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A SAFETY, QUALITY AND COST EFFECTIVENESS STUDY OF COMPOSITION A-3 PRESS LOADING PARAMETERS

MARCH 1976

NWS

NAVAL WEAPONS STATION, YORKTOWN, VIRGINIA 23691

by

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This report is a safety, quality and cost effectiveness study of loading gun ammunition with Composition A-3 explosive.

Processing parameters were required to increase gun firing safety and increase explosive load quality using material with a bulk density of less than 0.81 g/cc at the lowest possible cost.

Each processing variable was investigated and a set of processing parameters was established within which the loading facilities could operate safely and efficiently with unavoidable fluctuations in material and processing conditions and still meet production requirements. It was found that the combination of new processing parameters plus blending various bulk density materials were effective means for producing quality charges, but blending, per se, was not essential and need only be done to utilize very low bulk density material.

The cost savings that were realized were based on the following findings:

- Seven million pounds of suspended/rejected low bulk density Composition A-3 was proved certified for service use by appropriate process loading developments.
- Three million pounds of suspended/rejected low wax content Composition A-3 had been so classified erroneously and could be certified for service use.
- The replacement value of ten million pounds of Composition A-3 is approximately $9,000,000.

FOREWORD

1. This is a report documenting a safety, quality and cost effectiveness study of loading gun ammunition with Composition A-3 explosive.

2. The effort reported herein was authorized and funded under the Naval Sea Systems Command (SEA-9923E) Work Request 53555 of 21 Aug 1974 and Work Request 53557 of 7 Aug 1974.

Released by

W. McBRIDE, Director
Naval Explosives Development
Engineering Department
March 1976

Under authority of
LEO A. HIBSON, JR.
Commanding Officer

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A SAFETY, QUALITY AND COST EFFECTIVENESS STUDY OF COMPOSITION A-3 PRESS LOADING PARAMETERS

I. BACKGROUND

Composition A-3, a granular mixture of 91 percent cyclotrimethylenetrinitramine (RDX) coated with 9 percent desensitizing wax, came into general use in 1944 as the main burster charge for Navy 3" and 5" gun launched projectiles. The choice of Comp A-3 was made primarily because of its significantly superior terminal ballistic performance to other less potent, alternate fill explosives, and secondly, both because of its "cook-off" resistance and the fact that the Navy was already facilitated for press-load processing.

However, it should be noted particularly that 5" projectile explosive loads are subjected to severe setback and rotational forces when gun shock-launched. These forces have been demonstrated to be sufficient to cause premature initiation of poor quality explosive loads[1,2,3]. Because in-bore prematures can be highly catastrophic, Navy goals were established to reduce the expectancy of a hazardous incident, of whatever origin, to less than one per million projectiles fired.

The Naval Explosives Development Engineering Department (NEDED) of the Naval Weapons Station (NAVWPNSTA), Yorktown, Virginia is chartered to develop all non-nuclear explosive loading procedures for Naval weapons produced in Navy loading plants. Therefore, as part of its objective in meeting the aforementioned goal of less than one in a million failure rate, NEDED's first task was to establish quality standards - for the Comp A-3 explosive itself, for the projectile loading process, and for the quality and operating performance of the loaded projectile -

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[1]Beauregard, R.L., NAVORD TR 71-1, History of Navy Use of Composition A-3 and Explosive D in Projectiles, Jan 1971

[2]Culberton, D.W., et.al., NWL Dahlgren TR-2624, Investigation of 5" Gun In-bore Ammunition Malfunctions, Dec 1971

[3]NAVORD Rept 10009, Report of the Ammunition Special Study Group (U), 1 Aug 1970 CONFIDENTIAL

all in order to eliminate any explosive defects that could be potential contributors to in-bore initiation mechanisms. Establishing these quality standards was carried out in a straightforward manner in a relatively short time. Thus, for Comp A-3, it was determined that Class A RDX, coated with Grade A microcrystalline wax in such a way as to give a product having a bulk density not less than 0.81 grams per cubic centimeter (g/cc), was ideal for press loading 5" major caliber projectiles. In a like manner it was demonstrated that void and crack-free projectile loads having overall and core explosive densities in excess of 1.60 g/cc and 1.625 g/cc, respectively, could be produced consistently by press loading the bulk Comp A-3 at 70 degrees Fahrenheit (°F) in six preweighed increments at ram pressures of 13,500 pounds per square inch (psi) for finite dwell times. It had been established previously[3] that 5" projectiles loaded to even less stringent density and quality requirements than those just mentioned would function without incident in overpressure gun firing tests. Therefore, it was felt that uncomplicated, state-of-the-art materials and loading specifications had been definitized and all that remained to ensure the production of high quality, safely performing ammunition was that these specifications be adhered to rigorously.

However, in the real world of limited resources, the "best result possible" often must yield to the "best possible result." Old maxims such as these are currently propounded more impressively - if not more clearly - in acronyms such as BADCT (best available demonstrated control technology) and BATEA (best available technology economically achievable). In short, it soon developed that the ideal conditions just described could not always be achieved in practice without unexpected complications, prohibitive cost increases and/or time delays. For example:

- Only a small percentage of Navy Comp A-3 stockpiles met the desired 0.81 g/cc minimum bulk density.

- Holston Army Ammunition Plant (HAAP), the Comp A-3 supplier, announced in late 1972 that due to certain changes in the petrochemical industry, Grade A microcrystalline waxes would not be available in supply sufficient to meet triservice requirements.

- HAAP further declared that even when Grade A waxes were available from different suppliers, HAAP had lost the processing art to assure that the Navy's 0.81 g/cc minimum bulk density requirement could be met in new production. (Indeed, subsequent production densities varied from 0.75 to 0.85 g/cc.)

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[3] Ibid.

- Navy loading plants had already reported that 1.60 g/cc pressed densities could not be achieved reliably with marginal or low bulk density Comp A-3. They also reported seasonal manufacturing problems such as increment separations, cracking, and reassertion of the pressed charges after fuze cavity drilling. (It should be noted that Navy loading plants are not conditioned for the wide temperature-humidity flucuations experienced from summer through winter.)

NEDED's new challenge then was to define a matrix of operation parameters that would allow for the continued production of Comp A-3 loaded gun launched ammunition without compromising in any way the quality standards of the end product. This last point was of vital importance because: only after completion of the multimillion dollar study program[3] had it been firmly established, to a very high degree of confidence, that projectiles loaded to the standards just described would perform without malfunctioning. If these established standards were compromised in any way, it could mean not only another multimillion dollar qualification program to validate a new set of end product standards but could have caused prohibitive production delays during a critical phase of the Southeast Asia conflict.

The program instituted by NEDED was twofold: first, to resolve immeiate production problems with the current stockpile; and second, to exhaustively examine each of the variables that affected end product quality. The ultimate goal was to establish processing parameters within which the loading facilities could operate safely and efficiently despite the unavoidable fluctuations in materials and processing conditions.

This report primarily describes: the technical approach used; the parameters investigated; the results obtained; and conclusions and recommendations drawn from studies relevant to immediate production problems. Results of additional studies of variables affecting end product quality will be published in a later report.

II. TECHNICAL APPROACH

Four major variables control the ultimate quality of Comp A-3 press loaded projectiles. They are 1) explosive bulk density, 2) blend of explosive particle size, 3) temperature of explosive and projectiles, and 4) pressing parameters. The approach used to evaluate these four variables, together with numerous, dependent subvariables, was to establish a parametric matrix. This matrix was designed to:

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[3]Ibid.

- Isolate individual variable effects wherever possible.
- Carry out the least number of experiments that would still be statistically meaningful and from which conclusions with high confidence levels could be drawn.
- Establish raw materials and processing parameters from, and within, which projectiles of desired quality would result.
- Ensure that the established processing limits would not approach hazardous levels in normal production operations.

However, no data are any more useful than their accuracy and precision. Therefore, before any studies were begun, a comprehensive review was made of the analytical techniques used to qualify raw materials and to accept loaded projectiles. The procedures examined were:

- Bulk density measuring techniques.
- Overall pressed charge density measurements.
- Individual core density measurements.
- Compositional analysis of bulk Comp A-3.
- Radiographic procedures and standards for loaded projectiles.

The review resulted in standardization of four of the analytical techniques, with the incorporation of radiographic examination as part of the acceptance criteria. In turn, the new analytical procedures raised the confidence levels in the results obtained from the parametric studies that followed.

A. Bulk Density Studies

A matrix of experiments to examine all aspects of bulk density parameters was designed to determine whether or not low bulk density Comp A-3 could be safely and economically processed to produce high quality projectiles. Specific objectives were to establish the lowest bulk density material usable, and more importantly, the allowable operating tolerances. This involved correlation with other effective variables such as number of increments, temperature, and pressure. These studies were absolutely essential because it was known that even if blending of high and low bulk density material to achieve an average 0.81 g/cc was successful, the very limited stocks of high bulk density material were insufficient to blend off either the large stocks of suspended low bulk material from previous manufacturing periods or low bulk density material currently being manufactured at HAAP.

As a corollary, it seemed plausible that if Comp A-3 could be made to flow more easily under pressure, it might be possible to compress substandard bulk density material to the desired end product densities without having to change other processing parameters. Hence, a series of pressings were programmed to add varying percentages of graphite as a lubricant to the Comp A-3.

Finally, previous analyses of corings taken from Comp A-3 loaded projectiles showed that the average particle size of the RDX extracted from core samples after pressing had been materially reduced from what it had been in the virgin Comp A-3 before pressing. This reduction from an average size of 185 microns to 140 microns corresponded to an RDX classification change from Class A to Class G. It was reasoned that if Comp A-3 were manufactured with Class G particle size RDX at the outset, it might be both easier and safer to attain the end product quality objectives. Therefore, a parallel program was instituted to press load projectiles with Comp A-3 specially manufactured from Class G RDX even though bulk densities of the resultant Comp A-3 fell below 0.70 g/cc.

B. Blending Studies (an analysis of suspended stocks)

A threefold purpose lay behind the blending studies. Seven million pounds of Comp A-3 were stockpiled in a suspended status because they fell below the specified 0.81 g/cc minimum bulk density. As stated earlier, HAAP had warned both of limited wax supplies as well as of an inability to assure continuous production of Comp A-3 meeting this 0.81 g/cc minimum.

Therefore, parallel to the low bulk density investigations, studies were designed to determine whether or not it was feasible to stretch out existing stocks of Comp A-3 by blending materials having bulk densities above and below 0.81 g/cc to create a material whose average density was 0.81 g/cc.

It had long been noted that bulk density variations often showed up not only between boxes of Comp A-3 in a given lot of acceptable material but that variations even existed within boxes - particularly after rough and/or frequent transporting and handling. This segregation, by settling, of material into coarse and fine fractions was at one time considered so undesirable that it had become standard practice to blend small, 100-pound increments of Comp A-3 (two boxes) for all press loadings. This operation was time consuming, costly and, because of static build-up in the blender, potentially hazardous. Therefore, similarly to the objectives of inter-lot blending, a group of experiments was designed to determine whether or not intra-batch blending was statistically valid.

An additional three million pounds of Comp A-3 were suspended because the desensitizer wax content fell below the specified lower limit of 8.3 percent. Blends of high and low wax content Comp A-3 to attain the desired 9 percent mean were programmed in a manner similar to that for blending high-low bulk density materials. The same objectives, i.e., both conservation and usability of suspended materials without compromising end item quality, applied in all cases.

C. Temperature Effects Studies

There were several important reasons for undertaking a series of temperature variation studies:

Comp A-3 desensitizing waxes place restraints upon the temperature ranges over which the Comp A-3 can be processed. Thus, at too low a temperature, proper flow and consolidation is inhibited. At too high a temperature, the material becomes tacky and sticks to the press rams. In warm weather, loading plants complained of "reassertion," i.e., growth or creep of the Comp A-3 in the loaded projectiles. It was suspected that reassertion was the gradual expansion of compressed air that had been trapped in warm, tacky wax during the press loading operation.

Fleet return and surveillance radiographic inspection revealed that a large percentage of Fleet stock 5" projectiles had developed detectable cracks. Temperature cycling tests demonstrated that all Comp A-3 loaded projectiles will crack when subjected to wide temperature fluctuations. Since cracks or discontinuities in explosive charges have always been suspect. it became imperative to learn whether or not cracks that developed immediately after projectile loading were different from cracks that occurred in postmanufacture storage and whether either type of crack was more undesirable than the other.

A series of experiments were designed to load a predetermined number of 5" projectiles and temperature cycle them for varying lengths of time. The purpose was to determine both the conditions under which cracks form, how these cracks affected gun firing, and also to gain insight into methods of elimination and/or controlling crack formation. These studies, along with the pressing effects studies (II.D), not solely concerned with the immediate problem of salvaging the stockpile, will be documented in a later report.

D. Pressing Effect Studies

Navy projectiles were loaded originally by hand tamping. Eventually hydraulic press loading was introduced. However, loading procedures apparently were developed on a nonscientific, more or less trial and error basis. In any case, recent workers in the field could find no data base or rationale for the controls that had been established for ram pressures, ram configurations, ram speeds, dwell times, number of increments pressed or, for that matter, for any indication that any of these variables might be close to or far from the upper limits of acceptable processing safety margins.

A coordinated series of experiments incorporating these variables with those of the blending and temperature effects studies were matrixed. The purpose of the experiments again was to quantify, if possible, the effect of each variable upon process safety and end product quality.

Data was collected on:

- The flow characteristics of dyed, inert simulants and dyed, explosive in 5" projectiles.
- Pressure-density profiles of Comp A-3 in cylindrical small charges as well as in projectiles.
- Correlations between the minimum number of increments and dwell times (i.e., cost effectiveness) and Comp A-3 lots of different bulk densities required to give a quality product.
- Optimum weights for each increment.
- Upper pressure limits and pressing rates that would avoid potentially dangerous "flow-by" or sudden explosive column collapse.
- A variety of ram configurations to evaluate their effect on possible air entrapment, increment separation and reassertion problems.

E. Treatment of Data

NEDED's technical approach to all data reduction was to eliminate the possibility of unintentional, experimenter bias. To achieve this objective, whenever feasible, all raw data were submitted to an independent statistical data reduction division of the Quality Assurance Department of the Naval Ammunition Production Engineering Center (NAPEC), Naval Ammunition Depot (NAD) [now the Naval Weapons Support Center (NAVWPNSUPPCEN)], Crane, Indiana. NAPEC's mission was to make statistically meaningful interpretations of variable effects and to assign confidence limits to these computed judgments. From these data, NEDED's goal was to establish the loading parameters for 5" projectiles and also to define the gamut of usable grades of Comp A-3 as well.

III. PARAMETRIC STUDIES

A. Introduction - Review of Analytical Techniques

The analytical procedures used to evaluate the major variables that influence end product quality were themselves subjected to a critical review. Therefore, before describing the results and conclusions drawn from the parametric studies themselves, it is appropriate to first summarize the evaluation of these analytical procedures in terms of their accuracy and/or precision.

1. Bulk density measuring techniques

To press load explosives, it is essential that the press and die designer have a fairly accurate value of the bulk density of the explosive powder in order to correlate volume, increment, and ram stroke requirements for the processing equipment. In addition, there is a direct relationship between the final pressed density and the initial bulk density of a given specie of Comp A-3. By "given specie" is meant Comp A-3 formulated with a particular class of RDX. (See III.B.3.)

When the Ammunition Special Study Group[3] recommended 1.60 g/cc as the minimum overall pressed density for 5" projectiles, it was concluded that Comp A-3 exhibiting bulk density of less than 0.81 g/cc could not be pressed reliably to the recommended value.

As will be shown, this conclusion was not inviolable. However, at that time, during the height of the Southeast Asia conflict, firm standards had to be established quickly even if somewhat arbitrarily.

Discrepancies soon began to surface between bulk densities reported by HAAP (the Comp A-3 manufacturer) and Navy user stations, with HAAP bulk density values invariably reported as higher than those obtained at Navy user stations. It was soon determined that the two were using different analytical procedures as defined in MIL-STD-650. HAAP used Method 201.3 and the Navy was using Method 201.1. Suffice it to say, the differences between the two procedures are primarily that Method 201.3, which includes some consolidation of the bulk material, gave values which passed as acceptable almost all of HAAP's production, whereas 95 percent of this material did not meet the 0.81 g/cc minimum bulk density criteria when tested using Method 201.1[4].

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[3]Ibid.

[4]Holston Defense Corp Development Rept No. PX-32, Composition A-3 Bulk Density Study, Jun 1972

Eventually, minor modifications were made by NLDED to Method 201.1, resulting in Method 201.1.1, and a round robin evaluation between HAAP, Picatinny Arsenal, NAD Crane and NAVWPNSTA Yorktown was carried out. "The maximum difference between the arithmetic means obtained by the four activities was 0.011 for any four sets of samples taken. In general, no statistical differences in the results obtained was noted between the activities."[5]

Thus, a meaningful and reproducible procedure for measuring bulk density was achieved.

2. Overall pressed charge density measurements

The most useful measure of charge quality in a projectile is its density. The most accurate means of determining density is by an analysis of core samples. Core samples are obtained by removing a rod of explosive down through the center of the projectile with a hollow drill. The rod is then sawed into small sections (approximately 3/4" x 3/4") so that the density of the explosive can be determined at any point between the base and nose of the projectile. Unfortunately, the hole left after core sampling is not repairable and the projectile cannot be refurbished for use. Therefore, although core sampling is used on a limited basis, a less expensive, nondestructive method for measuring charge density is necessary. Measuring overall density is one such nondestructive technique.

Thus, the average density of the charge can be obtained easily provided certain measurements are made prior to and after loading; i.e., it is necessary only to know the volume of the projectile cavity and the weight of explosive loaded into it. The average density thus obtained presents a valid picture of charge quality and in projectile parlance is referred to as overall density.

Prior to the issuance of standardized projectile loading procedures in 1970 and the investigations reported herein, loading activities had no formalized system for monitoring explosive load quality. Some individual activities issued loading drawings that specified increment sizes, dwell times and press ram pressures with the supposition that if these were adhered to, satisfactory loads would be obtained. Sometimes they stipulated that any change in the various parameters would necessitate density checks. This and other methods used failed to provide any real control over charge quality since overall density requirements or measuring techniques were never clearly defined and varied among individual loading plants.

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[5]Allen, J.C., Gultz, H., Picatinny Arsenal TR 4364, Evaluation of Method to Determine Bulk Density of Composition A-3, May 1972

Several techniques were developed by NEDED to measure the overall charge density with a maximum measuring error of only 0.125 percent and a maximum reporting error of 0.6 percent. Current requirements specify a process control type of sampling plan to assure a continuous monitoring of the projectile charge quality. Furthermore, concurrent but reduced core sampling plans are used to verify the validity of the overall density measurement. The method for measuring overall density is now specified in all Weapons Specifications prepared by NEDED for all projectiles.

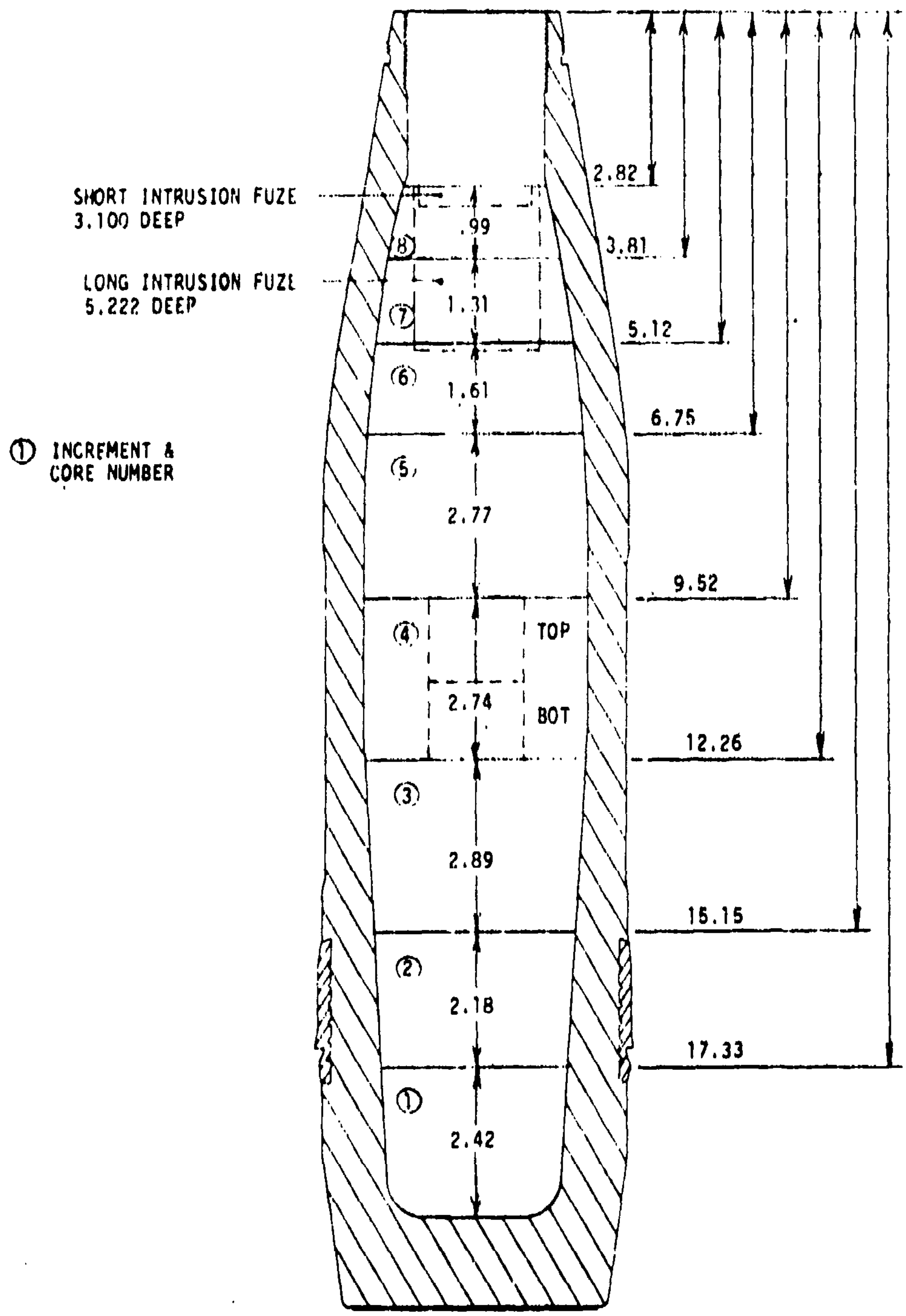
Thus, the second analytical technique for the press loading study was standardized.

3. Individual core density measurements

The objective of the gun ammunition explosive loader is to press the explosive into the projectile so uniformly and tightly that it will not move during gun launch. Gun firing experiments discussed in the Ammunition Special Study Group report[3] established an explosive charge density requirement to be at least 1.60 g/cc. To achieve this requirement, pressing parameters are established to give the production plants a high probability of meeting this density. Still, it is essential that actual density measurements be taken at predetermined intervals to ensure that the loading process has been kept under control. Such measurements are made by removing a single core of explosive, running from the nose to the base of the projectile as described in III.A.2. The core so taken is then carefully sectioned at the pressed increment boundaries. This normally yields five or six segments of explosive, each about 2 to 3 inches long. Each segment is further divided into two pieces, labeled top or bottom. The numbering of core samples begins with number one at the projectile base and moves upward successively to the nose. Each core is assigned the number of the pressing increment it came from, as shown in Figure 1.

Prior to the introduction of standardized techniques for determining core densities, each projectile loading activity used its own type of equipment, sampling techniques and a locally approved technique for determining density. As a result, disparities existed in the measured core densities of different loading plants, making it too difficult to correlate data. A standard procedure was developed by NEDED and is now mandatory for all projectile production. This procedure is contained in every projectile Weapons Specification published since 1970. The procedure describes such things as sample size, sample preparation, type of scales, and an additive to be put in the water to inhibit

[3] Loc. cit.



5"/54 PROJECTILE INCREMENT AND CORE SAMPLE PLAN

FIGURE 1

bubble formation on the sample. The procedures were originally developed by the NAVWPNSTA Yorktown for the density determination of Explosive D cores by water displacement[6] and adapted to Comp A-3 cores.

Thus, the third analytical technique for the press loading study was standardized.

4. Compositional analysis of bulk Comp A-3

The standard procedure for determining wax content in Comp A-3, as described in MIL-C-440B, 5 July 1961, was to extract the wax from the RDX with hot benzene and calculate the wax percentage by weight loss.

In March 1970, NEDED had run comparative studies of benzene, carbon tetrachloride and naphtha as wax extraction solvents[7]. The conclusion drawn from the study was that, under the conditions specified in MIL-C-440B, benzene was not the best wax solvent This was due to the fact that of the three procedures, the benzene extraction procedure showed the greatest variance in wax content values (in excess of 1 percent) using control samples of known composition in each case. Further, the use of benzene was being discouraged by Navy safety offices in all applications where less toxic and less flammable alternates were available.

For these reasons, the Navy switched to carbon tetrachloride or naphtha as alternate extraction agents for wax analyses in explosives.

However, all Army manufactured Comp A-3 had been purchased to the benzene extraction method specification. The result was that when Navy stockpiles were being reexamined for wax content by Navy procedures, a substantial quantity of material was found to lie below the 8.3 percent specification minimum. Fortunately however, in the interim, the Comp A-3 specification benzene procedure for wax extraction was modified to improve the reproducibility of the analytical method. These changes are detailed in MIL-C-440B Interim Amendment 2 (MU), 31 Jan 1972. This more accurate and precise procedure was then used to again examine the suspended lots of purportedly low wax content Comp A-3.

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[6] Parker, O.J., Cousins, E.R., NWSY TR 71-3, Procedure for the Density Determination of Explosive D by Water Displacement, 14 May 1971

[7] Cousins, E.R., Hogge, W.C., NWSY TR 70-1, A Comparison of Extraction Solvents for the Analysis of Composition A-3 Explosive, 25 May 1970

It was demonstrated that a substantial quantity of suspended material had indeed been produced to specification by the Army manufacturers and could be salvaged for use in loading 5" projectiles.

Thus, the fourth analytical technique for the press loading study was standardized.

5. Radiographic procedures and standards for loaded projectiles

Prior to 1970, the only quality controls on 5" projectile production were: standard operating procedures and drawings; overall density; and core densities. The latter is a destructive test and several days of poor quality production conceivably could be run before the results of core analyses became known and corrective action taken. Therefore, in February 1970, NEDED incorporated nondestructive radiographic examination as part of the acceptance criteria for 5" projectiles[8].

The Weapons Specification called out the following key points:

- There shall be no increment lines shown on radiograph indicating a separation or potential separation of increments. (This was later refined to include: voids - none permitted; cracks - none permitted.)
- Foreign material - none permitted.
- One projectile representative of production of each operating press per shift shall be selected at random and radiographed.
- The sampling plan for the loaded projectiles shall be in accordance with Level II of MIL-STD-105 with 100 percent inspection for CRITICAL defects, with an A ceptable Quality Level (AQL) of 1.0 for MAJOR defects, and with an AQL of 2.5 for MINOR defects, unless otherwise specified.
- Production represented by any sample projectile failing to meet the requirements shall be rejected.
- The explosive charge discontinuities shall be determined by radiography in accordance with the requirements of MIL-STD-746.

[8]WS 13271, Purchase Description for the Composition A-3 Explosive Loaded Projectile, 5 Inch 38 Caliber, Mk 52 Mod 0, 25 Feb 1970

The crack criteria were incorporated on recommendation of the Ammunition Special Study Group[8]. It later became apparent that the criteria for cracks - none permitted - were not realistic and that cracks in Comp A-3 loaded projectiles cannot be eliminated. They occur in loaded projectiles during Fleet storage, during temperature fluctuation and even after new production.

The crack studies resulted in the current requirements[9] for radiographic acceptance.

The key terms of the requirements are:

- Cracks or separations - total of two permitted as follows: none within the bottom 3 inches of the explosive filler.
- Cracks or separations shall not be closer than 2 inches apart nor wider than .050 inch.
- Not more than one crack shall be permitted between the top of the explosive filler and the bottom of the nose fuze cavity.

Because individual loading stations possessed X-ray equipment of varying output (i.e., 8 million volts at NAVWPNSTA Yorktown to 250 kilovolts at NAD Crane), further definition of procedures were spelled out above and beyond those prescribed in MIL-STD-746. These were:

- The explosive charge discontinuities shall be determined by radiography, in the 0 degree position only, in accordance with the requirements of MIL-STD-746 and applicable drawings.
- In all exposures, the center of the X-ray beam shall form a 90 $\pm$ 2 degree angle with the longitudinal axis of the projectile.
- The photographic density of the film used shall not be less than 1.5 when checked with a densitometer. The density shall be determined on the film in a region of sound charge plus metal corresponding to the portion of the material which is of the greatest combined thickness to be examined on the negative.

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[8] Loc. cit.
[9] WS 13574A, Projectile, 5 Inch 54 Caliber, Mk 64 Mod 0, Composition A-3 Explosive Loaded, 23 May 1975

- Test projectiles shall be maintained within a temperature range of 68° to 100°F until after projectiles have been radiographed. In the event that the projectiles have been allowed to deviate from the 68° to 100°F temperature range, they shall be confined to an area within this temperature range for a minimum of 36 hours before being radiographed.

- Failure of one of the projectiles selected to meet the explosive charge discontinuities shall be cause for rejection of the entire production lot that it represents. If a projectile fails because of an apparent crack, it shall be X-rayed again with the X-ray beam centered directly over the crack and the acceptance or rejection will be based upon the second X-ray to verify crack width.

More importantly, the sampling plan was changed from the almost statistically meaningless one projectile per press per shift to the following:

X-RAY SAMPLING

Production lot size	Sample size	Production lot size	Sample size
600-1000	29	51-100	25
251-599	28	26-50	22
151-250	27	19-25	18
101-150	26	1-18	All

With the incorporation of X-ray criteria and refined radiographic techniques, the evaluation of the last of the five analytical tools for the parametric study was completed.

B. Bulk Density Studies

1. Varying bulk density only

a. Purpose of this study phase

In early 1972, it was discovered that only 30 percent of the Navy's ten million-pound Code A* stockpile of Comp A-3 (three

*As will be discussed in III.B.3, an additional three million pounds of Comp A-3 were suspended in condition Code H for low wax content.

million pounds) met or exceeded the 0.81 g/cc bulk density criteria established by the Ammunition Special Study Group in 1968. The reasons for this were traced to the following circumstances:

- In the 1957 revision of the Comp A-3 specification, bulk density requirements unaccountably were dropped and this omission had gone undetected for over 10 years during which time the majority of Navy Comp A-3 stocks had been procured.

- Over the years, HAAP had lost the processing skills to guarantee consistent production of high bulk density material.

- Until discrepancies between HAAP and Navy bulk density measuring techniques were discovered, based upon HAAP supplies density records, it had been thought that 80 percent rather than 30 percent of the stockpile met Navy density requirements.

Joint Army-Navy technical conferrees concluded that it was not practical to reprocess the low bulk density Navy stockpile. Therefore, the only quick remedial recourse open to the Navy was to develop procedures for loading low bulk density Comp A-3 without compromising end product quality or processing safety.

b. Establishing the single variable matrix

Six variables affect end product density and quality of 5" Comp A-3 loaded projectiles.

- Ram speed

- Ram dwell time

- Raw material and projectile temperatures

- Loading or ram pressure

- The number of increments used in loading

- Bulk density of the explosive load

The first two variables, ram speed and dwell time, have been definitized in over 30 years of practical experience. Thus, it is probable that ram speeds in excess of 85 inches per minute can dangerously overheat the material during viscous shear and flow; insofar as ram dwell time is concerned, it has long been established that a 6-second minimum time is required to allow for completion of increment flow and for deaeration of the explosive. In this way, optimum pressed densities can be achieved and reassertion is minimized.

Empirically, over the years it had been decided that because of the wax characteristics used to formulate Comp A-3, a temperature range of 68° to 80°F cannot be exceeded at either extreme. Comp A-3 below 68°F is too stiff to flow smoothly under pressure and above 80°F is tacky and sticks to the press ram or to itself and inhibits the escape of entrapped air. It is more difficult to achieve optimum pressed densities at the lower temperature range than at the higher temperature range of the spectrum. This data was reverified more quantitatively in later temperature effects studies.

Therefore, the three variables - ram speed, ram dwell time, and temperature (85 inches per minute, 6 seconds, and 68°F, respectively) - were held constant for this portion of the parametric study.

In a like manner, preliminary investigations were also undertaken to fix ram pressures and numbers of increments so that the only variable remaining would be the Comp A-3 bulk density itself. Here too, a review of past experience quickly narrowed down the pressure options. Over many years of production, using 0.81 g/cc bulk density Comp A-3 in both 5"/38 and 5"/54 projectiles, it was generally believed that optimum pressed densities could not be achieved reproducibly below 13,000 psi and that insignificant improvements were obtained at pressures above 15,000 psi. However, at 15,000 psi, because of the internal geometry of 5"/38 projectiles, increment "breakdown" occasionally occurred. (Breakdown is the condition wherein the compressed explosive column under the ram suddenly collapses under sustained ram pressure allowing the ram to descend further at speeds in excess of the 85 inches per minute limit.) Therefore, the ram pressure variable was fixed at 14,000 psi for the 5"/38 study and at 15,000 psi for the 5"/54 study.

Similarly, the optimum number of increments were arrived at from both experience and practical limitations. From a production rate viewpoint, the fewest number of increments pressed are most economical, whereas from a quality standpoint, it had long been established that six increments was the minimum number that would reliably produce high quality end products using 0.81 g/cc bulk density Comp A-3. Prescreening experiments with low bulk density material proved that eight increments was the minimum number that would produce uniformity in the end product density.

Thus, from experiment, experience and a knowledge of production needs, all variables except bulk density were held constant in this portion of the bulk density study. Other secondary variables such as operator skills, chemical analyses, humidity, etc., were also held constant as far as possible.

The matrix examined covered nine sets of projectiles (50 per set) loaded with Comp A-3 having bulk densities of 0.75, 0.77, 0.79, 0.80 and 0.81 g/cc, with the last serving as a control. The study was divided into an investigation of 5"/38 projectiles consisting of five sets loaded with 0.75, 0.77, 0.79, 0.80 and 0.81 g/cc bulk density material, and of 5"/54 projectiles consisting of four sets loaded with 0.77, 0.79, 0.80 and 0.81 g/cc bulk density material.

Overall and core densities for all projectiles were determined. Thus a total of 450 overall densities were determined and 5400 core samples were taken and analyzed, except for those broken in sampling.

c. <u>5"/54 bulk density variation results</u>

Table I summarizes the results obtained and includes the average pressed densities and standard deviations for each set of projectiles, the average density and the standard deviation for the lowest or minimum core density found in each set, and the average density and standard deviation for the top and bottom of the No. 3 cores in each set. (This latter is singled out from the other six cores because it is normally that area of the projectile where the greatest variation is found and is considered to be the most critical.) The data was verified by the Weapons Quality Engineering Center (WQEC) at NAD Crane, who concluded that "the estimated percent below a press density specification of 1.60 relative to the process used in loading these projectiles is zero. This statement is applicable to both core density and overall density."[10]

Obviously, on the basis of averages, it would appear that the specification criteria established by the Ammunition Special Study Group could easily be attained from each bulk density type. However, it was also pointed out by NAD Crane[10] that significant differences resulted between averages for the lowest to the highest bulk density material used, and that there were more individual cores that showed up in the lower end of the density spectrum for the low bulk density material than for the high bulk density material. This possibility had been foreseen and it was for this reason that the set sizes were chosen large enough to be statistically analyzed. Accordingly, all density data from every core of every projectile was submitted to NAPEC for a computerized statistical analysis. The computer print out results for the four sets of cores are depicted in Figures 2 through 5.

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[10]NAD Crane ltr 30412-JGG:ofw 8030 of 17 Mar 1972 to NAVWPNSTA Yorktown (NEDED), Subj: Data analysis on special loading of 5"/54 Projectiles using various Comp A-3 bulk densities

TABLE I

5"/54 PROJECTILE - DENSITY SUMMARY

Bulk		.77	.79	.80	.81
Overall	n $\bar{x}$ s	50 1.6388 .00564	50 1.6399 .00681	48 1.6430 .00439	48 1.6425 .00351
Minimum Core	n $\bar{x}$ s	50 1.6204 .00631	50 1.6229 .00618	50 1.6284 .00584	48 1.6294 .01141
Core No. 3 Top and Bottom	n $\bar{x}$ s	99 1.6363 .01064	100 1.6389 .01061	100 1.6446 .00905	96 1.6449 .00928

n = Number tested
$\bar{x}$ = Sample mean (avg)
s = Sample standard deviation
Density in g/cc

Pressing constants

Temperature:	68°F
No. of increments:	8
Ram pressure:	15,000 psi
Ram speed:	85"/min
Dwell time:	6 sec

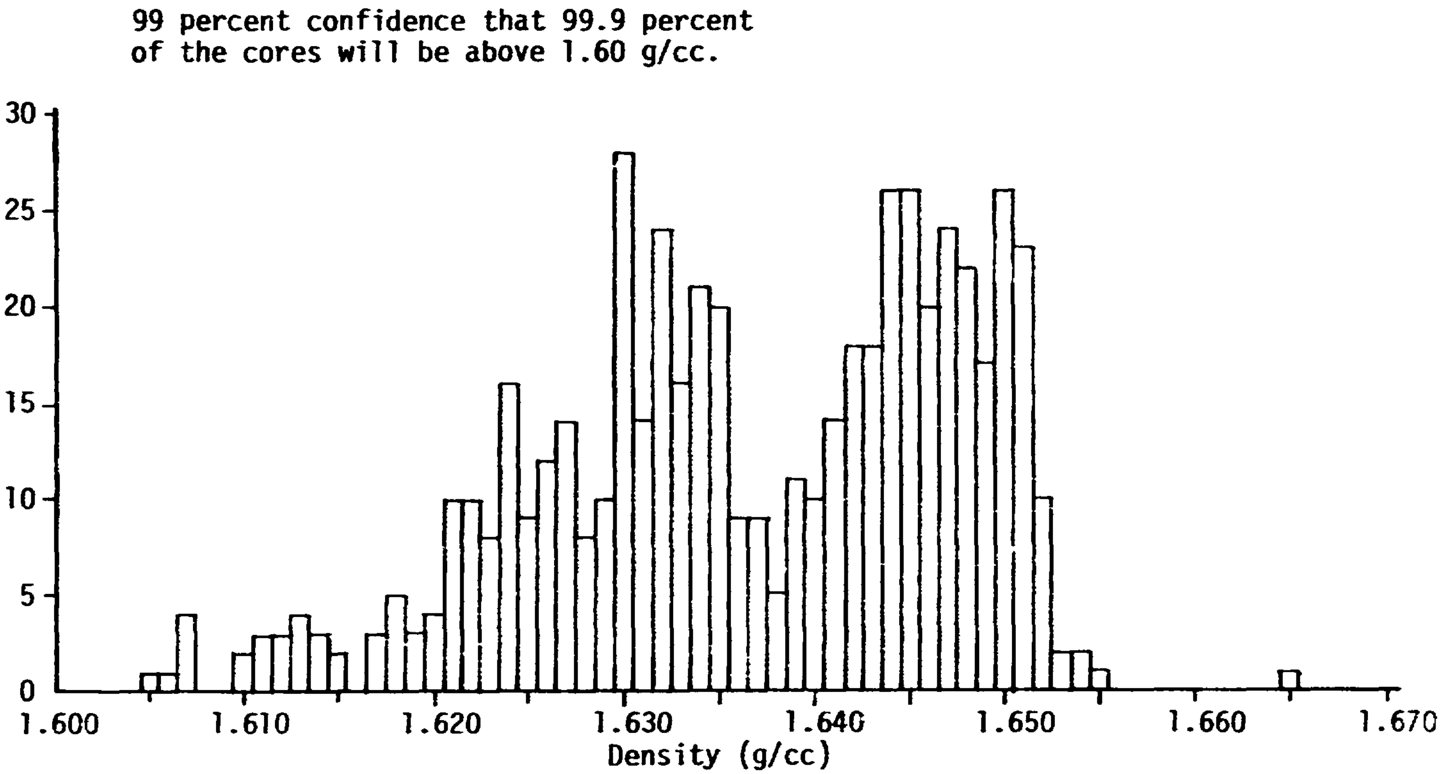

FIGURE 2. CORE DENSITY ANALYSIS - .77 G/CC BULK DENSITY

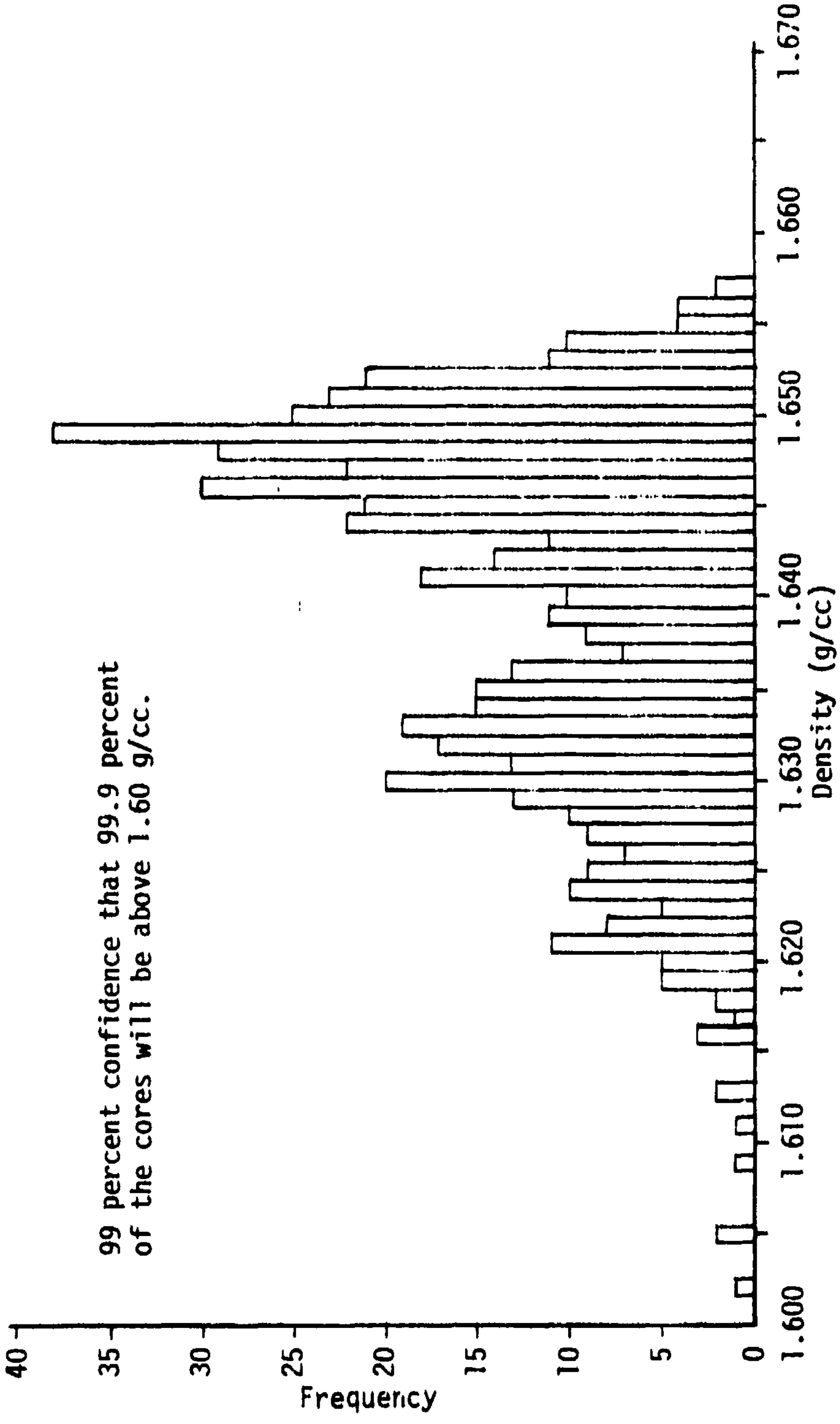

FIGURE 3. CORE DENSITY ANALYSIS - .79 G/CC BULK DENSITY

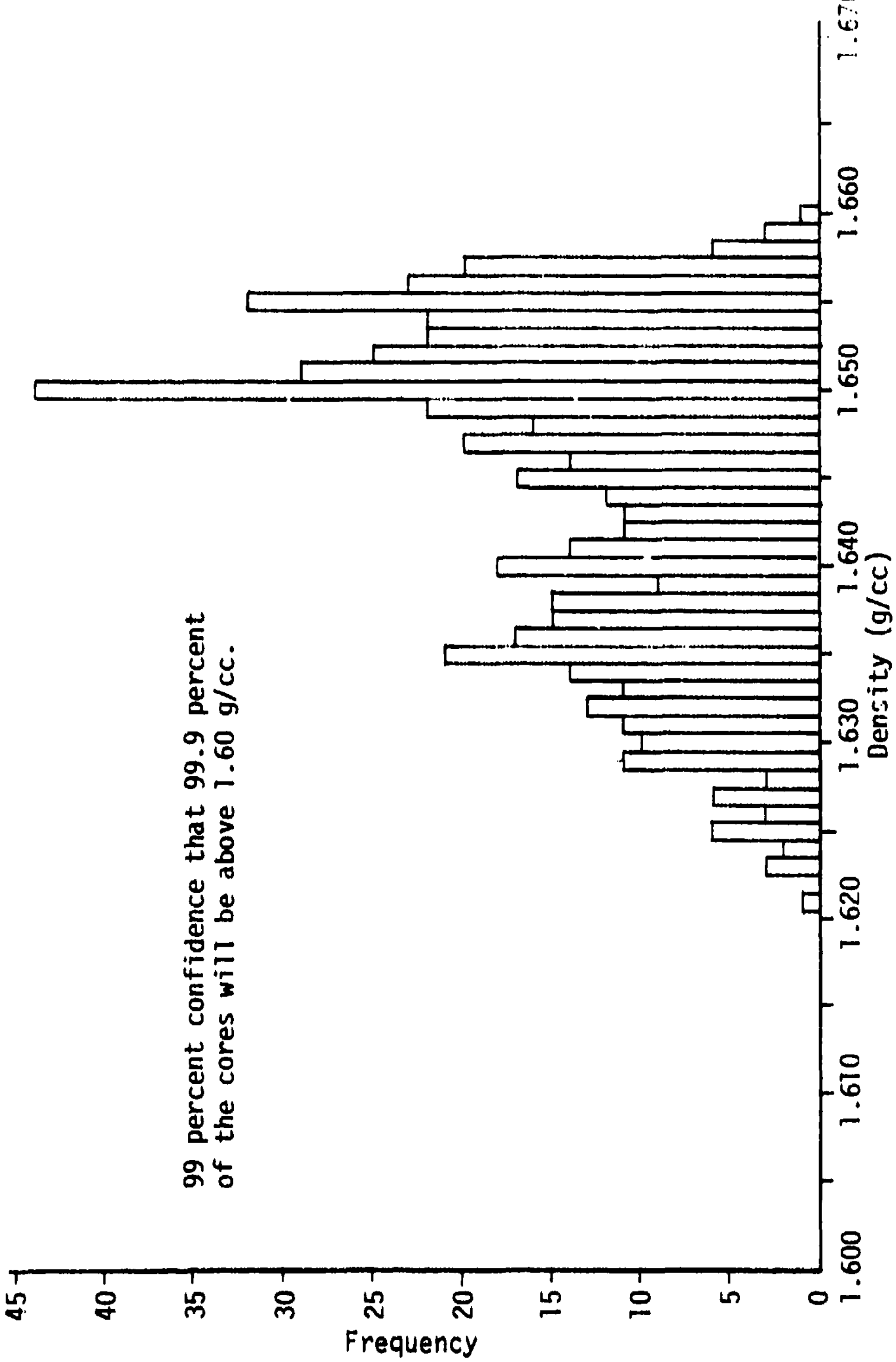

FIGURE 4. CORE DENSITY ANALYSIS - .80 G/CC BULK DENSITY

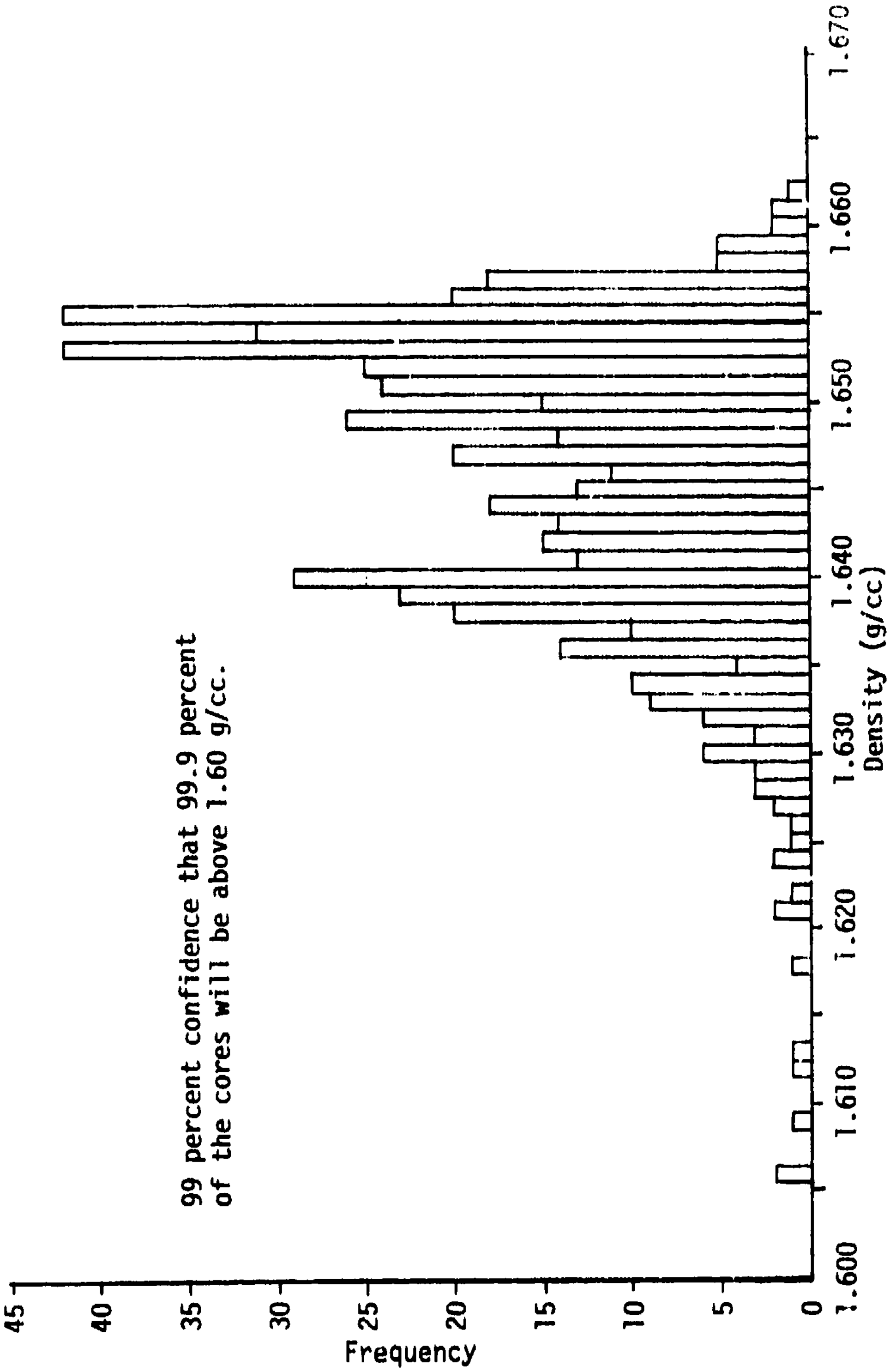

FIGURE 5. CORE DENSITY ANALYSIS - .81 G/CC BULK DENSITY

NAPEC's statistical analysis was summarized as being that there was "99 percent confidence that 99.9 percent of cores produced under the same processing conditions would be above 1.60 g/cc."[11]

d. 5"/38 bulk density variation results

The identical procedures and rationale for data treatment was applied to 5"/38 projectiles as was to 5"/54 projectiles. Two differences were that 0.75 g/cc bulk density Comp A-3 was included as one of the five sets studied and the press pressure, as noted earlier, was fixed at 14,000 psi rather than 15,000 psi. The coring pattern was the same for the 5"/54 projectiles, with slight dimensional differences due to the different projectile geometry. Table II summarizes the results obtained from the five sets of projectile loads. As in the case of the 5"/54, WQEC of NAD Crane[12] estimated that "using MIL-STD-414, no press density will fall below the specification of 1.60 g/cc...". They further concluded at most 19.9 percent of the minimum density cores would fall below 1.63 g/cc for 0.75 g/cc bulk density material.

In a like manner, NAPEC statistically verified that the 99 percent confidence level for producing cores in excess of 1.60 g/cc[13] were even higher in almost every case - i.e., up to 99.99 and 99.999 percent - than the 99.9 percent level calculated for 5"/54 cores.

e. Conclusions and recommendations

Based upon the analyses described above, NAVWPNSTA Yorktown recommended[14] to the Naval Ordnance Systems Command (NAVORDSYSCOM) [now Naval Sea Systems Command (NAVSEASYSCOM)] that, using the processing procedures developed at NEDED, the specification limit for Comp A-3 bulk density be lowered to 0.77 g/cc for use in 5"/54 projectiles and 0.75 g/cc as the lower limit for 5"/38 projectiles.

NAVORDSYSCOM accepted a 0.79 g/cc level for 5"/54[15] and requested that NAVWPNSTA Yorktown and NAPEC provide a coordinated statement and

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[11]NAPEC Rept, Yorktown Comp A-3 Density Data - Histogram Analysis for 5"/54 Projectiles, 16 Aug 1974

[12]NAD Crane ltr 30412-JGG:las 8030 of 25 Apr 1972 to NAVWPNSTA Yorktown (NEDED), Subj: Data analysis on special loading of 5"/38 Projectiles using various Comp A-3 bulk densities

[13]NAPEC Rept, Yorktown Comp A-3 Density Data - Histogram Analysis for 5"/38 Projectiles, 16 Aug 1974

[14]NAVWPNSTA Yorktown msg 281950Z Feb 1972 to NAVORDSYSCOM

[15]NAVORDSYSCOM msg 090247Z Mar 1972 to NAVWPNSTA Yorktown

TABLE II

5"/38 PROJECTILE - DENSITY SUMMARY

Bulk		.75	.77	.79	.80	.81
Overall	n	25	50	50	50	50
	$\bar{x}$	1.6387	1.6464	1.6457	1.6450	1.6488
	s	.00313	.00435	.00359	.00417	.00379
Minimum Core	n	24	50	50	50	50
	$\bar{x}$	1.6317	1.6357	1.6366	1.6378	1.6386
	s	.00199	.00273	.00304	.00481	.00615
Core No. 1 Bottom	n	24	50	50	50	50
	$\bar{x}$	1.6452	1.6482	1.6471	1.6479	1.6486
	s	.00243	.00233	.00320	.00371	.00414
Core No. 3 Bottom	n	24	50	50	50	50
	$\bar{x}$	1.6345	1.6382	1.6388	1.6399	1.6405
	s	.00363	.00272	.00339	.00422	.00415
Core No. 3 Top	n	24	50	50	50	50
	$\bar{x}$	1.6451	1.6493	1.6491	1.6497	1.6512
	s	.00451	.00184	.00267	.00421	.00439
Core No. 7 Top	n	24	50	50	50	50
	$\bar{x}$	1.6428	1.6451	1.6455	1.6445	1.6463
	s	.00350	.00342	.00329	.00497	.00499

n = Number tested
$\bar{x}$ = Sample mean (avg)
s = Sample standard deviation
Density in g/cc

Pressing constants

Temperature: 68°F
No. of increments: 8
Ram pressure: 14,000 psi
Ram speed: 85"/min
Dwell time: 6 sec

documentation revision addressing both 5"/54 and 5"/38 systems. This was accomplished via messages between NAVWPNSTA Yorktown[16] and NAPEC[17] and the Systems Command, the final decisions being to accept 0.79 g/cc bulk density for 5"/54 projectiles and 0.77 g/cc for 5"/38 projectiles. The net result was that usable stocks of Comp A-3 were increased by six million pounds. The potential disposition of the remaining one million pounds of material that fell below 0.77 g/cc bulk density is discussed in III.C.2.

2. Graphite additive effects on varying bulk density Comp A-3

Blending both high and low bulk density Comp A-3 resulted in a final bulk density lower than expected and this condition resulted from static charge buildup on the Comp A-3 during the blending operation.

Therefore, it was reasoned that graphite, in addition to being an excellent lubricant, is an excellent antistatic agent and might be used as an additive in Comp A-3. First, it was expected that blending graphite with low bulk density Comp A-3 would raise the overall bulk density to specification limits by static dissipation. Second, it was expected that the lubricity of graphite/Comp A-3 blends would flow more easily under pressure, resulting in the desired pressed densities of the final charge - even when low bulk density Comp A-3 was used at the start.

Accordingly, a systematic examination of graphite/Comp A-3 blends was undertaken. The program was divided into three parts:

- Varying the graphite content in a fixed Comp A-3 batch.
- Varying the bulk density of Comp A-3 using a fixed, 0.5 percent, graphite content.
- Gun firing of graphite/Comp A-3 loaded projectiles.

a. Variable graphite, fixed percent Comp A-3 analyses

One hundred pounds of low bulk density Comp A-3 (0.725 g/cc) was blended for 2 minutes with an increasing amount of

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[16]NAVWPNSTA Yorktown spdltr 504:EYM:dgh of 7 Aug 1972 to NAVORDSYSCOM (ORD-04M), Subj: Comp A-3 explosive; utilization of

[17]NAPEC Crane ltr ORD-04M/B32E/SCR:clb 8010 of 6 Sep 1972 to NAVORDSYSCOM (ORD-04M), Subj: Composition A-3 explosive; utilization of

graphite added at the end of each 2-minute interval. Samples of the blend were withdrawn after each blending operation for bulk density measurement. The graphite was added in increments of 0.1 percent until the graphite content totaled 1.0 percent and was added in 0.25 percent increments thereafter until a 4 percent level was reached. Results are plotted in Figure 6. It can be seen that except for a slight drop-off in density at the 0.1 percent graphite level, the bulk density was increased approximately 0.02 to 0.03 g/cc for each 0.5 percent graphite added. Thus, the first postulate, namely that graphite addition would indeed increase the bulk density of Comp A-3, was realized.

Before proceeding to an examination of variable bulk density Comp A-3 versus a fixed graphite content, it was necessary to determine the pressing characteristics of the individual blends of variable percentage graphite. Preliminary screening indicated that when the graphite content exceeded 1.0 percent, "breakthrough" of the first increment occurred occasionally - particularly in 5"/38 projectiles. Therefore, 0.5 percent was arbitrarily chosen as both the fixed and the maximum percent of graphite that would be used in subsequent studies. Next it became necessary to determine the optimum blending time for the 0.5 percent graphite/Comp A-3 mix. Figure 7 depicts the variation of bulk density with blending time. Two factors of interest can be noted. The first is that the sampling method of the bulk material influences the measured bulk density by as much as 0.01 g/cc. The second is that optimum density increase is achieved after approximately 1 minute of blending.

With this background, the second phase of the graphite/Comp A-3 blend study was begun.

b. <u>Effects of 0.5 percent graphite on varying Comp A-3 bulk density</u>

A matrix of experiments were established for both 5"/38 and 5"/54 projectiles similar to those described in III.B.1.

Table III abstracts the NAPEC summation of data[13] for 5"/38 projectiles obtained from varying bulk density Comp A-3 before versus after 0.5 percent graphite addition. There are several important facts to be noted in the table:

- For the Comp A-3 without graphite, 15,000 psi ram pressure was used versus 14,000 and 13,250 psi for the graphite blend. The latter were used both to simulate standard loading procedures and as an extra precaution against breakthrough of the graphited material.

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[13]<u>Loc. cit</u>.

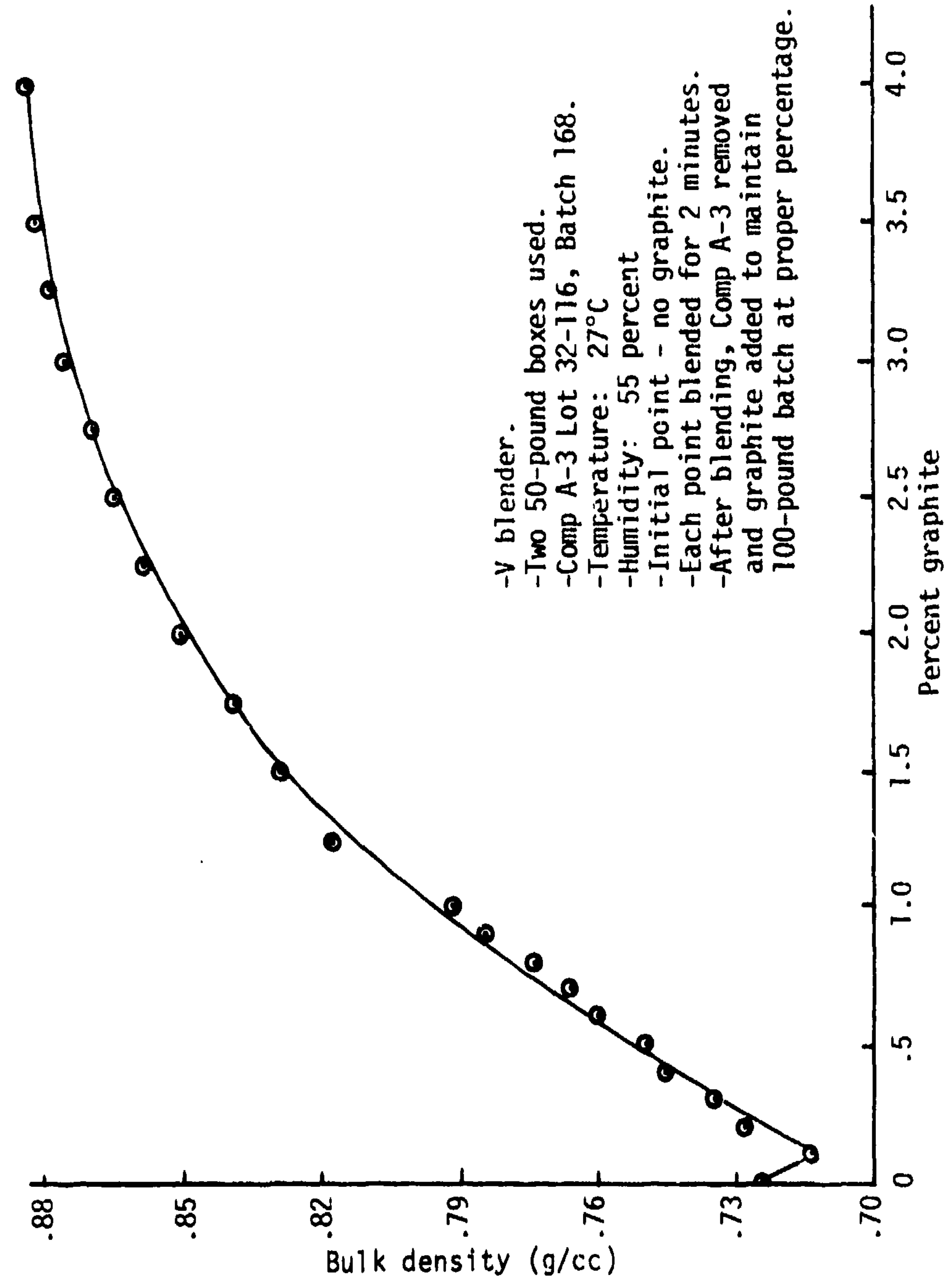

FIGURE 6. BLENDING STUDY - DENSITY VS PERCENT GRAPHITE

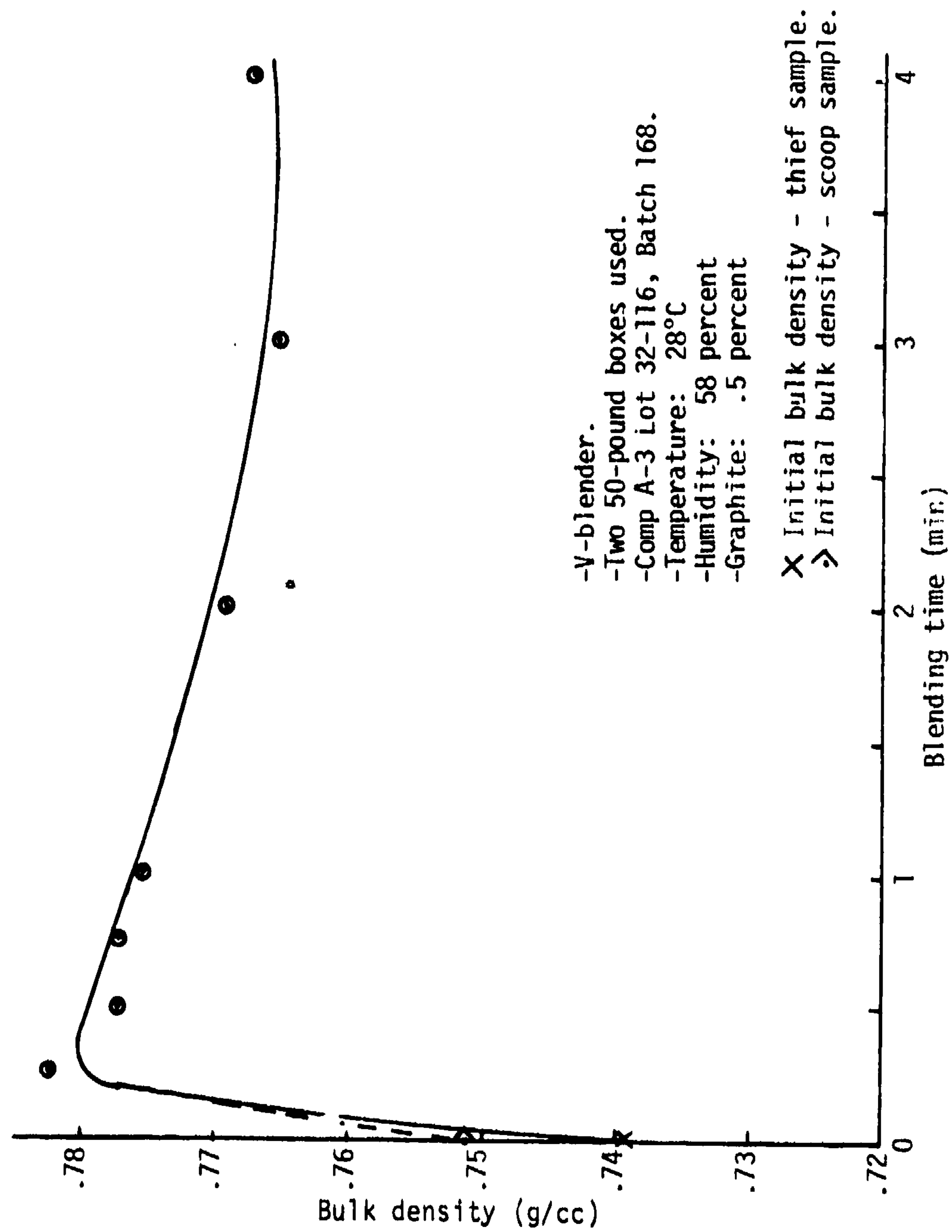

FIGURE 7. BLENDING STUDY - DENSITY VS BLENDING TIME

TABLE III. 5"/38 PROJECTILE - BLENDING SUMMARY

		Comp A-3 without graphite					Comp A-3 with 0.5% graphite						
Bulk density		A .75	B .77	C .79	D .80	E .81	A' .79	B' .80		C' .81		D' .82	E' .83
Ram pressure		15,000	15,000	15,000	15,000	15,000	14,000	13,250	14,000	13,250	14,000	13,250	13,250
Core No. 1 Bottom	n x̄ s	24 1.645 .0024	50 1.648 .0022	50 1.647 .0032	50 1.648 .0037	50 1.649 .0041	11 1.650 .0034	27 1.646 .0047	28 1.648 .0026	11 1.649 .0019	6 1.648 .0029	6 1.650 .0018	6 1.655 .0016
Core No. 2 Top	n x̄ s	24 1.645 .0038	50 1.648 .0021	50 1.647 .0043	50 1.647 .0046	50 1.651 .0039	11 1.653 .0012	27 1.651 .0042	28 1.652 .0024	11 1.651 .0011	6 1.652 .0013	6 1.655 .0015	6 1.657 .0015
Bottom	x̄ s	1.632 .0023	1.636 .0023	1.638 .0021	1.639 .0047	1.641 .0044	1.629 .0036	1.624 .0049	-	1.627 .0057	1.628 .0042	1.635 .0027	1.638 .0023
Core No. 3 Top	n x̄ s	24 1.645 .0045	50 1.649 .0018	50 1.649 .0027	50 1.650 .0042	50 1.651 .0044	11 1.654 .0020	27 1.651 .0031	28 1.652 .0028	11 1.652 .0009	6 1.652 .0010	6 1.655 .0016	6 1.657 .0019
Bottom	x̄ s	1.634 .0036	1.638 .0027	1.639 .0034	1.640 .0042	1.641 .0042	1.642 .0020	1.641 .0038	1.640 .0022	1.642 .0022	1.640 .0015	1.646 .0018	1.647 .0017
Core No. 4 Top	n x̄ s	24 1.647 .0031	50 1.650 .0019	50 1.651 .0023	50 1.651 .0037	50 1.653 .0038	11 1.655 .0019	27 1.651 .0035	28 1.653 .0026	11 1.653 .0019	6 1.652 .0008	6 1.655 .0026	6 1.657 .0022
Bottom	x̄ s	1.635 .0032	1.640 .0031	1.641 .0024	1.642 .0037	1.642 .0067	1.646 .0024	1.643 .0044	1.645 .0030	1.644 .0015	1.643 .0024	1.649 .0029	1.650 .0024
Core No. 5 Top	n x̄ s	24 1.645 .0024	50 1.651 .0019	50 1.650 .0057	50 1.651 .0046	50 1.653 .0037	11 1.654 .0019	27 1.652 .0033	28 1.652 .0025	11 1.652 .0012	6 1.651 .0013	6 1.653 .0023	6 1.656 .0014
Bottom	x̄ s	1.645 .0032	1.647 .0021	1.648 .0028	1.648 .0042	1.649 .0045	1.651 .0021	1.648 .0044	1.649 .0023	1.649 .0010	1.649 .0023	1.652 .0021	1.654 .0013
Core No. 6 Top	n x̄ s	24 1.645 .0034	50 1.649 .0027	50 1.648 .0027	50 1.648 .0048	50 1.651 .0040	11 1.648 .0018	27 1.646 .0039	26 1.645 .0036	10 1.647 .0013	- [illegible] .[illegible]04	6 1.649 .0021	6 1.651 .0021
Bottom	x̄ s	1.645 .0025	1.649 .0022	1.649 .0041	1.649 .0049	1.651 .0046	-	-	-	-	-	-	-
Overall density	n x̄ s	25 1.639 .0031	50 1.645 .0043	50 1.646 .0036	50 1.645 .0042	50 1.649 .0038	11 1.643 .0034	27 1.646 .0035	28 1.642 .0059	11 1.645 .0031	6 1.646 .0027	6 1.650 .0049	6 1.649 .0032

n = Number tested
x̄ = Sample mean (avg)
s = Sample standard deviation
Density in g/cc
Ram pressure in psi
A' is A Comp A-3 w/graphite, etc.

Pressing constants

Temperature:	68°F
No. of increments:	7
Ram speed:	85"/min
Dwell time:	6 sec

- The 0.5 percent graphite raised the bulk density approximately 0.02 g/cc in each case.

- Qualitatively, it appears that the same or better densities can be achieved at lower ram pressures when graphited versus ungraphited Comp A-3 is pressed.

- Because of the limited number of samples taken, no meaningful statistical evaluation could be run.

The reason for curtailing this program was the decision that Comp A-3/graphite represented a new explosive and, as such, would probably have to undergo complete WR 50 and qualification testing before its approval for Fleet use. The funds and time were not available to pursue such a program to solve the immediate problems with existing stocks of suspended Comp A-3. However, because it had been demonstrated that: graphite reduced static charge on Comp A-3, led to increased bulk densities, and pressed easily, a limited proof firing program described in par c. below was undertaken.

Table IV abstracts the NAPEC summation of data[11] for 5"/54 projectiles similarly to that for the 5"/38. The important facts to be noted in the table are:

- For the Comp A-3 without graphite, 15,000 psi ram pressure was used versus 13,250 and 15,000 psi for the graphite blend. The latter two pressures were used because preliminary studies had indicated that pressures no higher than 13,250 psi were needed for graphited material. This was confirmed in the tests run of 0.79 g/cc bulk graphite material pressed at 13,250 psi with overall density of 1.631 g/cc versus 0.80 g/cc graphite material pressed at 15,000 psi with overall density of 1.630 g/cc.

- The graphite raised the bulk density of the original Comp A-3 0.02 to 0.03 g/cc.

- Qualitatively, it appears that acceptable 5"/54 projectiles can be successfully loaded with graphited Comp A-3 but again, because of the limited samples pressed and because of curtailment of the program for reasons already described, no statistical evaluation was run.

c. Test firing of graphite/Comp A-3 loaded projectiles

In order to determine whether or not graphited Comp A-3 behaved comparably to Comp A-3 under gun launch conditions,

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[11]Loc. cit.

TABLE IV. 5"/54 PROJECTILE - BLENDING SUMMARY

		Comp A-3 without graphite					Comp A-3 with 0.5% graphite				
Bulk density		A .75	B .77	C .79	D .80	E .81	A' .78	B' .79	C' .80	D' .81	E' .84
Ram pressure		15,000	15,000	15,000	15,000	15,000	13,250	13,250	15,000	15,000	[illegible]
Core No. 1 Bottom	n	23	50	49	49	48	23	24	23	23	9
	x̄	1.639	1.641	1.644	1.649	1.648	1.645	1.646	1.648	1.650	1.652
	s	.0027	.0074	.0076	.0037	.0057	.0019	.0022	.0030	.0043	.0036
Core No. 2 Top	n	23	50	50(49)	50	48	23	24	23	23	9
	x̄	1.640	1.642	1.645	1.650	1.649	1.648	1.647	1.647	1.651	1.653
	s	.0025	.0080	.0068	.0049	.0090	.0022	.0047	.0041	.0060	.0015
Bottom	x̄	1.610	1.621	1.624	1.629	1.633	1.622	1.625	1.630	1.631	1.631
	s	.0042	.0063	.0068	.0043	.0137	.0036	.0029	.0055	.0082	.0108
Core No. 3 Top	n	23	49(50)	50	50	48	23	24	23	24(23)	9
	x̄	1.641	1.644	1.647	1.652	1.651	1.649	1.649	1.650	1.652	1.656
	s	.0033	.0083	.0069	.0045	.0075	.0027	.0030	.0026	.0037	.0029
Bottom	x̄	1.618	1.629	1.631	1.637	1.639	1.628	1.632	1.628	1.632	1.623
	s	.0039	.0064	.0063	.0054	.0066	.0037	.0030	.0067	.0063	.0122
Core No. 4 Top	n	23	50(49)	49(50)	50	48	23	24	23	24(23)	9
	x̄	1.641	1.645	1.648	1.653	1.652	1.649	1.648	1.650	1.653	1.657
	s	.0033	.0068	.0049	.0031	.0091	.0026	.0047	.0023	.0046	.0048
Bottom	x̄	1.619	1.627	1.631	1.637	1.639	1.626	1.630	1.633	1.635	1.629
	s	.0035	.0065	.0068	.0045	.0065	.0029	.0023	.0025	.0057	.0017
Core No. 5 Top	n	23	50	50	50	48	23	24	23	24(23)	9
	x̄	1.641	1.645	1.647	1.652	1.654	1.648	1.648	1.650	1.653	1.655
	s	.0034	.0057	.0051	.0083	.0025	.0021	.0049	.0032	.0037	.0041
Bottom	x̄	1.615	1.627	1.631	1.636	1.640	1.626	1.631	1.633	1.635	1.628
	s	.0042	.0070	.0064	.0041	.0038	.0064	.0062	.0036	.0054	.0037
Core No. 6 Top	n	23	45(50)	50	50	48	23(14)	24(10)	23(22)	24(21)	9
	x̄	1.635	1.645	1.648	1.651	1.653	1.641	1.643	1.650	1.653	1.649
	s	.0049	.0058	.0064	.0043	.0030	.0073	.0063	.0040	.0042	.0056
Bottom	x̄	1.625	1.637	1.639	1.643	1.646	1.633	1.640	1.642	1.643	1.638
	s	.0058	.0065	.0066	.0044	.0030	.0045	.0023	.0046	.0052	.0032
Overall density	n	25	51	51	51	49	23	25	23	23	8
	x̄	1.624	1.639	1.640	1.643	1.642	1.627	1.631	1.630	1.631	1.629
	s	.0032	.0056	.0067	.0079	.0035	.0076	.0129	.0055	.0057	.0036

n = Number tested [( ) bottom only]
x̄ = Sample mean (avg)
s = Sample standard deviation
Density in g/cc
Ram pressure in psi
A' is A Comp A-3 w/graphite, etc.

Pressing constants

Temperature:	68°F
No. of increments:	7
Ram speed:	85"/min
Dwell time:	6 sec

24 5"/38 projectiles with 0.5 percent graphited Comp A-3 were loaded for test firing at the Naval Weapons Laboratory (NWL) [now the Naval Surface Weapons Center (NAVSURFWPNCEN), Dahlgren Laboratory], Dahlgren, Virginia. Two projectiles were loaded with unadulterated Comp A-3 as controls. The projectiles were loaded to a pressed density ranging from 1.50 g/cc to 1.64 g/cc. Four projectiles were instrumented with copper ball pressure gauges to determine peak pressures exerted on the projectile side walls during launch. Eight projectiles were loaded with a 1/8-inch base plug intrusion.

The prefiring conditions are listed in Table V. Ball gauge positions are shown in Figure 8. All projectiles were fired at service pressure from a 5"/10 gun into sawdust-filled boxcars. The recovered projectiles were radiographed and sectioned at NEDED. NWL Dahlgren concluded[18] that:

- The presence of 0.5 percent graphite in a Comp A-3 load presents no increased hazard to operation in Navy 5"/38 gun systems.

- The presence of 0.5 percent graphite has no appreciable effect on filler compaction and/or cracking.

- Based on a limited number of projectiles, it appears that the presence of graphite lessens the forces transmitted by the load to the projectile.

Figures 9 through 12 are photographs showing sectional views of post-fired rounds from projectiles of overall densities 1.64, 1.60, 1.55, and 1.50 g/cc, respectively. They show only inconsequential separation in noncritical areas for the low density rounds. Comparably fired projectiles loaded to 1.45 g/cc density with ungraphited Comp A-3 exhibited considerable compaction in addition to cracking in the fuze cavity area[2].

d. <u>Conclusions and recommendations</u>

The data obtained illustrated that the addition of 0.5 percent graphite to Comp A-3:

- Reduces static charge.

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[18]NWL Dahlgren ltr EPM:OHG:jmv 8033 of 2 Jul 1973 to NAVWPNSTA Yorktown, Subj: Firing and analysis of 5"/38 Projectiles loaded with A-3 containing 0.5% graphite; report of

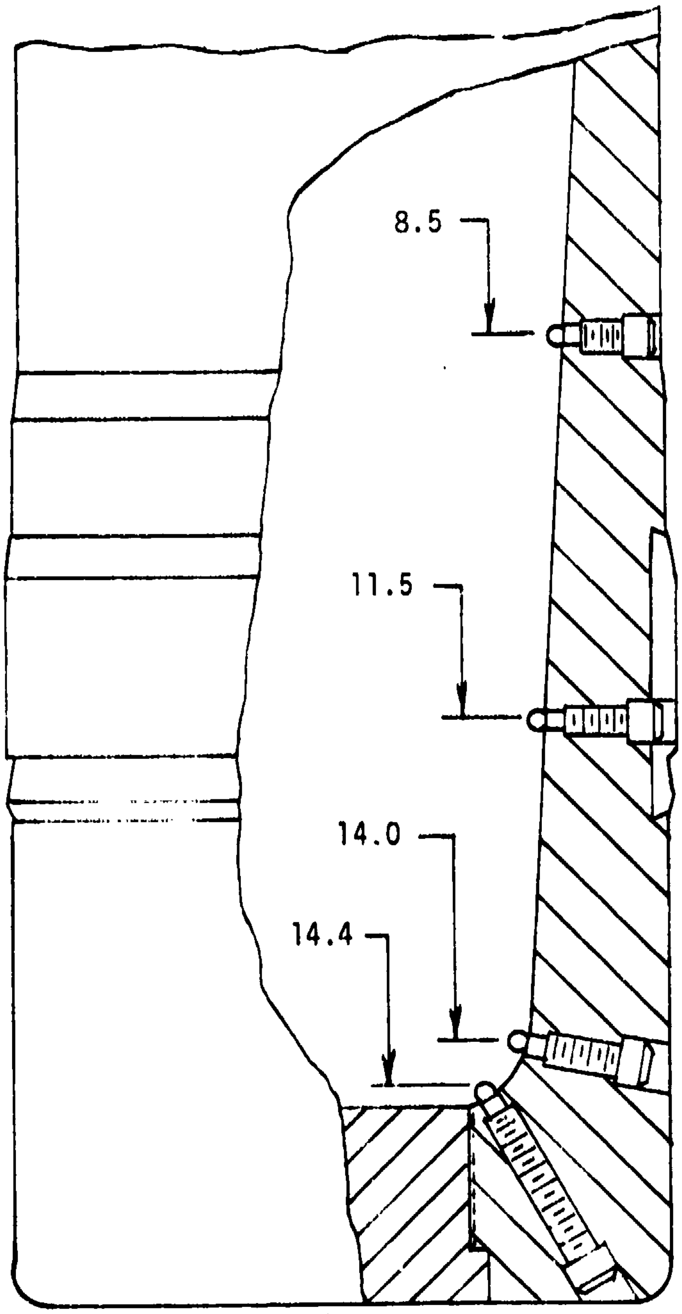
[2]Loc. cit.

TABLE V

PREFIRING CONDITIONS OF 5"/38 TEST PROJECTILES

	Gun fired round			
Density (g/cc)	1.64	1.60	1.55	1.50
Standard load, no instrumentation, with .5% graphite.	No. 1, 2, 3	No. 4, 5, 6	No. 7, 8, 9	No. 10, 11, 12
Standard load, instrumented as shown in Figure 8, with .5% graphite.	No. 13, 25*, 26*	No. 14	No. 15	No. 16
1/8" base plug intrusion, no instrumentation, with .5% graphite.	No. 17, 18	No. 19, 20	No. 21, 22	No. 23, 24

*Regular Comp A-3 without graphite.



Dimensions are to top of explosive charge

PRESSURE GAUGE LOCATIONS IN 5"/38 PROJECTILE

FIGURE 8

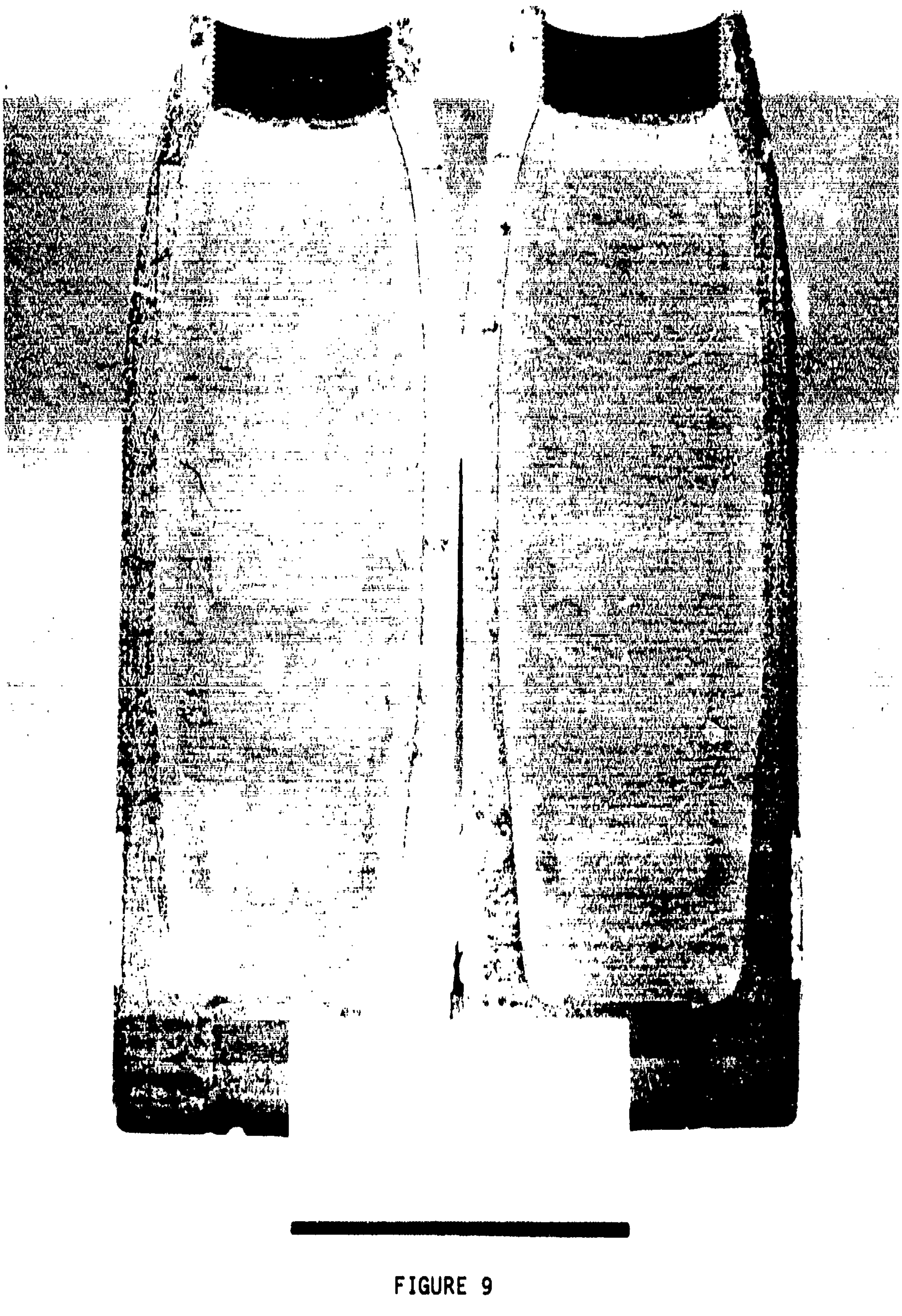


FIGURE 9

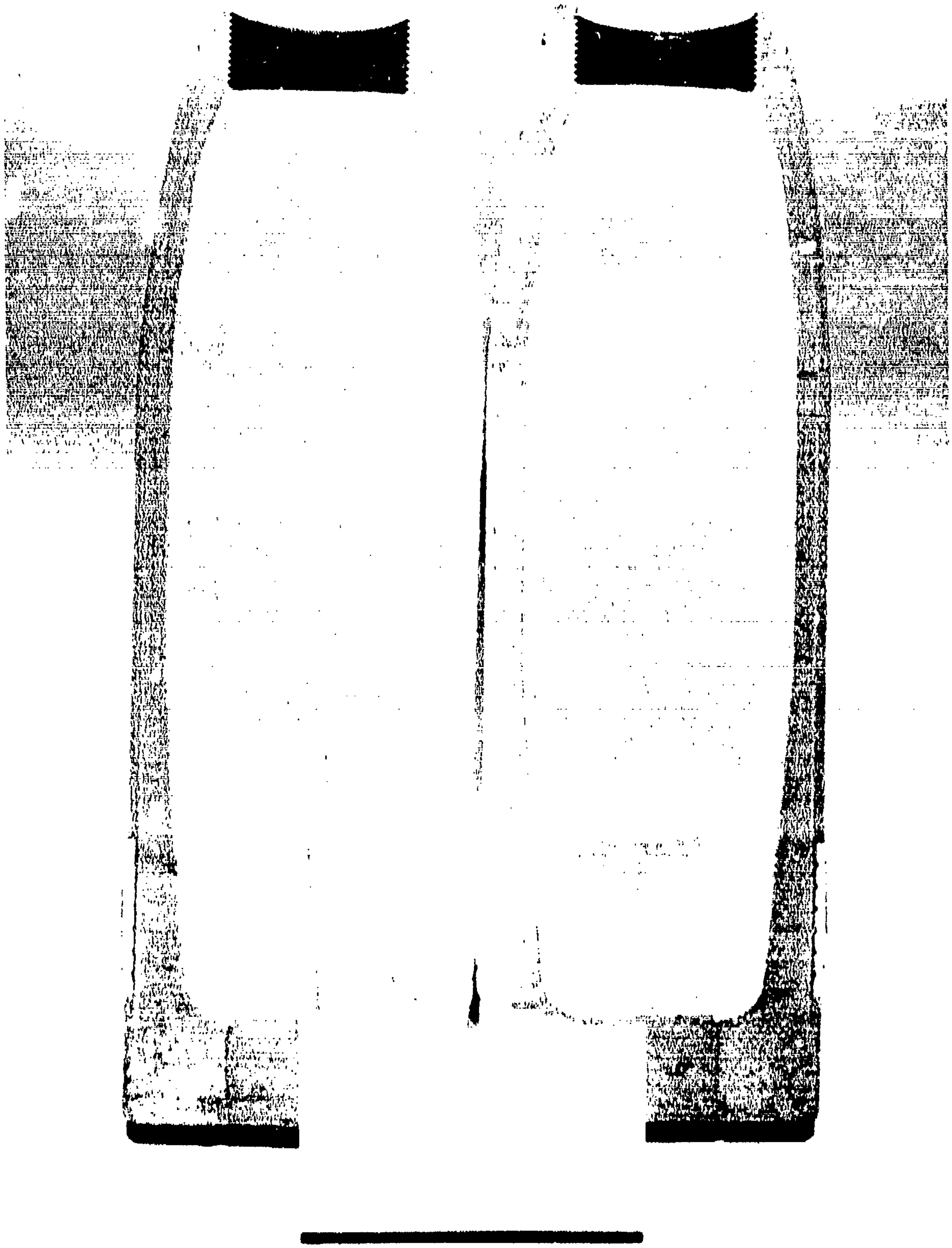


FIGURE 10

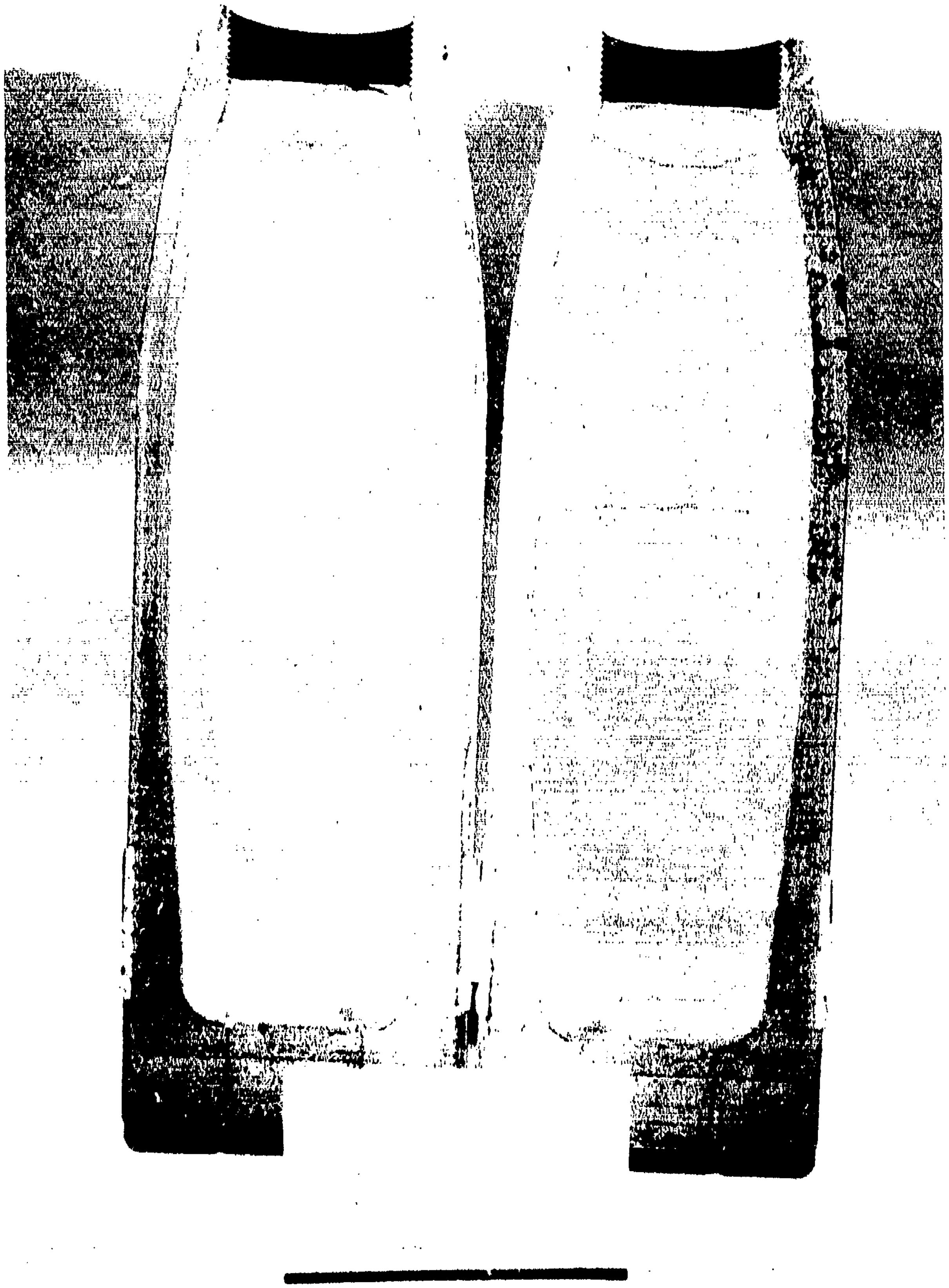


FIGURE 11

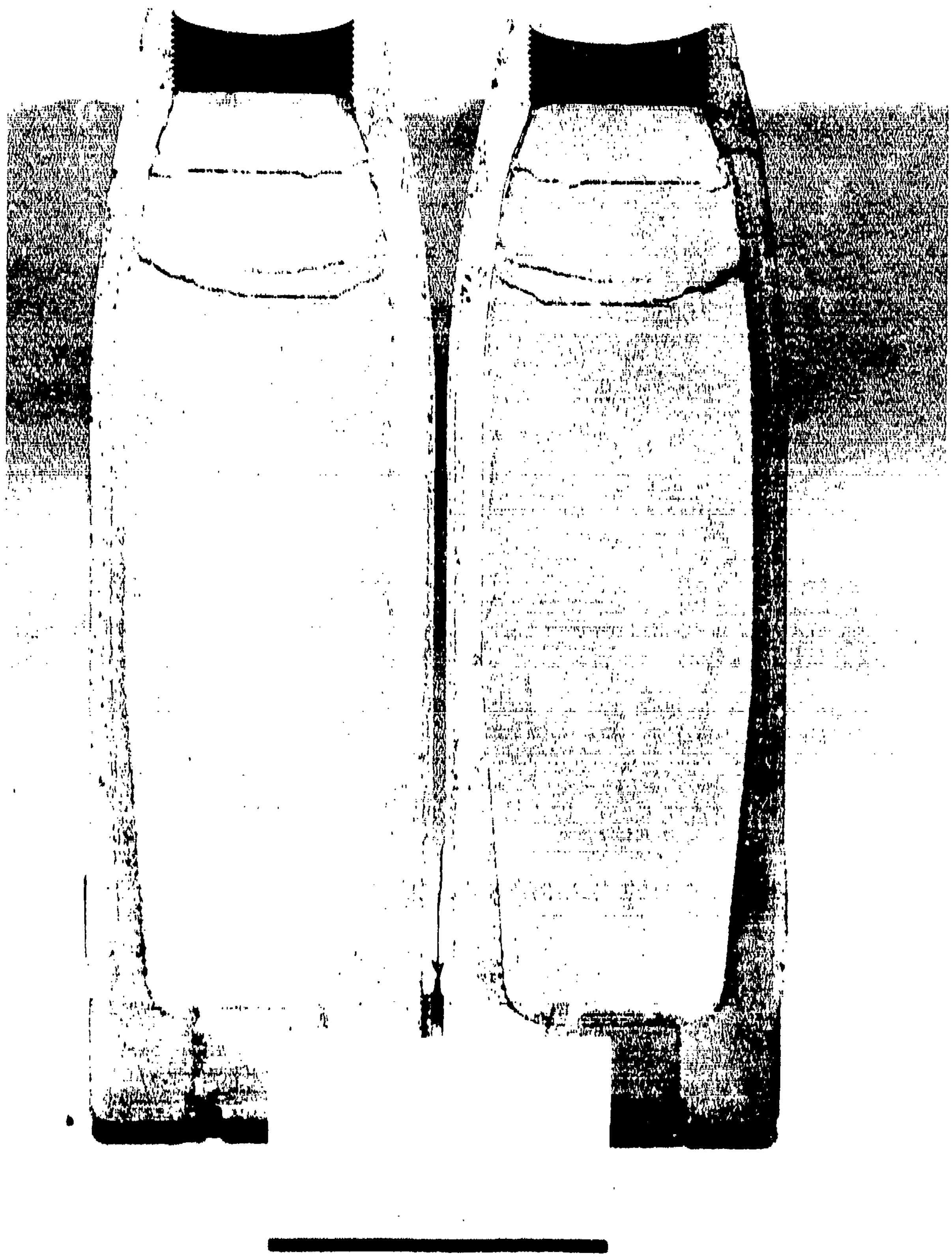


FIGURE 12

- Increases bulk density by 0.02 to 0.03 g/cc.
- Flows easily under pressure to desired density.
- Lessens the force to the projectile wall under gunfire load.
- May not crack as severely as Comp A-3 itself.

For all of the above reasons, it is recommended that graphited Comp A-3 be fully evaluated for qualification in projectile loads. This becomes even more imperative as the commercial waxes now being supplied to specification seem to have less lubricity than those produced before the petrochemical-oil crisis.

3. <u>RDX particle size effects on varying Comp A-3 bulk density</u>

a. <u>Purpose of the study</u>

It was noted that the RDX recovered from pressed Comp A-3 was reduced to Class G particle size (see II.A). This phenomena appeared analogous to that of beach sand being formed by the continuous abrasion of larger stones by ocean action. At a given diameter, further particle size reduction ceases. It was further hypothesized that ease of pressing would, in turn, make it possible to use low bulk density material and still obtain the end product quality desired.

Class G RDX is not a high volume production item of HAAP. Nonetheless, this program was implemented for three reasons:

- It had not yet been proved that low bulk density Class A RDX-Comp A-3 could be loaded to end product specifications (the programs being concurrent).
- HAAP stated that mass production of Class G RDX presented no problems to them.
- HAAP stated that their production problems might even be simplified if low bulk density Class G RDX-Comp A-3 should prove satisfactory in projectile loadings.

On that basis, four thousand pounds of Comp A-3 manufactured with Class G RDX was ordered with bulk densities to range from 0.65 to 0.81 g/cc. In practice, the material delivered covered a density range of 0.63 to 0.87 g/cc and it became necessary to blend material in order that the four matrix studies planned would be statistically meaningful. Parametric studies were developed similar to those in the low bulk density studies described in III.B.1. Ram speed and dwell time were fixed at 85 inches per minute and 6 seconds, respectively.

b. Establishing the multi-variable matrices

Because the quantity of material was limited and because no previous history existed for Comp A-3 made with Class G RDX, it became necessary to:

- Reduce the number of projectiles per set from 50 to 25 (still a statistically valid sample).
- Vary other conditions besides density (temperature and increments) between sets.

Table VI summarizes the conditions chosen.

The rationale for the sets selected follows:

- The 5"/38 and 5"/54 Matrix I parameters were chosen to duplicate the conditions normally used to press standard Comp A-3 made from Class A RDX having a 0.81 g/cc bulk density to make a direct comparison between it and the various low bulk density Class G RDX-Comp A-3's. Eight increments in lieu of six were chosen for the 5"/54 simply because its geometry prevents complete filling of the projectile when low bulk density material is used.
- The 5"/38 and 5"/54 Matrix II parameters were chosen at 76°F, and 14,000 psi and 15,000 psi, respectively, to compare optimum press temperatures and pressures to the standard set in Matrix I.
- Blends of 0.63/0.64/0.65 g/cc and 0.82/0.83 g/cc bulk material were used in the 5"/38 Matrix II study because there was not enough 0.65 g/cc and 0.82 g/cc bulk material available to press 25 projectiles each.

c. 5"/54 Class G RDX results

Table VII summarizes the data obtained for the Matrix I Class G RDX study carried out under "standard" conditions normally used for pressing Class A RDX-Comp A-3 having a bulk density of at least 0.81 g/cc.

Several observations should be made:

TABLE VI

PARAMETRIC CONDITIONS FOR CLASS G RDX STUDIES

	Press pressure (psi)	Material temp (°F)	No. of incre-ments	Bulk density (g/cc)			
5"/38 Matrix I	13,250	68	6	.65	-	.79	.81
5"/54 Matrix I	13,250	68	8	.65	.74	.78	.81
5"/38 Matrix II	14,000	76	8	.63/.64/.65	.71	.76	.82/.83
5"/54 Matrix II	15,000	76	8	.65	.72	.77	.82

25 projectiles for each matrix.

<u>Pressing constants</u>

Dwell time: 6 sec

Ram speed: 85"/min

TABLE VII. 5"/54 PROJECTILE STUDY I - CLASS G RDX DENSITY SUMMARY

Bulk		.65	.74	.78	.81
Overall	n	25	25	25	24
	$\bar{x}$	1.619	1.624	1.626	1.610
	s	.0089	.0061	.0086	.0041
Core No. 1 Bottom	n	25	22	-	25
	$\bar{x}$	1.636	1.640	-	1.644
	s	.0104	.0076	-	.0035
Core No. 2 Top	n	25(24)	25	24	25
	$\bar{x}$	1.637	1.643	1.645	1.642
	s	.0043	.0090	.0090	.0026
Bottom	$\bar{x}$	1.594	1.597	1.632	1.601
	s	.0071	.0058	.0032	.0050
Core No. 3 Top	n	25	25	24	25
	$\bar{x}$	1.638	1.641	1.646	1.642
	s	.0023	.0052	.0017	.0028
Bottom	$\bar{x}$	1.593	1.592	1.634	1.598
	s	.0079	.0072	.0040	.0060
Core No. 4 Top	n	25	25	24	25
	$\bar{x}$	1.640	1.642	1.648	1.648
	s	.0015	.0030	.0030	.0073
Bottom	$\bar{x}$	1.610	1.593	1.634	1.601
	s	.0033	.0099	.0021	.0106
Core No. 5 Top	n	25	25	24	22(25)
	$\bar{x}$	1.641	1.644	1.646	1.634
	s	.0012	.0028	.0048	.0076
Bottom	$\bar{x}$	1.621	1.621	1.635	1.615
	s	.0029	.0056	.0032	.0059
Core No. 6 Top	n	25	-	24	-
	$\bar{x}$	1.631	-	1.645	-
	s	.0044	-	.0038	-
Bottom	$\bar{x}$	-	-	1.641	-
	s	-	-	.0034	-

n = Number tested
[( ) bottom only]
$\bar{x}$ = Sample mean (avg)
s = Sample std deviation
Density in g/cc

Pressing constants

Temperature:	68°F
No. of increments:	8
Ram pressure:	13,250 psi
Ram speed:	85"/min
Dwell time:	6 sec

- Low densities of 1.594, 1.593, 1.597, 1.592, 1.598 and 1.601 g/cc were obtained in the bottom of cores No. 2 and 3 for 0.65, 0.74 and 0.81 g/cc bulk material, respectively. This is a critical area of the projectile where low densities are particularly undesirable due to the possible reconsolidation and compression during gunfiring.

- The 0.81 g/cc Class G material, unlike Class A RDX manufactured into Comp A-3 of the same density, gave abnormally low overall pressed densities, i.e., overall of 1.610 g/cc, where normally 1.64 to 1.65 g/cc would be expected. This indicates quite different flow characteristics of the two types of material.

Table VIII summarizes the data obtained for the Matrix II Class G study carried out under "optimum" pressures and temperatures. Here, as expected, overall and core densities are higher under these optimum conditions than those listed in Matrix I. Nonetheless, the same pattern exists, relatively low densities (1.599, 1.597 and 1.612 g/cc) for the No. 2 and No. 3 cores from 0.65 g/cc and 0.82 g/cc bulk material, and lower than expected overall density (1.628 g/cc) for the high bulk (0.82 g/cc) material.

The qualitative judgments were confirmed by NAPEC in their statistical analysis[11] of the data. Table IX summarizes their core by core analysis. From their statistical study, NAPEC concluded that:

- When Class G RDX was used in manufacturing Comp A-3, flow characteristics were different from Class A RDX manufactured Comp A-3 regardless of bulk density.

- Class G RDX should not be used in loading 5" projectiles so long as minimum pressed density requirements were 1.60 g/cc.

d. <u>5"/38 Class G RDX results</u>

Table X summarizes the data obtained for the Matrix I Class G RDX study carried out under "standard" conditions normally used for pressing Class A RDX-Comp A-3 having a bulk density of at least 0.81 g/cc.

Observations that should be made:

- No low density areas appeared in the critical cores No. 1, 2, and 3, as was the case for the 5"/54 projectiles.

[11] Loc. cit.

TABLE VIII. 5"/54 PROJECTILE STUDY II - CLASS G RDX DENSITY SUMMARY

Bulk		.65	.72	.77	.82
Overall	n	25	24	24	25
	$\bar{x}$	1.625	1.636	1.638	1.628
	s	.0004	.0113	.0042	.0047
Core No. 1 Bottom	n	24	-	-	25
	$\bar{x}$	1.617	-	-	1.627
	s	.0053	-	-	.0040
Core No. 2 Top	n	24	24	24	24(25)
	$\bar{x}$	1.623	1.644	1.645	1.630
	s	.0060	.0036	.0090	.0051
Bottom	$\bar{x}$	1.599	1.620	1.632	1.612
	s	.0068	.0054	.0032	.0072
Core No. 3 Top	n	24	24	24	25
	$\bar{x}$	1.624	1.643	1.646	1.630
	s	.0053	.0024	.0017	.0055
Bottom	$\bar{x}$	1.597	1.630	1.634	1.619
	s	.0129	.0040	.0040	.0017
Core No. 4 Top	n	24	24	24	25
	$\bar{x}$	1.625	1.645	1.648	1.630
	s	.0041	.0027	.0030	.0052
Bottom	$\bar{x}$	1.605	1.627	1.634	1.616
	s	.0071	.0031	.0021	.0053
Core No. 5 Top	n	24	24	24	25
	$\bar{x}$	1.624	1.644	1.646	1.630
	s	.0059	.0037	.0048	.0032
Bottom	$\bar{x}$	1.603	1.628	1.635	1.616
	s	.0068	.0033	.0032	.0057
Core No. 6 Top	n	5(24)	24	24	25
	$\bar{x}$	1.627	1.642	1.645	1.625
	s	.0029	.0034	.0038	.0052
Bottom	$\bar{x}$	1.615	1.637	1.641	-
	s	.0051	.0035	.0034	-

n = Number tested
[( ) bottom only]
$\bar{x}$ = Sample mean (avg)
s = Sample std deviation
Density in g/cc

Pressing constants

Temperature:	76°F
No. of increments:	8
Ram pressure:	15,000 psi
Ram speed:	85"/min
Dwell time:	6 sec

TABLE IX

5"/54 PROJECTILES WITH CLASS G RDX NAPEC HISTOGRAMIC CONFIDENCE/RELIABILITY LEVELS

For a 99 percent confidence, the reliabilities that projectiles produced under the same operating conditions would exceed 1.60 in overall and core densities are as listed.

	Study I				Study II			
Bulk density (g/cc)	.65	.74	.78	.81	.65	.72	.77	.82
	Reliability (%)							
Overall density	90.0	99.5	97.0	93.0	99.9	98.0	99.5	99.9
Core No. 1 Bottom	99.0	99.9	99.9	99.9	98.0	-	-	99.9
Core No. 2 Bottom	39.0	50.0	89.0	50.0	<50.0	99.0	99.9	83.0
Core No. 3 Bottom	37.0	31.0	66.0	50.0	50.0	99.9	99.9	85.0
Core No. 4 Bottom	97.0	43.0	74.0	50.0	57.0	99.9	99.9	97.0
Core No. 5 Bottom	99.9	99.5	99.5	94.0	50.0	99.9	99.9	96.0
Core No. 6 Bottom	-	-	-	-	97.0	99.9	99.9	-

Study I and Study II - All top cores No. 2 thru 6: 99.9 percent.

TABLE X. 5"/38 PROJECTILE STUDY I - CLASS G RDX DENSITY SUMMARY

Bulk		.65	.79	.81
Overall	n x̄ s	25 1.631 .0069	25 1.647 .0052	25 1.637 .0083
Core No. 1 Bottom	n x̄ s	23 1.642 .0072	25 1.648 .0033	24 1.646 .0047
Core No. 2 Top	n x̄ s	25 1.642 .0028	25 1.651 .0021	24 1.645 .0051
Bottom	x̄ s	1.619 .0077	1.632 .0046	1.623 .0058
Core No. 3 Top	n x̄ s	25 1.644 .0023	25 1.651 .0021	24 1.645 .0044
Bottom	x̄ s	1.629 .0065	1.645 .0015	1.636 .0050
Core No. 4 Top	n x̄ s	25 1.644 .0025	25 1.647 .0021	24 1.647 .0056
Bottom	x̄ s	1.636 .0045	1.646 .0015	1.639 .0048
Core No. 5 Top	n x̄ s	25 1.644 .0024	25 1.652 .0019	24 1.640 .0040
Bottom	x̄ s	1.640 .0035	1.647 .0020	1.644 .0038
Core No. 6 Top	n x̄ s	25(22) 1.643 .0023	25 1.648 .0015	24 1.641 .0050
Bottom	x̄ s	1.642 .0023	- -	- -

n = Number tested
[( ) bottom only]
$\bar{x}$ = Sample mean (avg)
s = Sample std deviation
Density in g/cc

<u>Pressing constants</u>

Temperature:	68°F
No. of increments:	6
Ram pressure:	13,250 psi
Ram speed:	85"/min
Dwell time:	6 sec

- No significant differences in pressed densities are apparent between 0.65 g/cc and 0.81 g/cc bulk material. This again indicates that Class G RDX-Comp A-3 flows differently than its Class A RDX counterpart.

Table XI summarizes the data obtained for the Matrix II Class G study carried out under "optimum" pressures and temperatures. Unlike the 5"/54 results, no significant changes in overall and core densities occurred when compared to the "standard" Matrix I study, except that the overall pressed density of the 0.82/0.83 g/cc bulk material (1.616 g/cc) is lower than expected. Qualitatively it appears that Class G RDX-Comp A-3 can be processed successfully to end product specifications even though the flow characteristics of this material are different.

These conclusions were confirmed by NAPEC's statistical analysis[13]. Table XII summarizes their analyses. NAPEC's general conclusions were that:

- Class G RDX exhibits different pressing patterns than Class A RDX in Comp A-3.
- The pressed densities are "well behaved" and tend to be well within the 1.60 g/cc specification limit.
- It is doubtful that low densities will exist when bulk material in the 0.71 to 0.81 g/cc range is used.
- Further studies should be run on 0.65 g/cc bulk material as a candidate for pressing.

e. Conclusions and recommendations

Based upon the above analyses and observations, it is concluded that low bulk density Comp A-3 manufactured with Class G RDX can be processed successfully in 5"/38 projectiles. This will formally be recommended to NAVSEASYSCOM should the need arise. It is also concluded that further studies should be undertaken using Class G material in pressing 5"/54 projectiles. It is believed that varying the number of increments and their sizes will overcome the different flow characteristics in the 5"/54 geometry. Until such a study is made, the use of Class G RDX in 5"/54 projectiles is not recommended.

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[13] Loc. cit.

TABLE XI. 5"/38 PROJECTILE STUDY II - CLASS G RDX DENSITY SUMMARY

Bulk		Blend .63/.64/.65	.71	.76	Blend .82/.83
Overall	n	25	22	25	25
	$\bar{x}$	1.630	1.641	1.634	1.616
	s	.0050	.0047	.0057	.0071
Core No. 1 Bottom	n	25	22	25	25
	$\bar{x}$	1.636	1.647	1.650	1.642
	s	.0058	.0024	.0035	.0046
Core No. 2 Top	n	25	22	25	25
	$\bar{x}$	1.635	1.644	1.648	1.642
	s	.0021	.0025	.0038	.0060
Bottom	$\bar{x}$	1.622	1.631	1.638	1.631
	s	.0026	.0025	.0038	.0047
Core No. 3 Top	n	25	22	25	25
	$\bar{x}$	1.636	1.645	1.647	1.638
	s	.0017	.0017	.0036	.0056
Bottom	$\bar{x}$	1.627	1.636	1.641	1.635
	s	.0133	.0032	.0033	.0079
Core No. 4 Top	n	25	22	25	25(24)
	$\bar{x}$	1.636	1.645	1.640	1.641
	s	.0047	.0079	.0036	.0054
Bottom	$\bar{x}$	1.632	1.639	1.641	1.637
	s	.0025	.0045	.0047	.0052
Core No. 5 Top	n	25	22	25	25(24)
	$\bar{x}$	1.635	1.647	1.648	1.641
	s	.0024	.0020	.0035	.0044
Bottom	$\bar{x}$	1.534	1.642	1.641	1.641
	s	.0024	.0047	.0081	.0067
Core No. 6 Top	n	25	22	24(25)	25(24)
	$\bar{x}$	1.634	1.626	1.627	1.637
	s	.0032	.0076	.0072	.0058
Bottom	$\bar{x}$	1.634	1.644	1.642	1.643
	s	.0027	.0028	.0047	.0046

n = Number tested
[( ) bottom only]
$\bar{x}$ = Sample mean (avg)
s = Sample std deviation
Density in g/cc

<u>Pressing constants</u>

Temperature:	76°F
No. of increments:	8
Ram pressure:	14,000 psi
Ram speed:	85"/min
Dwell time:	6 sec

TABLE XII

5"/38 PROJECTILES WITH CLASS G RDX
NAPEC HISTOGRAMIC CONFIDENCE/RELIABILITY LEVELS

For a 99 percent confidence, the reliabilities that projectiles produced under the same operating conditions would exceed 1.60 in overall and core densities are as listed.

	Study I			Study II			
Bulk density (g/cc)	.65	.79	.81	.63/.64/.65	.71	.76	.82/.83
	Reliability (%)						
Overall density	99.9	99.9	99.9	99.9	99.9	99.9	92.0
Cores No. 1 thru 6 Bottom	99.9*	99.9	99.9	99.9	99.9	99.9	99.9
Cores No. 2 thru 6 Top	99.9	99.9	99.9	99.9	99.0	99.0	99.9

*Bottom core No. 2: 93 percent.

C. Blending Studies

1. Introduction

Blending multicomponent explosives has been practiced for centuries to obtain homogeneous mixtures processable into uniform and reproducible end products.

Most explosives in use today are heterogeneous mixtures of two or more components that may be premixed in a blender or mix-melted in a kettle. However, inter-lot and intra-batch blending of Comp A-3 itself originally was initiated solely to achieve a uniform particle size distribution and, consequently, a uniform bulk density. This process resulted from a group of incomplete studies in the late 1960's from which it had been concluded that Comp A-3 blending produced more uniform projectile loads. As a result, Comp A-3 blending was begun on a large scale in 1970. A reinvestigation of blending effects was initiated in early 1972 for three basic reasons:

- To determine if blending equal portions of high and low bulk density Comp A-3 resulted in a linearly related average.
- To determine if intra-batch blending of Comp A-3 was, indeed, necessary to produce uniform projectile loads.
- To determine if blending equal portions of high and low wax content Comp A-3 resulted in a linearly related average wax content in a linearly related drop-hammer sensitivity.

The necessity for these studies has already been discussed and it need only be reiterated here that the results of these three investigations were urgently required because usable stocks of 0.81 g/cc bulk density Comp A-3 were nearly exhausted and because loading costs were climbing as a result of 100 percent bulk density and composition analyses and 100 percent blending of the stockpile.

2. Inter-lot blending studies

a. Purpose of this study phase

Briefly, Comp A-3 is blended in a "Y" shaped or so-called "twin" blender. One complete revolution of this type unit divides the material in half during the first half-cycle and recombines it during the second half-cycle. Safe practice limits the amount of Comp A-3 blended at any one time to 100 pounds. Obviously, this operation is slow and costly.

Initially the plan for this study phase was to determine if equal parts of high and low bulk density Comp A-3 could be blended to an average of 0.81 g/cc - the then specification requirement. However, once bulk density measuring techniques were standardized, it soon became obvious that only trivial quantities of Comp A-3 in excess of 0.81 g/cc bulk density were available for such blend-offs. Therefore, the study plan was modified to determine whether or not the stockpile could be blended to exceed the new minimum bulk densities approved by NAVORDSYSCOM rather than the previously required 0.81 g/cc. Thus, if quality end products could be produced from blends of Comp A-3 meeting or exceeding the 0.77 and 0.79 g/cc minimums for 5"/38 and 5"/54 projectiles, respectively, it would then be possible to process all ten million pounds of the Code A stockpile, including the one million pounds of material with a bulk density below 0.77 g/cc, as well as all newly manufactured Comp A-3. It was also decided that a direct comparison of the end product effects between blended and unblended material should be made concurrently.

b. Inter-lot blending effects on bulk density

Table XIII summarizes the bulk density results obtained after blending various combinations of high bulk density Comp A-3 for 2 minutes in the "Y" blender. In several cases, different lots of material having the same bulk densities were also blended as controls. Several observations can be made about the data:

- There is no linear relationship or arithmetic average obtained by blending equal parts of different or the same bulk density material.

- The average bulk density obtained was invariably 0.01 to 0.02 g/cc lower than calculated when measured immediately after blending.

- Twenty-four hours after blending, the blends approach the expected arithmetic average.

- The drop off in bulk density is attributed to static charge buildup.

- As long as the blended materials' bulk densities met or exceeded prescribed minimums, quality end products could be manufactured from them.

TABLE XIII. INTER-LOT BLENDING DENSITY SUMMARY

Blend No.	Densities before blending	Calculated avg density	Actual avg density immed after blending	Actual density 24 hrs after blending
1	.76/.80	.78	.76	.77
2	.79/.84	.81	.79	.81
3	.81/.83	.82	.81	.81
4*	.80/.80	.80	.78	.79
5	.85/.86	.85	.84	.85
6*	.79/.79	.79	.77	.78
7	.79/.81	.80	.78	.79
8*	.81/.81	.81	.79	.80
9	.78/.80	.79	.77	.78
10	.79/.82	.81	.79	.80
11	.77/.78	.78	.76	.77
12	.81/.82	.82	.81	.81
13*	.81/.81	.81	.80	.80
14*	.81/.81	.81	.80	.81
15	.80/.82	.81	.80	.80
16	.77/.78	.78	.76	.77
17	.80/.82	.81	.80	.80
18*	.80/.80	.80	.78	.79
19	.80/.83	.82	.80	.81
20	.78/.80	.79	.79	.79
21	.78/.80	.79	.78	.78
22	.83/.84	.84	.83	.83
23	.81/.83	.82	.81	.81
24	.85/.86	.86	.85	.86

*Controls.

c. The dual variable matrix: densities vs blended - unblended

For the direct comparison of blended and unblended material at different bulk densities, all other variables were held constant, i.e., ram pressure was held at 15,000 psi; ram dwell at 6 seconds; increments pressed at eight; and explosive pressing temperature at 68°F.

The two variables were 1) bulk densities at 0.77, 0.79 and 0.80 g/cc, each prepared from 2) blended and unblended stocks, respectively. Table XIV summarizes the data obtained. It should be noted that for this study, 5"/54 projectiles only were used because they are much more sensitive to change than are 5"/38 projectiles. Also, since all top cores exceeded 1.64 g/cc for both blended and unblended materials, only the density determinations of the more significant bottom cores are listed in Table XIV.

d. Inter-lot blended vs unblended results

All data received the same computerized statistical analysis by NAPEC[11]. Table XV summarizes NAPEC's confidence/reliability findings for the blends examined. As can be seen from the table, for a 99 percent confidence level, the reliabilities that projectiles produced under the same operating conditions would exceed 1.60 g/cc in both overall and core densities are 99 percent for both blended and unblended material. NAPEC interaction analyses led to the conclusion that "the difference between blended and unblended material had no statistical significance" despite the fact that "core densities for the unblended material were somewhat lower but still well within design requirements."[19]

e. Conclusions and recommendations

From the data generated, it was concluded that blending various bulk density materials was an effective means for producing quality pressed projectiles. It was also concluded after additional studies that blending, per se, was not essential to attain quality end products and need only be carried out to blend off "lower than specification" bulk density material. NAVORDSYSCOM concurred[20]

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[11]Loc. sit.

[19]NAVWPNSTA Yorktown ltr 504:EYM:dgh of 11 Feb 1974 to NAVORDSYSCOM (ORD-04M), Subj: Composition A-3 explosive blending; recommendation for discontinuing

[20]NAVORDSYSCOM spdltr ORD-04M1B/6:MYM 8030 of 26 Feb 1974 to NAVWPNSTA Yorktown, Subj: Composition A-3 explosive blending

TABLE XIV

5"/54 PROJECTILE - BLENDED VS UNBLENDED DENSITY COMPARISON

		Blended			Unblended		
Bulk		.77	.79	.80	.77	.79	.80
Overall	n	51	51	51	40	35	45
	$\bar{x}$	1.639	1.640	1.643	1.629	1.637	1.633
	s	.0056	.0067	.0079	.0039	.0062	.0070
Core No. 1 Bottom	n	50	49	49	40	35	45
	$\bar{x}$	1.641	1.644	1.649	1.646	1.638	1.646
	s	.0074	.0076	.0037	.0028	.0080	.0041
Core No. 2 Bottom	n	50	49	49	40	35	45
	$\bar{x}$	1.621	1.624	1.629	1.626	1.627	1.636
	s	.0063	.0068	.0043	.0039	.0063	.0117
Core No. 3 Bottom	n	50	49	50	40	35	43
	$\bar{x}$	1.629	1.631	1.637	1.632	1.631	1.632
	s	.0064	.0063	.0054	.0028	.0054	.0065
Core No. 4 Bottom	n	49	50	50	40	35	43
	$\bar{x}$	1.627	1.631	1.637	1.629	1.632	1.634
	s	.0065	.0068	.0045	.0040	.0050	.0050
Core No. 5 Bottom	n	50	50	50	40	35	43
	$\bar{x}$	1.627	1.631	1.636	1.629	1.630	1.636
	s	.0070	.0064	.0041	.0040	.0054	.0077
Core No. 6 Bottom	n	50	50	50	38	18	39
	$\bar{x}$	1.637	1.639	1.643	1.638	1.634	1.639
	s	.0065	.0066	.0079	.0032	.0077	.0029

n = Number tested
$\bar{x}$ = Sample mean (avg)
s = Sample standard deviation
Density in g/cc

<u>Pressing constants</u>

Temperature:	68°F
No. of increments:	8
Ram pressure:	15,000 psi
Ram speed:	85"/min
Dwell time:	6 sec

TABLE XV

5"/54 PROJECTILES INTER-LOT BLENDED VS UNBLENDED STUDY NAPEC HISTOGRAMIC CONFIDENCE/RELIABILITY LEVELS

For a 99 percent confidence, the reliabilities that projectiles produced under the same operating conditions would exceed 1.60 in overall and core densities are as listed.

	Blended			Unblended		
Bulk density (g/cc)	.68	.79	.80	.77	.79	.80
	Reliability (%)					
Overall density	99.9	99.9	99.9	99.9	99.9	99.9
Cores No. 1 thru 6 Bottom	99.9*	99.9#	99.9	99.9	99.9	99.9
Cores No. 2 thru 6 Top	99.9	99.9	99.9	99.9	99.9	99.9

*Bottom cores No. 2: 99.0 percent.
No. 5: 99.5 percent.
#Bottom cores No. 2: 99.5 percent.
No. 4: 99.5 percent.

with both of these NAVWPNSTA Yorktown recommendations to: delete the requirement for blending, and blending to recover low bulk density stocks may be practiced[19]. The net result was that all of the Comp A-3 stockpile formerly suspended for low bulk density could now be used, including the one million pounds of material that fell below 0.77 g/cc, provided appropriate blends with higher bulk material were made.

3. Intra-batch blending studies

a. Purpose of the study

The rationale for blending Comp A-3 has already been reviewed. One additional reason advanced by blending advocates was based on the observations of earlier investigators that Comp A-3 segregation occurred even within a single box. These earlier studies indicated that Comp A-3 stratified during shipping and handling with coarse Comp A-3 settling to the bottom of the shipping container while fines rose to the top. Since there is roughly 50 pounds of Comp A-3 per container - enough to press approximately eight 5" projectiles - it was believed that major quality differences between projectiles would result if the Comp A-3 was not reblended before being portioned out for loading. Hence, Comp A-3 blending was routinely introduced as a process step in 1970.

However, the costs associated with blending warranted that the need for this operation be reassessed, especially in the cases of Comp A-3 lots and batches that already were of an acceptable bulk density as compared to blendings needed to achieve acceptable densities. Also, aside from costs, processing and safety factors are involved. These latter result from a very undesirable property of Comp A-3, namely its ability to build up a static charge. For example, static charges up to 10,500 volts have been recorded immediately after blending Comp A-3 for only 2 minutes. Comp A-3 can be observed clinging to the blender walls even though the machine is well grounded. Further, the insulating properties of the wax in Comp A-3 cause retention of the static charge for many hours before it eventually dissipates. Figure 13 illustrates succinctly the static buildup phenomena.

Curves are plotted for the decrease in bulk density that occurs versus blending time for three different batches of Comp A-3 whose initial bulk densities were 0.727, 0.745 and 0.766 g/cc, respectively. It should be noted that the electrostatic repulsion between particles causes a drop in bulk density of from 0.015 to 0.02 g/cc in 2 minutes.

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[19] Loc. cit.

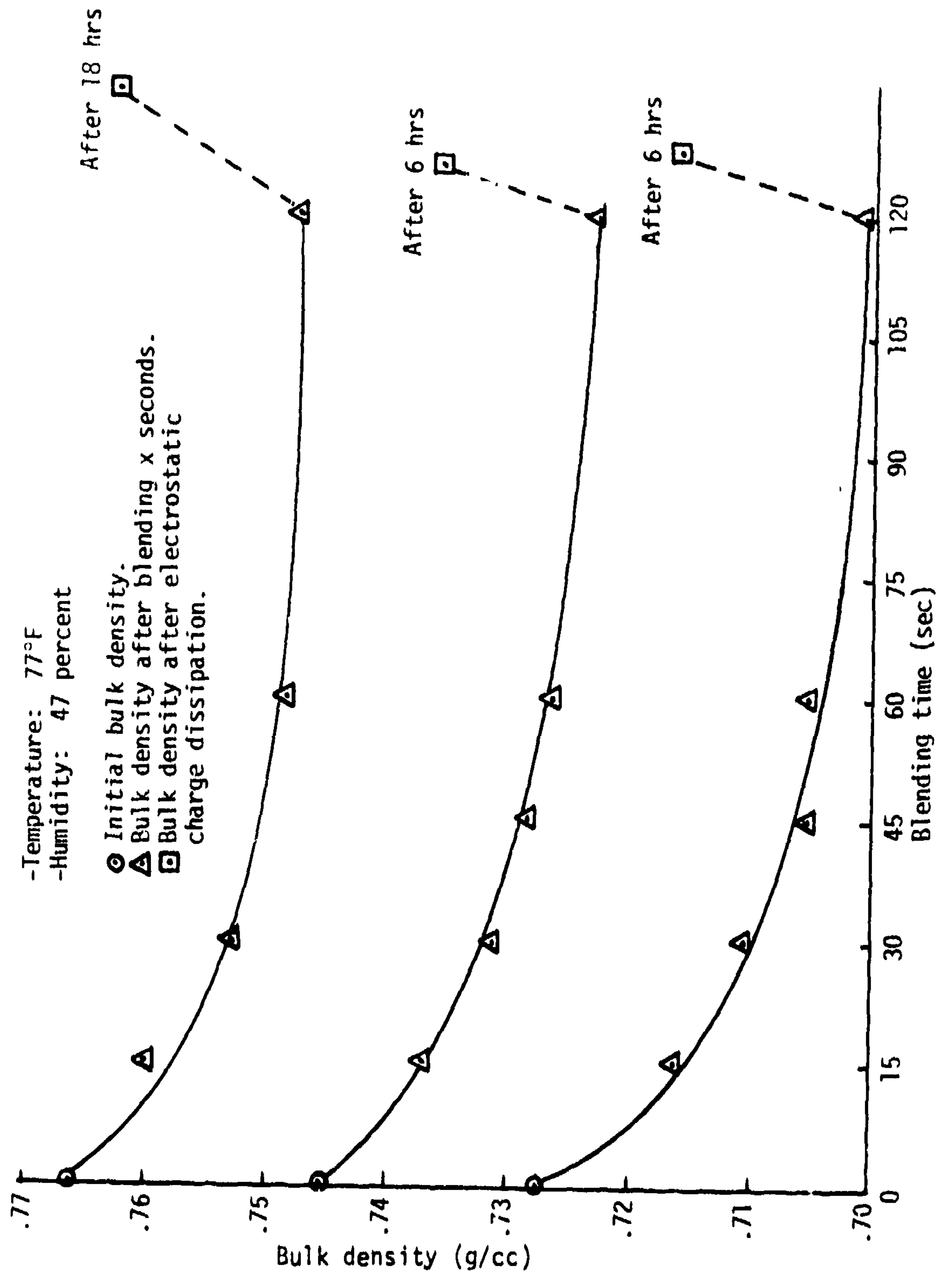

FIGURE 13. BLENDING STUDIES - DENSITY VS BLENDING TIME

Moreover, statically charged material does not press well, thus requiring additional production storage areas until charge dissipation occurs. Figure 13 also shows that it takes from 6 to 18 hours for this to happen. For these reasons, it was decided to re-examine blended versus unblended effects more thoroughly than in past investigations, including those initiated and described in III.C.1.

b. Establishing the single variable matrix

The inter-lot blending study was only partially controlled in that no historical data existed for the previous handling treatment of the unblended Comp A-3. That is, it was not known whether or not it had been transported many times, how roughly or gently it had been handled, whether or not containers had, at times, been turned over thereby inadvertently causing some partial blending, etc. In order to eliminate all variables except that of blending versus no blending, the controls listed in Table XVI were established. The most significant factors are:

- All Comp A-3, both blended and unblended, was chosen at a single, 0.79 g/cc, bulk density value.
- All loading operations were carried out under typical production conditions at NAD Crane using regular production personnel, unaware of the study and its purpose.
- All unblended material was prepared in an identical manner in that a deliberate attempt was made to cause maximum stratification in the Comp A-3. This was done by trucking the Comp A-3 containers over rough roads for 6 consecutive hours, making sure that no containers were upended or handled in any way that might result in reblending their contents.

c. Intra-batch blended vs unblended results

Table XVI summarizes the data from this study phase. Both 5"/54 and 5"/38 projectiles were loaded with 0.79 g/cc bulk density Comp A-3 and both with blended and unblended material. Qualitatively no major differences are apparent between any projectiles loaded with either blended or unblended material. NAPEC already had been cited as finding no meaningful statistical difference between the two[19].

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[19] Loc. cit.

TABLE XVI

5"/54 - 5"/38 PROJECTILES
BLENDED VS UNBLENDED DENSITY COMPARISON

		5"/54		5"/38	
		Blended	Unblended	Blended	Unblended
Bulk		.79	.79	.79	.79
Overall	n	26	35	44	45
	$\bar{x}$	1.640	1.637	1.638	1.635
	s	.0055	.0062	.0072	.0062
Lowest core*	n	26	35	44	44
	$\bar{x}$	1.611	1.620	1.621	1.619
	s	.0086	.0076	.0071	.0058

n = Number tested
$\bar{x}$ = Sample mean (avg)
s = Sample standard deviation
Density in g/cc

*Lowest core is the lowest density core found in each projectile sampled regardless of its position in the explosive load.

<u>Pressing constants</u>

Temperature:	68°F
No. of increments:	8
Ram pressure:	15,000 psi (5"/54)
	14,000 psi (5"/38)
Ram speed:	85"/min
Dwell time:	6 sec

d. Conclusions and recommendations

NAPEC's analysis[20] of the data reconfirmed the findings of the inter-lot blending studies and the conclusions that blending was not required, *per se*, to produce uniform projectiles was accepted by the Systems Command. The net result is a significant cost reduction resulting from lower manpower requirements, less material handling, and elimination of Quality Assurance blender sampling and testing.

4. High-low wax content Comp A-3 blends

a. Purpose of the study

Approximately three million pounds of Comp A-3 had been suspended because the wax content lay outside the 8.3 to 9.7 percent specification range. It was also shown that differences in analytical techniques were mainly responsible for discrepancies between Army acceptance data and Navy rejection data. Therefore, the objective here was to first reanalyze the wax content of suspended lots by the improved benzene extraction procedure described earlier (III.A.4) and then to examine the advisability of blending off those batches of material that still fell outside the specification limits.

b. Sampling plan

Samples were chosen in accordance with NAVORDSYSCOM instructions[21] with the expectation that the recommended procedures would result in a 99 percent confidence level and 95 percent reliability. This procedure included: random selection of a single sample from the geometric center of at least 20 boxes representing each suspended batch; compositing the 20 samples and running duplicate wax analyses on each composite in accordance with MIL-C-440B and its applicable refinements referenced earlier[7].

c. Results of reanalysis

Six hundred and seventy-one batches of Comp A-3, taken from 67 lots and representing over three million pounds of material, were each resampled and analysed. After two retests, all but 47 batches were found to be within the 8.3 to 9.7 percent

[20] *Loc. cit.*
[21] NAVORDSYSCOM msg 030108Z Nov 1972 to NAD Crane
[7] *Loc. cit.*

specification limits. These 47 batches represented less than 250,000 of the total three million pounds of suspended material. The remaining 624 batches not only fell within the specification limits but averaged 9.0 percent.

These tests were made independently by the analytical chemistry laboratory at NAD Crane and reported to the NAVORDSYSCOM and NEDED for guidance and disposition[22].

Table XVII lists the retest analyses on the 47 batches of Comp A-3 still outside the wax specification limit.

There are two factors of interest that should be noted in Table XVII:

- While most reanalyses were reproducible, 9 of the 43 retests gave values far outside the precision of the test method, i.e., batches 122A, 3-422, 3-424, 3-428, 3-495, 3-669, 3-818, 3-823, and 3-826. More importantly, of the nine non-reproducible batches, five of them (3-422, 3-424, 3-495, 3-818 and 3-823) had at least one of the two analyses within specification limits. Three analyses reversed the reason for rejection in going from a too high to a too low wax content or vice versa - batches 122A, 3-428 and 3-669. Only one batch, 3-826, fell below the 8.3 percent minimum on both analyses.

- The arithmetic mean for all 94 analyses was 8.9 percent with a 0.1269 standard deviation.

d. Conclusions and recommendations

Two conclusions were drawn from the data gathered in this study. The first was that 90 percent of the three million pounds of Comp A-3 suspended for out-of-specification wax content had been so classified erroneously. The second conclusion was that the remaining 250,000 pounds represented by the 47 out-of-specification batches were not any different in quality from those within specification limits. This conclusion was based on several different sets of information:

- The average wax content for the 47 lots was 8.9 percent.

- The spreads in nine of the retests exceeded the precision of the analytical technique. This strongly indicated that the RDX was not uniformly coated with wax in the HAAP process

[22] NAD Crane spdltr 2043-TS:jal 8010 of 29 May 1973 to NAVORDSYSCOM, Subj: Low wax content - Composition A-3

TABLE XVII. WAX ANALYSES OF COMP A-3 IN REJECT STATUS AT NAD CRANE

Lot No. HOL-32-	Batch	Percent wax 1st retest	Percent wax 2nd retest	Lot No. HOL-32-	Batch	Percent wax 1st retest	Percent wax 2nd retest
-117	182	10.0	10.0	-340	3-513	10.0	10.0
-126	49A	7.9	8.1	-343	3-540	8.0	7.6
-126	51	8.0	8.0	-343	3-541	8.2	8.1
-126	53A	7.3	8.2	-350	3-609	9.8	9.1
-133	117	10.0	10.0	-355	3-669	8.2	11.2
-133	118	10.0	10.0	-356	3-673	7.7	7.8
-133	119	10.0	10.0	-356	3-674	8.1	8.2
-133	122A	7.8	10.0	-356	3-675	7.8	7.8
-149	286	7.9	7.8	-356	3-677	8.1	8.1
-166	448	10.0	10.0	-363	3-739	10.0	9.8
-166	454	9.9	10.0	-365	3-764	10.6	10.5
-179	582A	10.0	10.0	-365	3-767	9.5	10.0
-227	4-1030	10.0	10.0	-371	3-818	8.9	5.2
-227	4-1038	10.0	10.0	-371	3-820	8.3	8.0
-244	4-1192A	9.8	10.0	-371	3-822	7.4	7.4
-244	4-1194	10.0	10.0	-371	3-823	9.5	7.8
-244	4-1195	10.0	10.0	-371	3-826	8.0	6.9
-323	3-357	10.0	8.0	-371	3-830	8.8	8.1
-331	3-422	9.1	7.7	-383	4-412	10.0	10.0
-331	3-424	9.3	6.8	-392	3-1121	8.2	9.5
-332	3-428	9.8	7.3	-393	3-1135	8.2	7.3
-338	3-486	7.9	8.1	-393	3-1136	8.1	7.6
-338	3-495	9.1	7.6	-393	3-1141	7.9	7.5
-339	3-499	10.0	10.0				

and that small test samples would invariably accentuate micro differences within a batch of material.

- There was no observable difference in drop hammer sensitivity between batches of Comp A-3 that had been designated high or low in wax content.

For these reasons, NEDED recommended[23] that all Comp A-3 batches passing wax retest analyses be accepted, reclassified as Class A and returned to stock. It also recommended that those batches having a wax content below 8 percent be blended with those at 10 percent and the resulting material be released for loading. NAVORDSYSCOM concurred with these recommendations[24], the net result being that three million pounds of suspended stockpile was salvaged for use.

IV. REFERENCES

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8 WS 13271, Purchase Description for the Composition A-3 Explosive Loaded Projectile, 5 Inch 38 Caliber, Mk 52 Mod 0, 25 Feb 1970

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[23] NAVWPNSTA Yorktown ltr 504:EYM:rdh of 16 Oct 1973 to NAVORDSYSCOMHQ, Subj: Wax content - Comp A-3

[24] NAVORDSYSCOM spdltr ORD-04M1B/246:MYM 8030 undated to NAVWPNSTA Yorktown, Subj: Wax content - Composition A-3 (Rec'd 14 Nov 1973)

9 WS 13574A, Projectile, 5 Inch 54 Caliber, Mk 64 Mod 0, Composition A-3 Explosive Loaded, 23 May 1975

10 NAD Crane ltr 30412-JGG:ofw 8030 of 17 Mar 1972 to NAVWPNSTA Yorktown (NEDED), Subj: Data analysis on special loading of 5"/54 Projectiles using various Comp A-3 bulk densities

11 NAPEC Rept, Yorktown Comp A-3 Density Data - Histogram Analysis for 5"/54 Projectiles, 16 Aug 1974

12 NAD Crane ltr 30412-JGG:las 8030 of 25 Apr 1972 to NAVWPNSTA Yorktown (NEDED), Subj: Data analysis on special loading of 5"/38 Projectiles using various Comp A-3 bulk densities

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21 NAVORDSYSCOM msg 030108Z Nov 1972 to NAD Crane

22 NAD Crane spdltr 2043-TS:jal 8010 of 29 May 1973 to NAVORDSYSCOM, Subj: Low wax content - Composition A-3

23 NAVWPNSTA Yorktown ltr 504:EYM:rdh of 16 Oct 1973 to NAVORDSYSCOMHQ, Subj: Wax content - Comp A-3

24 NAVORDSYSCOM spdltr ORD-04M1B/246:MYM 8030 undated to NAVWPNSTA Yorktown, Subj: Wax content - Composition A-3 (Rec'd 14 Nov 1973)

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