	90 min	60 min	75 min
Explosion	5 hr +	5 hr +	5 hr +	5 hr +	5 hr +	5 hr +

APPENDIX D

BORE GAGING RECORDS

Distance from Muzzle (in.)	Diameter (in.)											
	Lot FAP 564; Rifle No. 823422				Lot FAP 564; Rifle No. 861763C				Lot FAP 564; Rifle No. 167512			
	Start of Test		End of Test		Start of Test		End of Test		Start of Test			
	Land	Groove	Land	Groove	Land	Groove	Land	Groove	Land	Groove	Land	Groove
0.5	0.2199	0.2239	a	a	0.2195	0.2237	b	b	0.2195	0.2238	c	c
1	0.2199	0.2239			0.2195	0.2238			0.2195	0.2238		
2	0.2199	0.2240			0.2195	0.2238			0.2195	0.2240		
3	0.2199	0.2237			0.2195	0.2238			0.2195	0.2237		
4	0.2199	0.2238			0.2195	0.2238			0.2195	0.2237		
5	0.2199	0.2239			0.2193	0.2238			0.2195	0.2237		
6	0.2199	0.2239			0.2193	0.2238			0.2194	0.2237		
7	0.2199	0.2240			0.2192	0.2238			0.2195	0.2237		
8	0.2149	0.2239			0.2192	0.2239			0.2195	0.2237		
9	0.2197	0.2239			0.2192	0.2239			0.2194	0.2237		
10	0.2197	0.2239			0.2192	0.2239			0.2195	0.2237		
11	0.2197	0.2239			0.2192	0.2239			0.2195	0.2237		
12	0.2198	0.2239			0.2193	0.2239			0.2195	0.2238		
13	0.2198	0.2240			0.2195	0.2239			0.2195	0.2238		
14	0.2198	0.2240			0.2197	0.2239			0.2195	0.2238		
15	0.2199	0.2240			0.2198	0.2240			0.2195	0.2237		
16	0.2199	0.2240			0.2195	0.2240			0.2194	0.2237		
17	0.2198	0.2238			0.2198	0.2239			0.2194	0.2237		
17.5	0.2199	0.2239			0.2199	0.2239			0.2194	0.2237		

[a] After firing 1000 rounds, Precisionaire spindle would not enter muzzle due to metallic fouling buildup.

[b] After firing 1000 rounds, Precisionaire probe (spindle) would not eneter bore. Fouling deposits completely fill grooves in forward portion of barrel.

[c] Excessive fouling on lands and grooves would not allow entry of Precisionaire gage spindles from muzzle end. Fouling visible from gas port to muzzle of rifle.

Distance from Muzzle (in.)	Diameter (in.)											
	Lot FAP 565; Rifle No. 823422				Lot FAP 565; Rifle No. 861763CN				Lot FAP 565; Rifle No. 859740			
	Start of Test		End of Test		Start of Test		End of Test		Start of Test		End of Test	
	Land	Groove	Land	Groove	Land	Groove	Land	Groove	Land	Groove	Land	Groove
0.5	0.2197	0.2243	0.2197	0.2244	0.2197	0.2238	0.2197	0.2238	0.2196	0.2238	0.2195	0.2238
1	0.2197	0.2242	0.2197	0.2243	0.2197	0.2238	0.2197	0.2238	0.2196	0.2238	0.2195	0.2237
2	0.2197	0.2242	0.2197	0.2241	0.2197	0.2238	0.2197	0.2238	0.2196	0.2238	0.2195	0.2237
3	0.2197	0.2242	0.2194	0.2241	0.2197	0.2238	0.2196	0.2237	0.2195	0.2238	0.2238	0.2237
4	0.2197	0.2242	0.2195	0.2241	0.2197	0.2238	0.2196	0.2239	0.2193	0.2238	0.2238	0.2237
5	0.2197	0.2242	0.2195	0.2241	0.2197	0.2238	0.2195	0.2239	0.2195	0.2238	0.2195	0.2237
6	0.2197	0.2241	0.2197	0.2241	0.2196	0.2238	0.2195	0.2238	0.2193	0.2237	0.2195	0.2237
7	0.2197	0.2241	0.2195	0.2241	0.2196	0.2238	0.2197	0.2238	0.2192	0.2237	0.2183	0.2237
8	0.2197	0.2241	0.2195	0.2241	0.2198	0.2239	0.2195	0.2237	0.2191	0.2237	0.2193	0.2237
9	0.2197	0.2241	0.2196	0.2241	0.2197	0.2239	0.2195	0.2238	0.2191	0.2238	0.2194	0.2238
10	0.2197	0.2241	0.2195	0.2242	0.2197	0.2239	0.2195	0.2238	0.2191	0.2238	0.2192	0.2238
11	0.2197	0.2241	0.2195	0.2242	0.2197	0.2239	0.2195	0.2238	0.2190	0.2238	0.2192	0.2238
12	0.2197	0.2241	0.2196	0.2242	0.2196	0.2239	0.2194	0.2238	0.2191	0.2238	0.2191	0.2238
13	0.2196	0.2241	0.2195	0.2240	0.2196	0.2239	0.2196	0.2238	0.2191	0.2238	0.2191	0.2238
14	0.2196	0.2241	0.2196	0.2240	0.2196	0.2239	d	0.2237	0.2191	0.2238	0.2192	0.2238
15	0.2196	0.2241	0.2197	0.2242	0.2196	0.2239	d	0.2240	d	d	0.2197	0.2238
16	0.2196	0.2241	0.2201	0.2242	0.2196	0.2239	d	0.2241	d	d	e	0.2238
17	0.2196	0.2241	0.2206	0.2246	0.2196	0.2239	d	0.2244	d	d	e	0.2243
17.5	0.2196	0.2242	0.2208	0.2248	0.2196	0.2238	d	0.2246	d	d	e	0.2248

[d]Probe will not enter.
[e]Over maximum calibration of 0.2200.

APPENDIX E

NOTES RELATIVE TO TEST RESULTS

FAP 564

Rifle No. 167512

After 1000 rounds:

Broken extractor spring found; excessive fouling on land and grooves would not allow entry of Precisionaire gage spindles from muzzle end; fouling visible from gas port to muzzle of rifle.

Between 2000 and 3500 rounds:

Several double shots; 2 BOB's,* 2 bolt assists; key loose on carrier.

Between 4700 and 4950 rounds:

Two double shots; 3 BOB's.

Rifle No. 861763C

At 1050 rounds:

Metallic fouling buildup on lands and grooves on forward portion of bore prevented entrance of gaging spindles. A considerable number of double shots were found to occur throughout the test with this rifle (approximately 50 total).

*BOB - Bolt overrode base of round, feeding from magazine.

Rifle No. 823422

At 1050 rounds:

Metallic fouling buildup in forward portion of bore prevented air gaging spindles from entering the muzzle; fouling buildup in flash suppressor.

At 2913th round:

Bullet lodged in barrel; total of 9 BOB's and 5 double shots. On investigation of the bullet in the barrel, it was found that, apparently, the primer had malfunctioned. Particles of unburned primer material were found in the charge. The propellant had not ignited. It is assumed that primer malfunction was due to a small or damaged pellet.

FAP 565

Rifle No. 861763CN

One round did not have a primer vent hole; considerable buildup of fouling in flash suppressor; three rounds failed to feed.

Rifle No. 859740

Considerable fouling in flash suppressor.

Rifle No. 823422

Considerable fouling in flash suppressor; 3 BOB's. Replaced 3 bolt rings after 2000 rounds.

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13. ABSTRACT

Electron microprobe and x-ray diffraction techniques were used to characterize and quantitatively determine the composition of the fouling residue found in the gas tube of the M16A1 rifle. It was found that the residue was composed of a continuous phase of calcium carbonate in which particles of gilding metal and certain metallic primer combustion products were embedded. Organic material was not present in the residue to any significant degree.

Results of atomic absorption analysis of the inorganic constituents of ten propellant lots were correlated with their known fouling characteristics. Those with high $CaCO_3$ content were found to produce gas tube clogging. No relationship was found to exist either between the shape of the pressure-time curves of the ammunition or the deterrent content of the propellants and gas tube fouling. Fouling tests, run with special ammunition to compare ball propellants with high and low calcium carbonate content, confirmed these results. It was shown that when the $CaCO_3$ content is sufficiently low, no significant deposits form in the gas tube or in the barrel.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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M16 Rifle						
Guns						
Ammunition						
Gun Propellants						
Solid Propellants						
Fouling						
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