MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES
3 4456 0422838 8

ORNL/TM-12839

ornl

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

# Artillery Ammunition Marking Tests

B. S. Weil
J. C. Lewis

AMMUNITION LOGISTICS PROGRAM

OAK RIDGE NATIONAL LABORATORY
CENTRAL RESEARCH LIBRARY
CIRCULATION SECTION
4500N ROOM 175
LIBRARY LOAN COPY
DO NOT TRANSFER TO ANOTHER PERSON
If you wish someone else to see this report, send in name with report and the library will arrange a loan.

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from the Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831; prices available from (615) 576-8401, FTS 626-8401.

Available to the public from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161.

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

ORNL/TM-12839

Ammunition Logistics Program

# ARTILLERY AMMUNITION MARKING TESTS

B. S. Weil
J. C. Lewis
Robotics and Process Systems Division

Date Published–April 1995

Research sponsored by the
Army's Project Manager,
Advanced Field Artillery System/Future Armored Resupply Vehicle
under the Interagency Agreement 1892-A078-A1
between the Department of Energy and the
Armament Research, Development, and Engineering Center
at the Picatinny Arsenal

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

MARTIN MARIETTA ENERGY SYSTEMS LIBRARIES

3 4456 0422838 8

## CONTENTS

LIST OF FIGURES ..... v

LIST OF TABLES ..... vii

ABSTRACT ..... ix

1. INTRODUCTION ..... 1

2. EXPERIMENTAL APPROACH ..... 3

3. INK-JET MARKING TESTS ..... 7
   - 3.1 INK-JET SYSTEM ALIGNMENT TESTS ..... 7
     - 3.1.1 Printer Head Distance Test ..... 7
     - 3.1.2 Printer Head Tilt Angle Test ..... 9
     - 3.1.3 Printer Head Skew Angle Test ..... 9
   - 3.2 MARKING PERFORMANCE TESTS ..... 10
     - 3.2.1 Print Contrast Tests ..... 10
     - 3.2.2 Enhanced Printing Tests ..... 10
     - 3.2.3 Ink Drying Time Tests ..... 10
     - 3.2.4 Printing Speed Tests ..... 11
   - 3.3 SURFACE CONDITION TESTS ..... 11
     - 3.3.1 Temperature Effects ..... 11
     - 3.3.2 Moisture Effects ..... 12
     - 3.3.3 Dust Effects ..... 12
     - 3.3.4 Oil Effects ..... 12
   - 3.4 OVERALL INK-JET SYSTEM PERFORMANCE ..... 12

4. LABEL APPLICATION TESTS ..... 13
   - 4.1 APPLICATOR ALIGNMENT TESTS ..... 13
     - 4.1.1 Distance Effects ..... 13
     - 4.1.2 Wrap Angle Effects ..... 15
     - 4.1.3 Skew Effects ..... 15
     - 4.1.4 Projectile Misalignment ..... 15
   - 4.2 SURFACE CONDITION TESTS ..... 15
     - 4.2.1 Temperature Effects ..... 15
     - 4.2.2 Moisture Effects ..... 15
     - 4.2.3 Dust Effects ..... 16
     - 4.2.4 Oil Effects ..... 16
   - 4.3 OVERALL LABELING SYSTEM PERFORMANCE ..... 16

5. SUMMARY ..... 17

APPENDIX A INK-JET PRINTER SPECIFICATIONS ..... 19

APPENDIX B LABEL PRINTER/APPLICATOR SYSTEM SPECIFICATIONS ..... 21

## LIST OF FIGURES

Fig. 1. Actual size matrix symbols for artillery marking application ..... 1

Fig. 2. Dummy projectile with fuze, showing the proposed concept for the location of a machine-readable symbol array ..... 2

Fig. 3. Ammunition support stand (foreground) and control system cabinet (background)..... 4

Fig. 4. Schematic of artillery ammunition marking control system ..... 5

Fig. 5. Ammunition support stand for ink-jet marking tests ..... 8

Fig. 6. Symbol distortion caused by a skew angle of 21° ..... 10

Fig. 7. Marking test bed with CPA-150 label printer/applicator ..... 14

## LIST OF TABLES

Table 1. Effects of ink-jet printer head distance on symbol readability ..... 7

Table 2. Effect of ink-jet printer wrap angle on symbol readability ..... 9

Table 3. Effect of ink-jet printer head skew angle on symbol readability ..... 9

Table 4. Measured ink drying times ..... 11

Table 5. Results of printing speed tests ..... 11

# ABSTRACT

This report describes the testing results of two approaches being considered for marking artillery ammunition with machine-readable data symbols. The first approach used ink-jet printing directly onto projectiles, and the second approach employed thermal-transfer printing onto self-adhesive labels that are subsequently applied automatically to projectiles. The objectives of this evaluation for each marking technology were to (1) determine typical system performance characteristics using the best commercially available equipment and (2) identify any special requirements necessary for handling ammunition when these technologies are employed.

# 1. INTRODUCTION

The Artillery Ammunition Marking Project (AAMP) is a development activity of the Robotics and Process Systems Division (RPSD) at Oak Ridge National Laboratory (ORNL) for the U.S. Army's Project Manager, Advanced Field Artillery System/Future Armored Resupply Vehicle (PM-AFAS/FARV) at the Picatinny Arsenal in New Jersey. The project objectives are to (1) evaluate automatic identification technologies for 155mm artillery ammunition and (2) recommend and develop the most feasible technologies for use in the Advanced Field Artillery System/Future Armored Resupply Vehicle (AFAS/FARV) system. Among the identification technologies being considered, machine-readable data symbols show promise. Machine-readable data symbols are a proven and inexpensive technology, but finding the appropriate method for marking ammunition items with these symbols is key to their successful application on the battlefield.

Previous work funded by the Project Manager for Ammunition Logistics (PM-AMMOLOG) evaluated and recommended two-dimensional matrix code symbologies for identifying individual ammunition components. The principal advantages of matrix codes over traditional bar codes are improved information density and high-speed omnidirectional scanners that can read moving symbols in any orientation. Also, the symbol design and error correction capability of matrix codes make them more tolerant of poor image quality factors that might result from the printing process or exposure to wear and tear. In the proposed AFAS/FARV application, a circumferential array of duplicate matrix symbols would be placed on each artillery projectile to permit automatic identification of the assembled round after fuzing. Each symbol on the round would contain encoded lot numbers and identification codes for projectile and fuze types, as well as the total firing weight of the round. To ensure that, regardless of projectile rotation, at least one symbol is within the scanner field of view, all symbols on a projectile would contain the same encoded data. Figure 1 shows the actual size of a symbol array encoding the data string "N290ALP93L001S639 D544YPG91M001S451 4317." Figure 2 shows the proposed concept for a marked artillery projectile.

**Fig. 1. Actual size matrix symbols for artillery marking application.**

ORNL-PHOTO 9425-93

Fig. 2. Dummy projectile with fuze, showing the proposed concept for tbc location of a machine-readable symbol array.

## 2. EXPERIMENTAL APPROACH

This report covers the evaluation of two approaches being considered for marking artillery ammunition by the AFAS/FARV project. The first approach involves printing machine-readable data symbols directly onto artillery projectiles with an ink-jet printer that uses a water-based black ink. The ink-jet printer for this evaluation was selected for its high-resolution output, exceptional printing speed, and small physical size. Appendix A contains specifications for the ink-jet printer. The other approach employs thermal-transfer printing of data symbols onto self-adhesive labels that are subsequently applied to projectiles automatically. A special printer/applier system was designed and built for this project. The system incorporated a high-resolution thermal-transfer printer and automated label applicator accommodating label lengths up to 20-in. long. Appendix B contains specifications for the thermal-transfer printer and labels. A common ammunition support and control system was used for both technologies (see Fig. 3).

A PC-based man-machine interface (MMI) was used to input all system parameters to the marking controller and acquire data from the operator and weight from a digital scale (Fig. 4). After checking the validity of the data, the computer would format a data string and send it to the marking controller. The marking controller would pass the data string to the symbology encoder with error correction, symbol format, and matrix density parameters. The encoder would return a binary pattern string to the controller, which the controller would use to create a graphic image for the printer. After downloading the graphic image to the printer with symbol spacing, speed, and direction settings, the controller would issue a print command.

ORNL-PHOTO 508-94

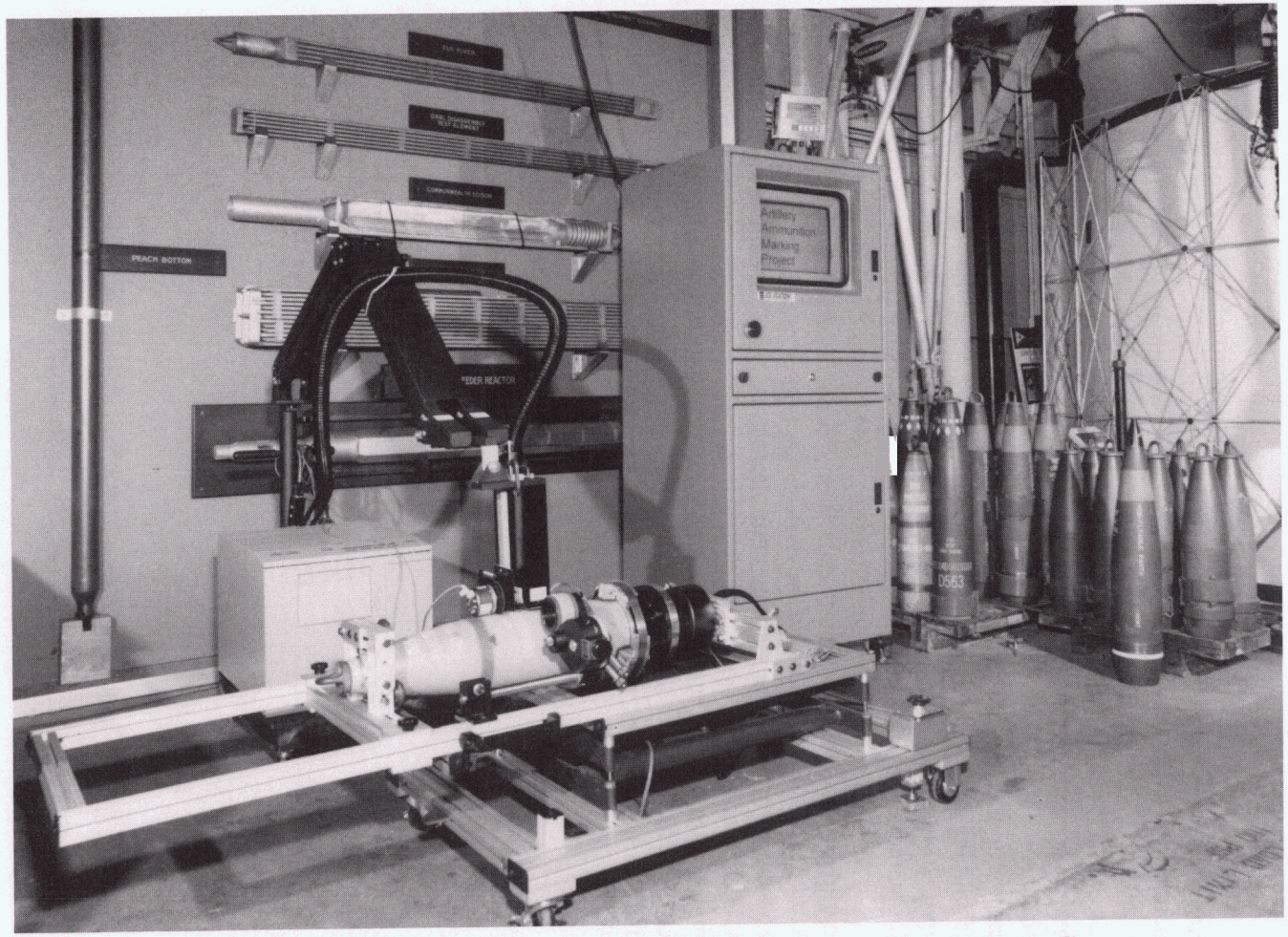


**Fig. 3. Ammunition support stand (foreground) and control system cabinet (background).**

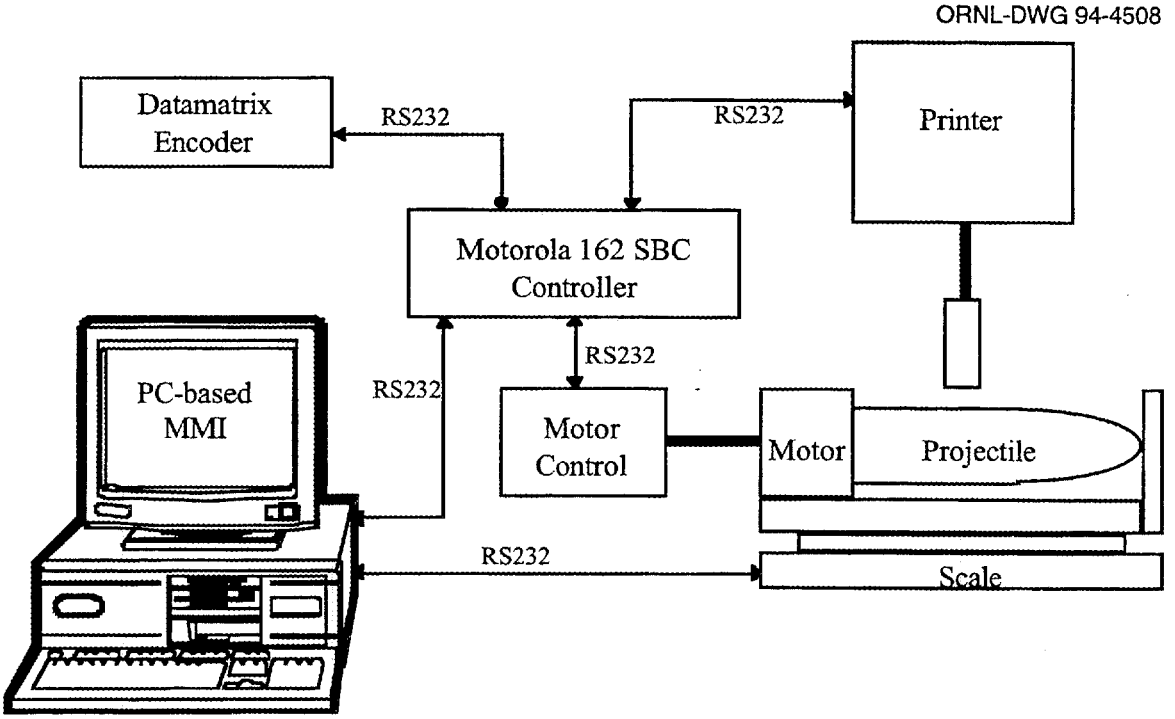


**Fig. 4. Schematic of artillery ammunition marking control system.**

# 3. INK-JET MARKING TESTS

The decision to use the water-based ink-jet printer in this evaluation was based on several factors. A vendor search was conducted to find ink-jet systems incorporating a single print head able to produce 1-in.-high graphic images with high resolution. Currently, there are only two printers on the market that meet this requirement. The first uses inks based on the solvent methylethylketone, while the other uses water-based inks. The first system is very large and unsuitable for eventual integration on the FARV, while the other is more compact and could easily fit on the FARV. Although solvent-based inks have shorter drying times than water-based inks, this advantage is somewhat offset by the fire and health hazards associated with the solvent. For these reasons, the water-based ink-jet printer was selected for the following tests. Figure 5 shows the ink-jet printer configured for printing a projectile in a horizontal position.

## 3.1 INK-JET SYSTEM ALIGNMENT TESTS

These tests were designed to determine the sensitivity of symbol readability to changing print head distances and angles. A test was also conducted to determine any measurable performance changes affected by the printing orientation of the projectile, either horizontal or vertical. Printer head distance was measured in millimeters from the projectile surface to the printer orifice, and tilt and skew angles were measured in degrees from the projectile axis. Symbol readability was evaluated with the ITRAN Datamatrix decoder system.

### 3.1.1 Printer Head Distance Test

The results in Table 1 indicate that symbol readability is not adversely affected by printer head distances between 1 and 23 mm. Below 1 mm the printer head is so close that the ink can smear. Above 23 mm the printer head is so far away that small air currents may affect the ink-jet droplets.

**Table 1. Effects of ink-jet printer head distance on symbol readability**

| Printer head distance (mm) | Readable symbol |
|---|---|
| 0.5 | No |
| 1.0 | Yes |
| 1.5 | Yes |
| 2.0 | Yes |
| 12.7 | Yes |
| 23.0 | Yes |
| 25.4 | No |

ORNL-PHOTO 2116-94

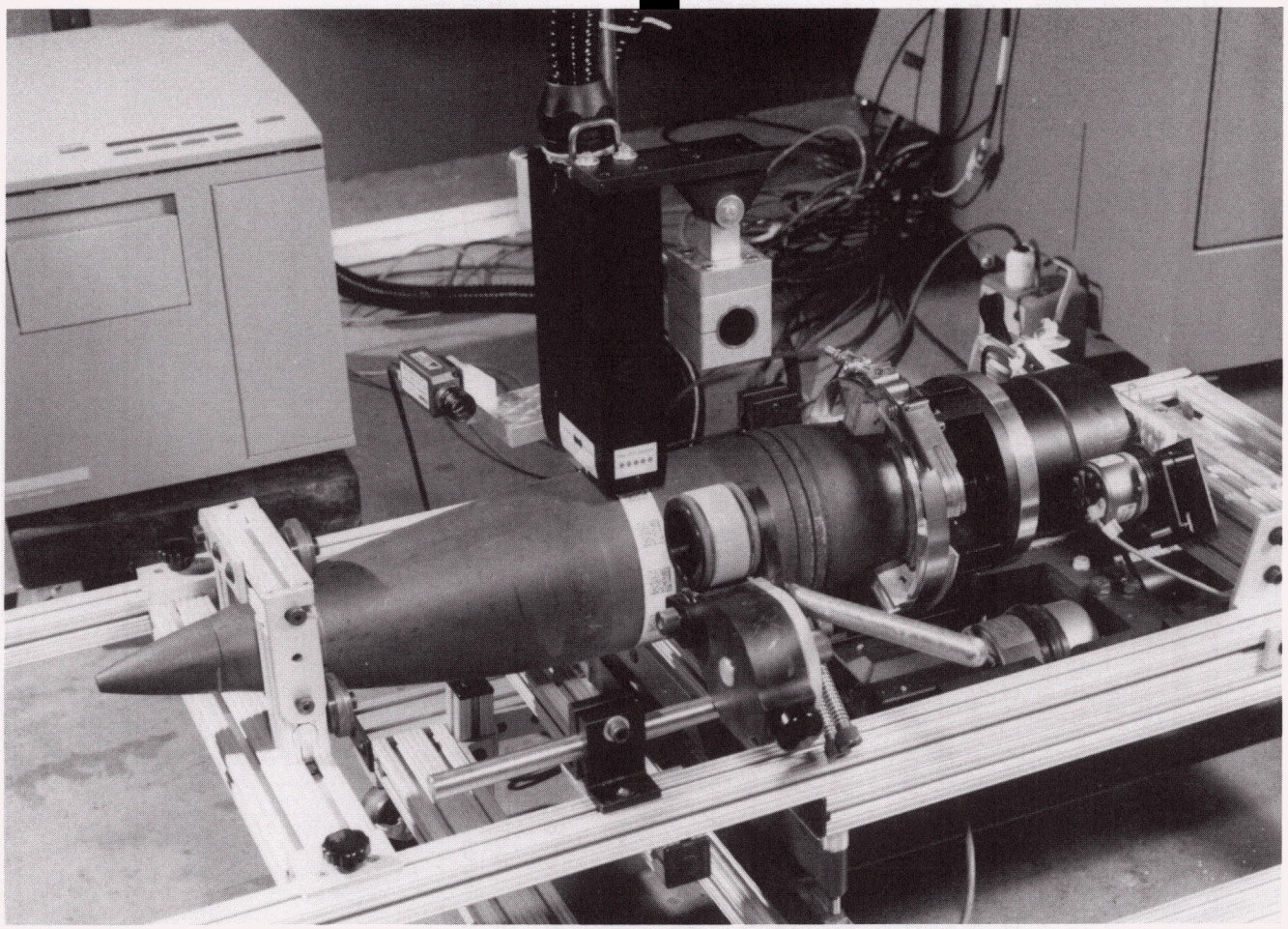

**Fig. 5. Ammunition support stand for ink-jet marking tests.**

### 3.1.2 Printer Head Tilt Angle Test

The printer head distance used for this test was 12.7 mm, and the scanner position was adjusted to maintain the printed symbol within the field of view. The results in Table 2 indicate that symbol readability is not adversely affected by printer head tilt angles ranging from ±20°. If the scanner is not adjusted to capture the symbol within the field of view, then the symbol is unreadable at tilt angles above ±2°.

### 3.1.3 Printer Head Skew Angle Test

The printer head distance used for this test was 12.7 mm, and the tilt angle was 0°. The results in Table 3 indicate that symbol readability is not adversely affected by printer head skew angles ranging from ±22°. The symbol distortion caused by a 20° skew angle is shown in Fig. 6.

**Table 2. Effect of ink-jet printer wrap angle on symbol readability**

| Printer head tilt angle (°) | Readable symbol |
|---|---|
| 0 | Yes |
| -5 | Yes |
| -10 | Yes |
| -15 | Yes |
| -20 | Yes |
| -24 | No |
| -29 | No |

**Table 3. Effect of ink-jet printer head skew angle on symbol readability**

| Printer head skew angle (°) | Readable symbol |
|---|---|
| 0 | Yes |
| 13 | Yes |
| 21 | Yes |
| 22 | Yes |
| 24 | No |
| 30 | No |

**Fig. 6. Symbol distortion caused by a skew angle of 21°.**

## 3.2 MARKING PERFORMANCE TESTS

Symbol contrast, ink drying time, and printing speed are critical performance factors for artillery projectile marking. Symbol readability is adversely affected by insufficient symbol contrast, and ink drying time and printing speed are factors that would limit the processing rate of the overall marking system. Tests were conducted to measure print contrast, ink drying time, and printing speed effects.

### 3.2.1 Print Contrast Tests

Using black ink on the olive drab surface of projectiles produces a low contrast image. Prior to testing the ink-jet printer, we predicted this low contrast condition to be below the minimum requirements needed for successfully reading symbols. A roll marker filled with an alcohol-based ink was proposed for placing a white stripe on the projectile before printing symbols. The experimental plan included tests to measure the contrast and drying time for applying the stripe. While debugging the test stand software, it was expedient to place ink-jet markings directly onto projectiles without the white stripe. It was during these early tests that we discovered the decoder system from ITRAN could successfully read matrix symbols printed with black ink on the olive drab projectile. For this reason, contrast and drying time tests for a white ink stripe were not necessary.

### 3.2.2 Enhanced Printing Tests

Ink density is a user-selectable feature on the printer that was tested. Normal ink-jet printing uses a single ink drop for each image pixel, while enhanced printing uses two drops. Print contrast and the resulting symbol readability should be improved by enhanced printing. However, doubling the ink density causes excessive bleeding of the ink on a nonporous surface, and data symbols are not readable.

### 3.2.3 Ink Drying Time Tests

Ink drying time is a factor that limits the processing rate of an ink-jet marking system. In this test, drying time was measured from the completion of the printing process until there was no detectable smearing of the last symbol printed. Table 4 contains the measured drying times for several tests conducted at ~20 °C and ~54% RH.

**Table 4. Measured ink drying times**

| Test conditions | Drying time (s) |
|---|---|
| Normal printing on bare projectile | 75 to 110 |
| Normal printing on white ink stripe | 65 to 80 |
| Enhanced printing on bare projectile | ~180 |

### 3.2.4 Printing Speed Tests

Printing speed is another factor that affects the processing rate of the overall marking system. This test was designed to determine if excessive printing speed has an adverse affect on symbol readability. For this test normal printing was employed at a print head distance of 6 mm. Symbol readability was evaluated with the ITRAN decoder system. The qualitative data for this test is shown in Table 5. Since the actual printing process occurs during one rotation of the projectile, printing speed is reported in seconds per revolution so that printing times can be directly determined from the data table.

**Table 5. Results of printing speed tests**

| Seconds per revolution | Readable symbol |
|---|---|
| 4.29 | Yes |
| 2.14 | Yes |
| 1.07 | Yes |
| 0.71 | Yes |

The results in Table 5 indicate that readable symbols can be produced up to 84 rpm (0.71 s/revolution), but higher printing speeds might be possible since 84 rpm was the limit of the test stand. The vendor claims that linear printing speeds up to 3 m/s are possible. This would translate to 360 rpm or 0.17 s/revolution. For safety reasons, rotation speeds of fuzed projectiles should remain below 300 rpm.

## 3.3 SURFACE CONDITION TESTS

The surface condition of projectiles will certainly affect the ink-jet marking process and ultimately the readability of the symbols in the marking. Factors such as extreme temperatures, moisture, and oil or dust contamination must be considered real possibilities for artillery ammunition on the battlefield.

### 3.3.1 Temperature Effects

The acceptable storage temperature range for artillery ammunition is between –51 and 71°C and (–60 and 160°F). The use of special preconditioning procedures prior to marking

ammunition is undesirable during battlefield operations. Therefore, a test was conducted to determine if extreme temperatures have an adverse effect on the ink-jet marking process. Sections of painted steel pipe were chilled with dry ice or heated to simulate ammunition storage conditions.

The results of this test indicated that elevated temperatures actually improve the marking process by decreasing the ink drying time, as expected, while temperatures below the dew point produce unacceptable results. The problem at low temperatures stems from condensation or ice crystals that form on cold surfaces exposed to humid air. When ink-jet printing with a water-based ink, the ambient temperature must be well above the dew point to achieve reasonable drying times.

### 3.3.2 Moisture Effects

During rainy weather conditions, artillery ammunition will get wet during storage, transportation, or uploading. Soldiers could quickly wipe excess moisture from projectiles before uploading, but this would be time consuming and, at best, leave a damp projectile surface. A test was conducted to determine the adverse effect of a damp projectile surface on ink-jet printing. Before printing, each test projectile was sprayed with a water mist and excess water was wiped away with a dry rag. Test results proved that ink-jet printing requires a dry surface. Symbols printed with a water-based ink onto damp projectiles exhibit excessive bleeding and produce unreadable symbols.

### 3.3.3 Dust Effects

Dusty conditions can exist on the battlefield where ammunition is temporarily stored. A test was conducted to determine if surface dust on projectiles has an adverse effect on the ink-jet marking process. For this test, projectiles were powdered with chalk dust before ink-jet marking. The test revealed that symbols printed over heavy dusting were distorted and unreadable, while symbols printed over a light dusting remained readable. Since a qualitative measure of dust contamination was not available, these results are obviously very subjective.

### 3.3.4 Oil Effects

Another test was conducted to determine if an oily projectile surface has an adverse effect on the ink-jet marking process. For this test projectiles were sprayed with WD-40 lubricant, and excess lubricant was removed with a cloth before marking. As expected, the water-based ink beaded up on the projectile surface, and the symbols printed with a water-based ink in this test were not readable.

## 3.4 OVERALL INK-JET SYSTEM PERFORMANCE

The quality and contrast of matrix symbols produced by the ink-jet printer on dry and clean surfaces are acceptable for ammunition marking applications at high speeds. Symbols printed with existing water-based inks on damp, dusty, or oily surfaces are not acceptable. Print head alignment parameters, such as distance, tilt, and skew, are not critical, and the system can be easily adapted to marking horizontal and vertical surfaces. Currently, water-based inks for the system do not provide a permanent marking, and further ink development by the vendor is needed.

# 4. LABEL APPLICATION TESTS

The equipment used for the following tests is shown in Fig. 7. The system incorporates a 208-dpi thermal-transfer label printer and automated label applicator. The operation of the system involves sending data to the printer and signaling to begin the printing process. The thermal-transfer printing process uses special heat-sensitive ribbons. The type of ribbon, either wax or resin, is determined by the label material and heat capacity of the printer head. The printed image is transferred from the ribbon to the label as both media pass the thermal array of the printer head. After passing the thermal array, the used ribbon is rewound inside the printer and the printed label continues with its coated paper backing until it reaches the sharp corner of the release bar. At the bar, the more flexible coated paper continues around the corner, but the label releases from the paper and extends out of the printer. A jet of compressed air is also used to assist the release of the label from coated paper. As the printer produces the label, the applicator pulls the label from the printer with a motorized vacuum belt.

The belt continues to move the label until its leading edge is positioned between an air-driven tamping foot and a rotating projectile. When the tamping foot is triggered, it tacks the leading edge of the label onto the projectile. The label is wrapped around the projectile as the rotation pulls the label away from the vacuum belt.

The labels used in the following tests were made from a white, nonglossy, top-coated extruded vinyl film. The thickness of each label was 4 mil. The width and length of each label was 38 mm (1.5 in.) and 500 mm (19.7 in.) respectively. The label adhesive was a very aggressive rubber-based type necessary to prevent loose labels and the resulting adverse projectile ballistics.

## 4.1 APPLICATOR ALIGNMENT TESTS

Tests conducted by others have shown that loose adhesive labels attached to 80mm mortar rounds will cause excessive range dispersion. Therefore, good label application is required to prevent this adverse range dispersion of projectiles on the battlefield. The following tests were designed to determine the effects of system misalignments while applying self-adhesive labels to artillery projectiles.

### 4.1.1 Distance Effects

A test was conducted to determine if the automatic application of a self-adhesive label is adversely affected by the applicator stand-off distance. Stand-off distance was measured in millimeters from the projectile surface to the vacuum belt. The manufacturer's recommended stand-off distance was ~10 mm (0.375 in.), and this was the only setting that would provide repeatable success when applying labels. When this distance was decreased to 6 mm, labels sometimes attached to the projectile prematurely as they protruded beyond the vacuum belt. At distances above 10 mm, the tamping foot could not attach the label to the projectile.

ORNL PHOTO 2118-94

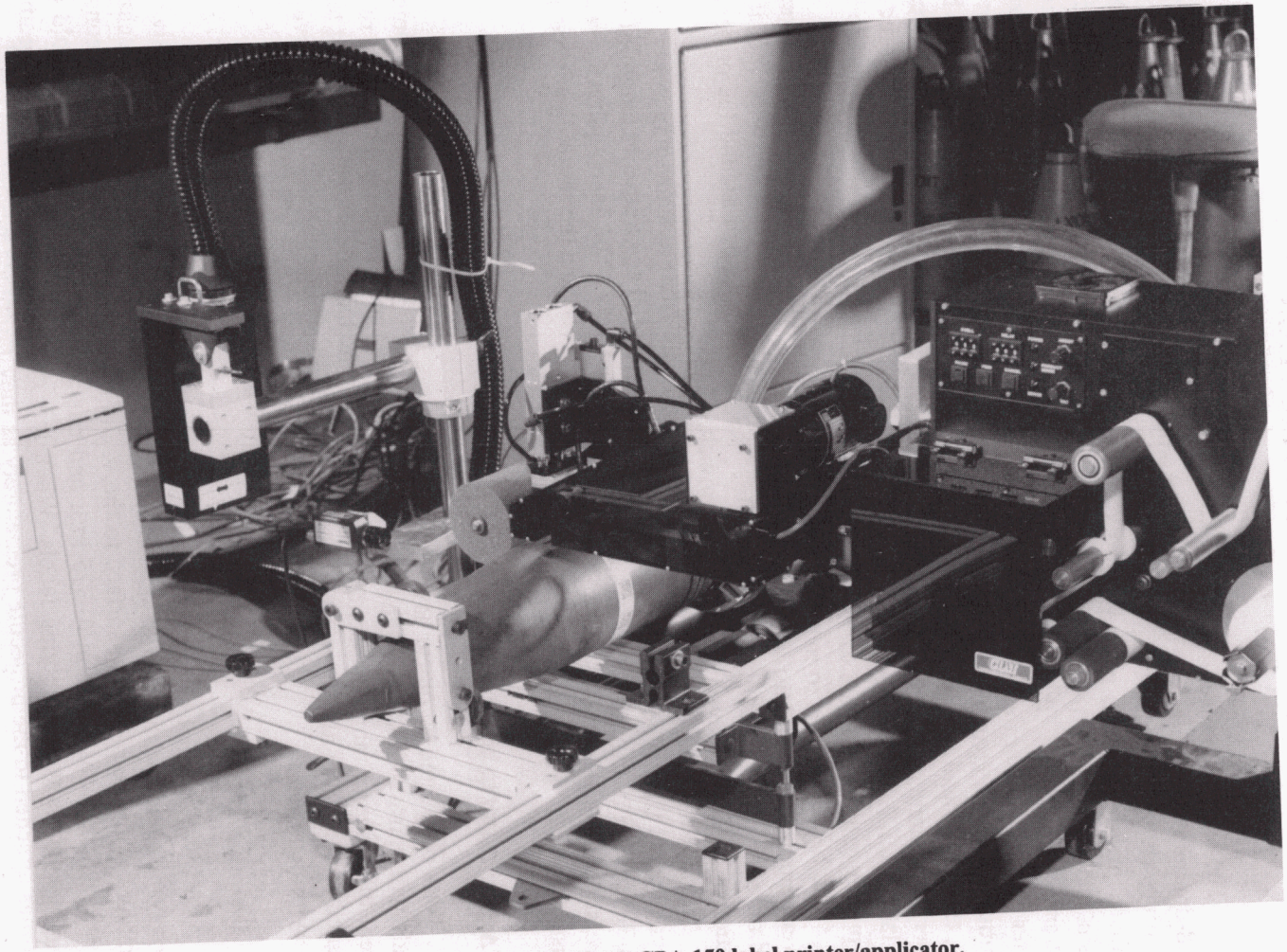

**Fig. 7. Marking test bed with CPA-150 label printer/applicator.**

### 4.1.2 Wrap Angle Effects

A test was conducted to determine if the automatic application of a self-adhesive label is adversely affected by the applicator wrap angle. The design wrap angle for the system is 90°, measured from the axis of the projectile to the direction of the vacuum belt. At angles between ±3° from the design angle, labels will wrap the projectile in a slight spiral fashion, but no label wrinkling will occur. Beyond this range wrinkling begins to occur in addition to the spiral effect.

### 4.1.3 Skew Effects

A test was conducted to determine if the automatic application of a self-adhesive label is adversely affected by the applicator skew angle. The design skew angle for the system is 0°, measured from the axis of the projectile to the narrow dimension of the label. At skew angles between ±2° from the design angle, labels will wrap the projectile correctly without wrinkling. At skew angles above ±2° up to ±6°, slight wrinkles occur while applying the label to the projectile. Above ±6° wrinkling occurs frequently.

### 4.1.4 Projectile Misalignment

A test was conducted to determine if the application of a self-adhesive label is adversely affected by wobble that might result from rotating a misaligned projectile. For this test the stand-off distance was adjusted to 10 mm, measured from the surface of a properly aligned projectile to the vacuum belt surface. Labels were successfully applied without wrinkles to projectiles with misalignments up to 5 mm.

## 4.2 SURFACE CONDITION TESTS

The surface condition of projectiles will certainly affect the label application process and possibly adhesion for the label to the projectile. Extreme temperatures, moisture, and oil or dust contamination must be considered possible factors for artillery ammunition on the battlefield.

### 4.2.1 Temperature Effects

A test was conducted to determine if extreme temperatures have an adverse effect on the label application process. A length of painted steel pipe was chilled with dry ice or heated to simulate ammunition storage conditions. At 60°C (140°F) there were no adverse effects detected while applying labels to the material. The configuration of the label printer/applicator would not permit testing at low temperatures; however, the moisture test results indicate that the presence of condensation or ice crystals on the projectile would probably prevent good label adhesion.

### 4.2.2 Moisture Effects

A test was conducted to observe the adverse effect of a damp projectile surface on the label application process. Before printing, each test projectile was sprayed with a water mist, and excess water was wiped away with a dry rag. The label that was subsequently applied did not adhere to the projectile but remained in place because the ends of the label overlapped and adhered to each other. This condition could have unpredictable consequences while handling or firing the labeled projectile.

### 4.2.3 Dust Effects

A test was conducted to observe the label application process using a projectile coated with dust. The results were similar to those of the moisture test, but the label adhered slightly better to the projectile. This condition could also have unpredictable consequences while handling or firing the labeled projectile.

### 4.2.4 Oil Effects

Another test was conducted to determine if an oily projectile surface also has an adverse effect on the label application process. For this test projectiles were sprayed with WD-40 lubricant, and excess lubricant was removed with a cloth before marking. As expected, the label did not adhere to the oily projectile surface, but label ends that overlapped remained together.

## 4.3 OVERALL LABELING SYSTEM PERFORMANCE

The output produced by the thermal transfer printer is consistently high quality. Labels successfully produced by the printer always provide readable symbols. Often, however, problems are encountered while transferring the printed label to the applicator. One problem occurs when the leading edge of a label does not release from its coated paper at the release bar. Most of the time the label remains attached to the paper and is rewound harmlessly inside the printer. To compensate for this problem the pressure of the assist jet can be increased; however, this can blow the label edge above the vacuum belt or fold the label. When this happens a jam usually occurs as the adhesive attaches the label to the vacuum belt or rollers inside the printer. These operational problems indicate that label media, adhesive, and ribbon selections are very application dependent and critical to the successful performance of any printer/applicator system. On factory product conveyors where these systems are used, the conditions of the product and environment are more easily controlled than those on the battlefield.

The tests conducted have shown that label applicator alignment is critical. Misalignments of wrap and skew angles have a more significant negative impact than applicator stand-off distance. As with ink-jet printing, the tests have also shown the importance of a properly prepared projectile surface for good label adhesion.

## 5. SUMMARY

To permit the high rates of fire proposed for the AFAS, the U.S. Army is developing an automatic reloading system to remove the soldier from the process. To ensure that correct ammunition is being handled without human verification, some method for automatically identifying ammunition is required. One proposed approach would employ machine-readable matrix symbols on each projectile to convey important data such as projectile and fuze types, lot numbers, and total weight. These recommended symbols function like a bar code but have several advantages. First, matrix symbols have a higher data capacity and offer error correction capabilities that traditional bar codes do not. Also, unlike bar codes that are decoded with a laser scanner, matrix symbols are decoded with a small video camera. This type scanner allows matrix symbols in any orientation to be decoded even if they are moving. The video scanner can also decode matrix symbols with low contrast or poor image quality.

The key technology needed for the proposed approach is an acceptable method for placing the matrix symbols on artillery projectiles in the FARV. Tests were conducted to evaluate two methods for marking artillery ammunition with machine-readable symbols. The first method uses ink-jet printing directly onto projectiles, and the second uses thermal-transfer printing onto self-adhesive labels that are subsequently applied automatically to projectiles.

Results of testing both systems indicate that projectiles must be clean and dry before marking with either method. This places a requirement on soldiers or an automated system that may be difficult to achieve under extreme battlefield conditions.

Label printing and application tests demonstrated the importance of proper media selection and system alignment to successfully attach self-adhesive labels to projectiles. Given the unpredictable nature of environmental conditions on the battlefield and the importance of system alignment for proper label application, labeling systems are not recommended for marking projectiles.

The ink-jet tests demonstrated that small misalignments of the printing head will not adversely affect the readability of printed symbols, and symbols can be printed at high speed on either vertical or horizontal surfaces. Existing water-based black inks provide adequate contrast for reading symbols from olive drab projectiles, but the ink is not permanent on projectile surfaces. The printer manufacturer is currently developing a permanent ink for nonporous surfaces, but a sample was not available for the tests described in this report. If a permanent water-based black ink can be developed, then the ink-jet printing system that was tested can be adapted for use in the FARV.

## APPENDIX A
## INK-JET PRINTER SPECIFICATIONS

A cabinet 19-in. high × 18-in. wide × 22.75-in. deep weighing 95 lb encloses the ink-jet system and solid state electronics. A flexible 12-ft-long protective umbilical connects the printer cabinet and remote self-cleaning print head. Printer head dimensions are 10-in. high × 2.27-in. wide × 5.25-in. deep. The combined weight of the printer head and umbilical is 10.5 lb. The printer head has a 120- by 120-dpi resolution in normal mode for both text and graphic images. Improved 240- by 120-dpi resolution is optional. The maximum dimensions of a single image are 1.067-in. high by 18-in. long, with printing speeds up to 950 ft/min. Power requirements are 120 Vac, 4 A, at 50/60 Hz. The standard communication interface is an industrial standard RS-232C serial port. A parallel Centronics interface is optional. The system uses proprietary water-based inks and can operate at temperatures from 50 to 104°F from 20 to 90% RH, noncondensing.

# APPENDIX B
# LABEL PRINTER/APPLICATOR SYSTEM SPECIFICATIONS

**Printing**

Type: Thermal transfer and direct thermal
Print speed: 2.0 to 6.0 in./s
Minimum dot size: 0.005 in.
Print area: 4.1-in. wide by 24-in. long

**Media**

Width: 0.75 to 4.65 in.
Length: 0.05 to 24.0 in.
Thickness: 0.0023 to 0.010 in.
Type: Roll-fed, die-cut, external wrap
Supply roll capacity: 12-in. maximum OD on 3-in. core
Label material: Thermal transfer plain coated papers, vinyl, mylar, metalized paper
Ribbon: Black or colored inks

**Communications Interfacing**

IEEE RS-232C and RS-422 at 300 to 19,200 baud
Character set: ANSI ASCII
Word length: Selectable 7 data bits, 2 stop bits, no parity or 8 data bits, 1 stop bit, no parity
Handshaking: XON/XOFF (on receive mode only) and CTS/DTR
Input buffer: Approximately 7000 B

**Electrical**

Input voltage: 115 Vac ±10%, single-phase 50/60 Hz
230 Vac ±10%, single-phase 50/60 Hz

**Mechanical**

Size: 18.75-in. high × 13.375-in. wide × 31.5-in. long
Weight: 72 lb

## *INTERNAL DISTRIBUTION*

1. S. M. Babcock
2. E. C. Bradley
3. B. L. Burks
4. W. A. Camp
5. J. B. Chesser
6. J. H. Clift
7. D. C. Cunningham
8. R. M. Davis
9. M. H. Ehinger
10. C. M. Gallaher
11. V. B. Graves
12. D. C. Haley
13. W. R. Hamel
14. J. H. Hannah

15-17. J. N. Herndon

18. C. T. Kring

19-20. L. M. Kyker

21. J. C. Lewis
22. E. D. Miller
23. M. W. Noakes
24. C. E. Oliver
25. K. E. Plummer
26. A. H. Primm
27. T. L. Ray
28. S. L. Schrock
29. B. H. Singletary
30. D. M. Speaks
31. K. U. Vandergriff

32-41. B. S. Weil

42. H. R. Yook

43-44. Laboratory Records

45. Laboratory Records (ORNL-RC)
46. RPSD Publications Office
47. ORNL Patent Section
48. Central Research Library
49. Document Reference Section

## *EXTERNAL DISTRIBUTION*

50. P. Bonnett, U.S. Army, SIMCAR-FSS-DF, Attention: Pete Bonnett, Building 3159, Picatinny Arsenal, New Jersey 07806-5000.

51. W. Denery, Attention: SFAE-ASM-FR, Picatinny Arsenal, New Jersey 07806-5000.

52. M. Dolecki, Commander, USA TACOM, Attention: AMSTA-ZED (Mr. Matt Dolecki), Warren, Michigan 48397-5000.

53. Col. B. Ellis, Office of the Project Manager-Crusader, Attention: SFAE-FAS-CR-M (LTC Bernie Ellis), Picatinny Arsenal, New Jersey 07806-5000.

54. K. Fahey, Attention: SFAE-ASM-FR, Picatinny Arsenal, New Jersey 07806-5000.

55. J. Fedewitz, PM-AMMOLOG, HQ ARDEC, AMCPM-AL Picatinny Arsenal, New Jersey 07801-5001.

56. T. Fitzgerald, Project Manager, FARV, Attention: SFAE-ASM-FR, Picatinny Arsenal, New Jersey 07806-5000.

57. Dr. G. Goble, FARV, Attention: SFAE-ASM-FR, Picatinny Arsenal, New Jersey 07806-5000.

58. N. F. Gravenstede, PM-AMMOLOG, HQ ARDEC, AMCPM-AL Picatinny Arsenal, New Jersey 07801-5001.

59. G. L. Kent, PM-AMMOLOG, HQ ARDEC AMCPM-AL Picatinny Arsenal, New Jersey 07801-5001.

60. Col. W. Sheaves, Office of the Project Manager-Crusader, Attention: SFAE-FAS-CR (COL William Sheaves), Picatinny Arsenal, New Jersey 07806-5000.

61. A. Simon, U.S. Army, SIMCAR-FSS-DF, Attention: Alex Simon, Building 3159, Picatinny Arsenal, New Jersey 07806-5000.

62. Office of Assistant Manager for Energy Research and Development, Oak Ridge Operations Office, Department of Energy, P.O. Box 2008, Oak Ridge, Tennessee 37831-6269.

63. Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, Tennessee 37831.