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Technical Report ARFSD-TR-91009

PURSUIT DETERRENT MUNITION RESERVE-CELL AMMONIA BATTERY REDESIGN ANALYSIS

John Printz

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& CHEMICAL COMMAND
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The M86 pursuit deterrent munition (PDM) went into full-scale production in early 1989. At this time a serious design flaw was discovered in the electronics system of the mine. The reserve ammonia battery in the system had a serious performance problem at cold temperatures. This performance problem had not been apparent on the M692/M731 area denial artillery munition (ADAM), a ballistically-launched antipersonnel land mine that was later adapted for hand-emplacement (and subsequently evolved into PDM). A thorough engineering analysis, involving a Taguchi design of experiments, was necessary to determine how the battery could be improved to solve the performance problems encountered. This report discusses this engineering analysis, in detail, from the development of the PDM until the incorporation of the corrective fix for the system.

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BACKGROUND

PDM System Overview

The M86 PDM (fig. 1) is a hand-emplaced antipersonnel land mine to be used by Special Operations Forces (SOF) beyond the forward line of troops. The mine is an adaptation of the artillery-delivered M692/M731 area denial artillery munition (ADAM, Fig. 2).

PDM retains ADAM's basic operating and functioning sequences. The mine has seven tripline sensors that detect personnel movement. The mine also has an antidisturbance (AD) switch that detects any tampering of the mine. The mine will self-destruct (SD) due to an electronics malfunction, a low battery voltage (by means of a low voltage detection or LVD circuit), or at a predesignated SD time.

Two PDM's are packaged inside of a cloth bandoleer (fig. 3). Six bandoleers are packed inside a PA19 shipping container (fig. 4) for transport. Each soldier is issued one bandoleer for use in the field.

PDM Development

The M86 PDM was developed to be used by SOF as a hand-emplaced antipersonnel mine for use beyond the forward line of operation. The letter of requirement (LR) for the PDM was approved on 11 January 1983. The full-scale development contract (DAAA10-84-C-0239) was awarded to Honeywell, Incorporated in September 1984 (ref 1).

Honeywell's design scheme was to take the existing M731 ADAM (an artillery-delivered antipersonnel mine) (fig. 2) and modify its configuration for hand emplacement (ref 1). The primary functioning modes of the M731 ADAM would be retained in PDM. These modes are the seven tripline sensors, the AD switch, and the same SD time. Therefore, PDM retained the same sensors, timing integrated circuit (IC) and system battery as ADAM. Also, the PDM retained the same basic physical configuration as ADAM (fig. 2).

However, several changes to ADAM had to be made for the PDM configuration. The first change was that the safe and arming (S&A) mechanism had to be redesigned to enable hand-emplacement and provide adequate safety. The next change was the incorporation of a transistor clamp circuit (fig. 5). The clamp circuit had to be placed on the firing capacitor to provide a 25-sec safe separation time for the troops; that is, the clamp circuit will deny electrical energy to the firing capacitor for at least 25 sec and therefore will provide system safety in case of a gross IC malfunction. The final change to be made was the installation of an external arming strap assembly (fig. 1) to arm the mine by hand (activate the battery and remove the detonator's shorting bar).

Development Testing

Cold Regions Testing

As part of Development Testing II (DT II), the PDM was tested in Alaska from 22 October 1986 to 18 March 1987. The purpose of the test was to evaluate system safety, system reliability, and human factors in an arctic environment. The testing was performed by the Test and Evaluation Command (TECOM) and was evaluated by the Army Material Systems Analysis Activity (AMSAA). The testing was TECOM Project Number 8-MU-010-086-004.

During the functional portion of the testing, several performance problems associated with the PDM electronic system were uncovered. Specifically, there were early detonations during SD testing and hazardous duds (mines that detonate after the maximum SD time, critical defects) during SD testing. These failures were traced back to the system battery (the 4-volt reserve ammonia battery also used in ADAM) which experienced activation problems at cold temperatures.

When the testing was scored by AMSAA, the hazardous duds were recorded as "no tests" because the temperature was too low during the testing. That is, the temperatures of the test area on those particular days was below the minimum temperature as specified by the LR.

Proposed Battery Problem Solutions

When Honeywell prepared the PDM final report as part of their development effort, the report stated that:

> "When batteries with lower than normal ammonia levels were activated, the battery voltage would rise and then drop off until the ammonial electrolyte became fully saturated. . . Units which exhibited this problem may result in an early function via LVD. . ." (ref 1).

It was also stated that this problem is unique to PDM because the PDM mine does not experience the spinning that the ADAM mine experiences during its ballistic deployment. Honeywell's suggested corrective action to this problem was to control the amount of ammonia in the battery to ensure for proper battery activation at cold temperatures (ref 1).

INITIAL PRODUCTION PROBLEM AREA

First Article Acceptance Testing

For the fiscal year (FY) 1988 production contract, Honeywell was scheduled to perform first article acceptance testing (FAAT) on 15 January 1989. However, the FAAT was delayed until 13 July 1989. During this testing, 32 mines were tested for electronic performance as outlined below:

Cold testing	Hot testing	Ambient testing
3 breakwire	3 breakwire	4 breakwire
3 antidisturbance	3 antidisturbance	4 antidisturbance
4 self-destruct	4 self-destruct	4 self-destruct

The units to be tested at hot and cold were conditioned for 4 hours in an environmental chamber and then tested at ambient in the Honeywell factory.

Battery Capacity Problems at Hot

During the testing, three of the four SD units at hot (condition hot, test at ambient) detonated before the minimum SD time. The engineering analysis that followed suggested that the battery did not have an adequate capacity to maintain the PDM electronics during the hot-to-ambient temperature transition due to the excessive current drain on the battery. The PDM has a 2000 Ω "killing load" resistor connected in parallel with the electronic system (fig. 6). This resistor is in the circuit to drain the battery of its energy when the mine has timed out to its maximum SD time.

Honeywell's proposed solution to this problem was to increase the resistance of the killing load resistor from 2000 Ω to 3300 Ω. It was the opinion of Honeywell that by simply changing the resistance, without changing the design of the battery, that the problem would be solved. The belief was that the mine would draw less current from the battery, not exhausting the battery and causing the mine to detonate LVD before the minimum SD time, but still draw enough current to exhaust the battery by the maximum SD time.

Resistor Change Verification Tests

To evaluate the proposed solution by Honeywell, ARDEC engineers drafted a test plan to evaluate the PDM's performance with the new resistor across the entire temperature spectrum not just as the condition hot, test ambient condition for FAAT (as discussed above). The test plan (table 1) called for groups of 8 PDM's to be tested for SD functioning at constant hot temperature, constant cold temperature, a cold-to-ambient temperature transition, and a hot-to-ambient temperature transition.

When the tests were performed, the problem during the hot-to-ambient temperature transition was solved; however, a more serious performance problem was uncovered. During the constant cold testing (with 3300 Ω killing load resistors), one mine self-destructed within minutes of arming (early SD functioning) and another mine self-destructed after the maximum SD time. The mine detonating after the maximum SD time (a hazardous dud) is a critical safety defect. The requirement for a hazardous dud is one hazardous dud per every 1000 mines tested. This problem is much more serious than the early detonations.

MAJOR PROBLEM AREA

Hazardous Dud Analysis

Upon encountering the hazardous dud during the 3300 Ω prove-out testing, Honeywell performed several tests to quantify the conditions that caused this problem. The first such test was a temperature test to determine the temperature range in which hazardous duds would likely occur (for mines with 3300 Ω killing load resistors). The results of this test indicated that hazardous duds would occur in temperatures below 0°F, and that early SD detonation (within minutes of arming) would occur in temperatures below +7°F. These results indicated unacceptable performance characteristics within the temperature spectrum. That is, the PDM must be fully functional down to -25°F.

The next to be performed at Honeywell was a battery orientation test. During this test, PDM batteries (the ADAM battery) with 3300 Ω killing load resistors connected across each battery were monitored throughout the SD time of the PDM. The batteries were equally divided with half tested horizontally and half tested vertically (fig. 7). Of the batteries tested in the horizontal position, there were two that would have caused hazardous duds, two that would have caused early SD functioning at -15°F, and three that would have cause early SD functioning at -10°F. There were **no** failures out of all of the batteries tested in the vertical position. These results indicated that the ADAM/PDM battery is a position-sensitive device. These results further indicated that the ADAM/PDM battery's activation mechanism is the ammonia vapor in the glass ampule and the activation intensity depends upon the vapor pressure of ammonia at the time of activation.

The temperature test was repeated with mines with 2000 Ω killing load resistors. There were three early SD functionings and one hazardous dud out of 30 mines tested at 15°F; however, there were **no** failures out of 10 mines tested at 0°F. This indicated that the cold-temperature performance problems were independent of the value of the killing load resistance.

Several conclusions can be drawn from the results listed above. These conclusions are:

1. No early SD functionings occurred at temperatures above +7°F.

2. No hazardous duds occurred at temperatures above 0°F.

3. Hazardous duds and early SD functionings were encountered with both 2000 Ω and 3300 Ω killing load resistors.

4. The ADAM/PDM battery is activated by ammonia vapor; therefore, the activation intensity depends upon the vapor pressure of ammonia at the particular temperature of the battery.

The conclusions listed above clearly indicate that the batter, **not the killing load resistor**, was the cause of the performance problems at cold.

PDM Red Team

To help determine the causes of the severe performance problems encountered, a red team was formed to perform an independent evaluation of the situation. The red team was comprised of systems, quality, electronics, and failure analysis specialists. The team's charter was to determine the root cause of the failures encountered at Honeywell.

Upon a thorough analysis (including a briefing by personnel at Honeywell), the red team concluded that (ref 2):

"• The hot-to-ambient battery problems were believed to be caused by an increase in the battery's internal impedance at hot temperatures. However, this is only a theory and has yet to be proven.

• Batteries with a high ampule fill (85 to 95 ml) perform better across the entire temperature spectrum than batteries with a standard ampule fill (65 to 95 ml).

• Constant temperature SD testing is more realistic than the extreme-to-ambient testing performed by Honeywell. Furthermore, the test temperatures should be altered: hot testing should be at +120°F rather than +145°F and cold testing should be at -15°F rather than -25°F.

• Changing the killing load resistor from 2000 Ω to 3300 Ω should only be done as a last resort. The primary reason for the performance problems is the battery not the resistor.

• A new battery design, rather than the ADAM battery currently used, is necessary to eliminate both the hot-to-ambient performance problems and the cold performance problems."

The conclusions of the red team, in addition to the findings of the PDM project engineers, indicated that a major redesign of the ADAM was necessary to correct the performance problems of PDM.

PDM Blue Team

In conjunction with the red team, a blue team (or action team) was formed to propose, verify, and implement a solution to the PDM's performance problems. The blue team was composed of systems, quality, and electronics specialists from both ARDEC and Honeywell. The charter of the blue team was to determine:

- Can the ADAM battery be optimized to provide better performance for PDM?

- What changes are the most crucial for enhancing the battery's performance?

- How should the redesigned (or new) battery be qualified for use in PDM?

It was decided by the blue team that the best approach would be to subject the ADAM battery to a Taguchi analysis. This analysis would determine what factors in the battery's design are the most crucial in optimizing its performance.

TAGUCHI BATTERY ANALYSIS

Critical Factors

The initial meeting of the blue team at Honeywell was a brainstorming session to determine what possible factors are crucial in the ADAM battery's performance. The two key areas of concern in the battery design were the internal distribution paths for the ammonia vapor and the electrochemistry of the ammonia battery.

The discussions that followed at Honeywell and ARDEC produced eight design factors that related to the two areas listed above. These design factors are:

- Cell 1 slot width
- Cell 2 slot width
- Cell 1 slot length
- Cell 2 slot length
- Ampule fill
- Bulkhead alignment
- Ampule breakage, external arming forces
- Internal vacuum pull

Inside the ADAM battery (fig. 8), the two cells are separated by a plastic collar. This spacer has slots that port the ammonia to both cells. It was felt by Honeywell and ARDEC that increasing the length of these slots and the width of the slots would allow for an easier porting of the ammonia to both cells of the battery.

The electrolyte for the battery is ammonia, stored in its liquid state in a glass ampule located inside of the battery (fig. 8). The electrolyte fill for the ampule is specified at 65 to 95 ml. During full-scale engineering development (FSED) of PDM, it was decided by Honeywell to screen the production ADAM batteries for those with ampules filled at 85 to 95 ml. However, the Honeywell production team did not screen for batteries with high ampule fills. Regular ADAM batteries with the 30 ml ampule fill tolerance were used. The blue team decided to verify, by means of the Taguchi analysis, that the higher ampule fill (i.e., a tighter ampule fill tolerance) was crucial to improving the battery's performance.

The two cells of the battery are separated by a thin metal bulkhead. This bulkhead has indentations that roughly correspond to the position of the slots in the plastic separator between the two cells. During assembly of the ADAM battery, this bulkhead is simply placed inside of the battery regardless of the position of the bulkhead's indentations relative to the position of the separator's slots. One of the tests proposed by the blue team was to determine whether aligning the indentations of the bulkhead with the slots of the separator would improve the performance of the battery.

When the PDM is armed, an external arming strap is pulled upward and outward (fig. 9). This cam action creates a force on the battery ball, pushing it inward toward the mine, crushing the glass ampule, and activating the battery. This force is a constant force unlike the sharp impulse that the battery ball receives upon ejection from the ADAM projectile. One test of the Taguchi analysis was to determine whether more of an impulse was needed to properly activate the battery statistically for PDM.

The metal can of the ADAM battery has small grooves cut in its inside. These grooves are allow a vacuum to be pulled on the battery to remove all of the air in the battery allowing a thorough dispersion of the ammonia. The vacuum that is pulled on the ADAM battery lasts for 2 seconds. The final test of the Taguchi analysis was to determine whether increasing the width and depth of the grooves and whether increasing the vacuum pull time from 2 to 30 seconds (while keeping the vacuum pressure constant) would enhance the battery's performance.

Taguchi Test Plan

The Taguchi testing was carried out in two phases. The first phase consisted of an L8 test matrix of the eight critical factors listed above (table 2, fig. 10). This portion of the testing was to determine the relative importance of the eight factors in enhancing the battery's performance. The second phase consisted of a prove-out test (table 3). Two groups of batteries were to be constructed: one group with all of the enhancement changes made (a good group) and one group without any of the enhancement changes made (a bad group). These groups were then tested to verify that batteries with the necessary changes worked and that batteries without the necessary changes do not work. The verification testing is performed in this manner so that the reliability of the battery can be evaluated with a reduced sample size.

The test method of the batteries was changed for the Taguchi analysis. Previously, ADAM batteries were tested in a test fixture that induced a high rate of spin prior to activating the battery. This was to simulate the ballistic environment that the batteries would encounter inside of the ADAM projectile. For the Taguchi analysis (and for all subsequent battery testing), batteries were to be molded in a plastic "brick" and activated by means of an arming cam to simulate the cam action that is used in PDM.

When the batteries were tested, they were connected across a 3300-Ω resistor rather than a 2000-Ω resistor. It was decided by the blue team that the performance of the battery at cold temperature could not be improved by using a 2000 Ω killing load resistor. It was decided to go forward with the change to the 3300-Ω resistor which was used throughout the test. The 3300-Ω resistor would properly simulate the power demand on the battery because the remainder of the PDM's electronic system has an equivalent resistance of 50,000 Ω, which is in parallel to the 3300 Ω killing load resistor.

Design of Experiments

When the testing of the L8 matrix was performed at Honeywell, it was determined (through a statistical analysis of the data) that the most critical factor in enhancing the batteries performance, **in their order of importance**, are:

1. Cell 1 slot width

2. Ampule fill

3. Bulkhead alignment

4. Vacuum duration (See table 2 for a total listing of the results.)

The other four factors (cell 1 length, cell 2 width and length, and ampule breakup) caused a negligible change in the battery's performance (in fact, making cell 2's slot wider hindered the battery's performance slightly).

Prove Out Testing

One hundred and fifty batteries were constructed in the new or "good" configuration. This configuration was ADAM batteries with the following modifications:

- High ampule fill: 85 to 95 ml

- Aligned bulkhead

- Increased vacuum by means of a modified cell cup and a 30-sec vacuum pull duration

- Modified separator (collar) with all four slots longer and wider

During this testing, two batteries out of the 100 tested at cold temperature (-25°F constant) failed and none of the 50 batteries tested at hot temperature (+125°F constant) failed. This 2% failure rate was predicted during the statistical analysis of the data (table 3).

One hundred batteries were tested in the "bad" condition. These batteries were essentially ADAM batteries with a low ampule fill; that is, none of the changes listed above were incorporated into the battery. There were 31 failures out of the 50 batteries tested at cold (-25°F constant) and 1 failure out of the 50 batteries tested at hot (+125°F). This verified that the bad batteries would not work for PDM (table 3).

The final verification test was to build 48 PDM mines with the new battery. Twenty-four mines were tested at cold and twenty-four mines were tested at hot for SD functioning. There were no failures encountered out of the 48 total mines tested. This, in addition to the two previous verification tests, verified that the new battery design (enhancement) would provide the proper performance for PDM, (table 3).

BATTERY FIRST ARTICLE ACCEPTANCE TESTING

New Procedure

A new procedure was needed to qualify the new battery design for use in PDM. As was stated before, the ADAM battery was tested by using a test fixture that induced a high rate of spin on the battery. Also, the fixture activated the battery with an impulse, rather than a cam action that exists in PDM.

The new procedure was drafted for testing and qualifying the PDM battery (the enhanced ADAM battery). Each battery was placed into a housing and connected across a 3300-Ω resistor. A total of 32 batteries in the housing were molded into a block of PDM molding compound. Electrical leads were connected from an automated data logger to the batteries to record the voltages for a 4-hr duration. The batteries were activated by a cam action across the block, similar to the activation system in PDM.

Another Problem Area

During lot acceptance testing (LAT) of the batteries, approximately 5% from one particular lot failed due to insufficient energy throughout the 4-hr test. It was determined that when the molding compound of the testing block was heat treated, the temperature slightly exceeded +160°F (the maximum cure temperature). This excess temperature caused the pressure of the ammonia in the ampule to rise to the point where the glass cracked causing a slow leak of the ammonia gas and a marginal activation of the battery.

This problem had been experienced on ADAM before, but at a much lower fallout rate. The higher ampule fill of the PDM battery would make it more likely that an increase in ammonia pressure in the ampule would cause the battery to activate. This was another problem area that had to be investigated further.

BATTERY PRE-ACTIVATION TEST PLAN

When this pre-activation of batteries was reported to the engineering community at ARDEC and at TECOM, it was determined that some type of testing was necessary to both quantify the pre-activation of batteries and determine if there is any safety risk associated with the pre-activation of batteries. This theme was also expressed by the Chairman of the New Material Release Board (NMRB) for PDM.

A test plant (app) was drafted to analyze the pre-activation of batteries in detail and incorporates two procedures to analyze the pre-activation of batteries. Procedure A is to have 36 PDM mines thermal cycled at +150°F, +160°F, +170°F, and +180°F for cycles of 24 hours for each temperature. The battery voltage of each mine is to be recorded throughout the entire test. It can be determined when and in which temperature cycle a battery pre-activates and what its voltage profile is throughout the subsequent cycles.

Procedure B is to take 14 mines and slightly depress the battery ball to simulate pre-activation. After this pre-activation, the mines are to be armed at various times after pre-activation occurs to determine the effects that pre-activation has on the system safety performance.

At the time of the writing of this report, the test plan was approved by ARDEC engineering. However, the testing has not occurred as of this time. Testing is anticipated to occur in late 1990 and the results are to be provided to TECOM for its safety assessment report (SAR) and to the chairman of the NMRB for PDM's first unit equipment (FUE). It is believed that battery pre-activation does not hinder system safety; it only causes a decline in system reliability. All of the pre-activated batteries at Honeywell had voltages at low enough level to prevent electronic and pyrotechnic enablement. However, testing is required to verify this over a significant statistical sample of mines (not just batteries).

CONCLUSIONS

It was determined early in pursuit deterrent munition (PDM) production cycle, but rather late in PDM's engineering cycle, that the area denial artillery munition (ADAM) battery was insufficient for use in PDM. The ADAM battery had design characteristics that enhanced its performance in a ballistic environment; however, these same design characteristics hindered its performance in a static environment.

The Taguchi analysis easily evaluated the proposed modifications to the ADAM battery and determined which changes would most enhance the performance of the battery. The analysis performed developed a new, PDM-unique battery that fulfilled the system's performance requirements throughout the entire temperature spectrum.

There exists a performance problem with the new battery that still has to be evaluated. The pre-activation of batteries at hot temperature could potentially be the cause for some concern. However, the approved test plan and subsequent testing could quantify the pre-activation of batteries and provide the means for preventing the pre-activation of batteries (high temperature warnings, visual inspections, etc.).

For any artillery-delivered submunition that is being developed for hand emplacement (static emplacement), a detailed engineering analysis of **all** design factors is necessary before the item is type classified and put into full-scale production. It may well turn out, as was the case with PDM, that the design characteristics that helped the system in the ballistic environment will hurt the system in a static environment.

Table 1. PDM killing load resistor verification test

- 40 PDM's with 2000 ohm killing load resistors:

  8 tested cold (-25°F) to ambient (room temperature)

  8 tested hot (+125°F) to ambient (room temperature)

  8 tested constant hot (+125°F)

  8 tested constant cold (-25°F)

  8 tested hot (+125°F) to cold (-25°F)

- 40 PDM's with 3000 ohm killing load resistors:

  8 tested cold (-25°F) to ambient (room temperature)

  8 tested hot (+125°F) to ambient (room temperature)

  8 tested constant hot (+125°F)

  8 tested constant cold (-25°F)

  8 tested hot (+125°F) to cold (-25°F)

Table 2. Taguchi battery optimization analysis

TAGUCHI ANALYSIS L8 MATRIX

	A	B	C	D	E	F	G	
TEST GROUP	CELL #1 SLOT LENGTH	CELL #1 SLOT WIDTH	CELL #2 SLOT WIDTH	BULK HEAD ALIGNMENT	AMPULE FILL	AMPULE BREAKUP	VACUUM DURATION	TEST RESULTS
1	OLD	OLD	OLD	MISALIGNED	LOW	HAMMER	STANDARD 2.0 SEC	5/10;5 DROPPED BELOW 3.5 VDC @ 2.1%
2	OLD	OLD	OLD	ALIGNED	HIGH	AIR HAMMER	MODIFIED COLLAR 30 SEC	1/10;1 DROPPED BELOW 3.5 VDC(MAX LVD) @2.1%
3	OLD	NEW	NEW	MISALIGNED	LOW	AIR HANNER	MODIFIED COLLAR 30 SEC	1/10;1 DROPPED BELOW 3.5 VDC(MAX LVD) @2.1%
4	OLD	NEW	NEW	ALIGNED	HIGH	HAMMER	STANDARD 2.0 SEC	0/10
5	NEW	OLD	NEW	MISALIGNED	HIGH	HAMMER	MODIFIED COLLAR 30 SEC	2/10;2 DROPPED BELOW 3.5 (MAX LVD) VDC BETWEEN 1% -2.10%
6	NEW	OLD	NEW	ALIGNED	LOW	AIRHAMMER	STANDARD 2.0 SEC	3/10;3 DROPPED BELOW 3.5 (MAX LVD) VDC BETWEEN 2% -7%
7	NEW	NEW	OLD	MISALIGNED	HIGH	AIRHAMMER	STANDARD 2.0 SEC	0/10
8	NEW	NEW	OLD	ALIGNED	LOW	HAMMER	MODIFIED COLLAR 30 SEC	0/10

CONSTANTS: 2.0K LOAD RESISTOR USED THROUGHOUT
TEMPERATURE: -20F-5F
BATTERY BALL HORIZONTAL

Table 3. Prove-out testing

Taguchi verification test phase I (best battery)

Battery configuration:

- High ampule fill: 85-95 mg
- Aligned bulkhead
- Modified collar (molder): 4 larger additional slots
- Modified cell cup
- 30 second vacuum duration

Constants:

- 3.3 K ohm resistor
- Battery ball horizontal

Temperature:	Results:	
at -25°F	_2/100	Two batteries dropped below LVD at 2.1% of SD
at +125°F	_0/50	

Taguchi verification test phase II (worst battery)

Battery configuration:

- Low ampule fill
- Misaligned bulkhead
- Standard ADAM battery parts
- Standard ADAM production process

Temperature:	Results:	
at -25°F	_31.50	• 13 batteries dropped below LVD at 2% and 5.5% • 2 batteries would have been hazardous duds
at +125°F	_1/50	One battery came up late and voltage was below 2.9 V

Taguchi verification test phase III (molded assembly)

Battery configuration same as "best battery"

Temperature:	Results:
at -25°F	_0.24
at +125°F	_0/24

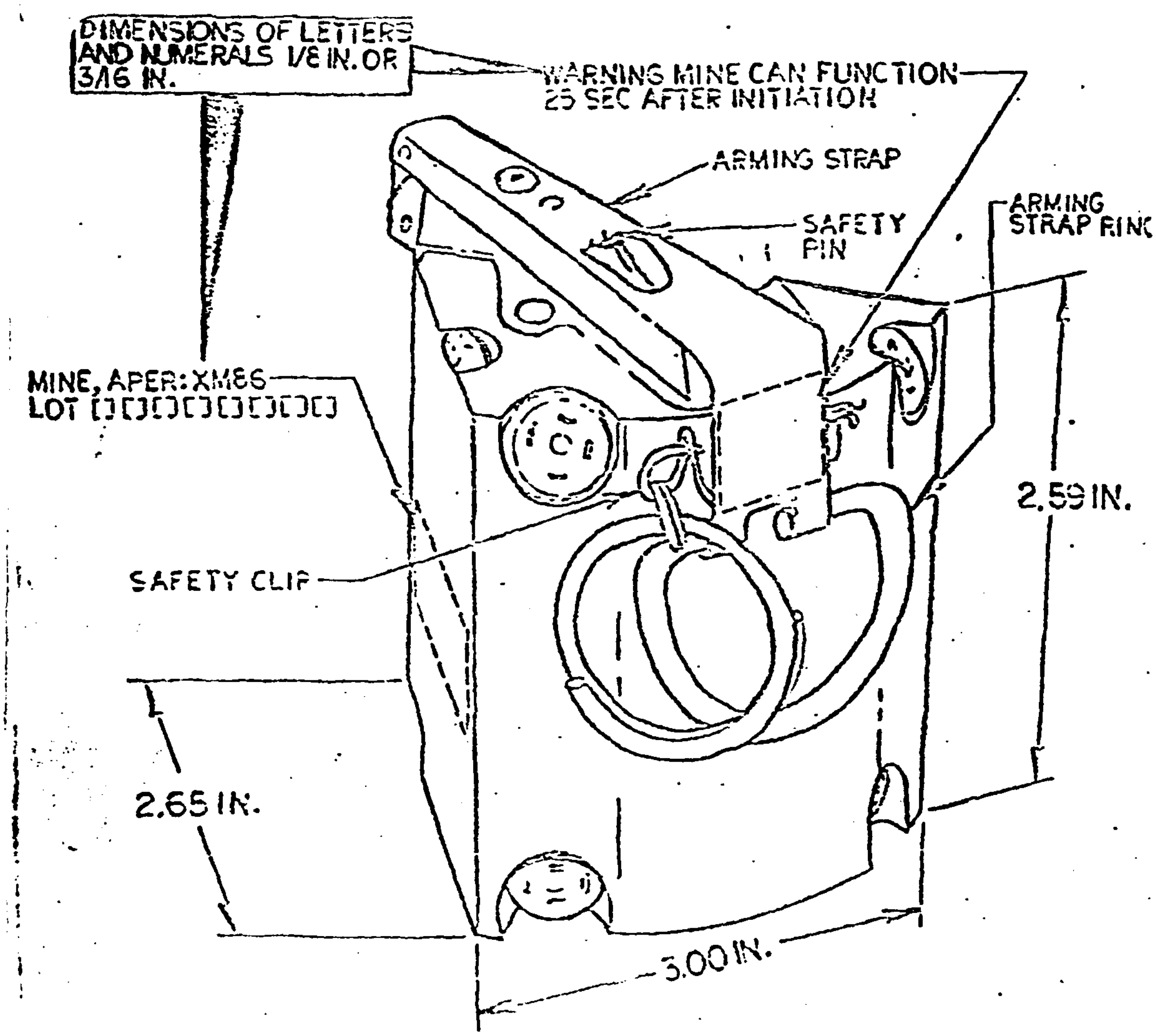


Figure 1. PDM mine configuration

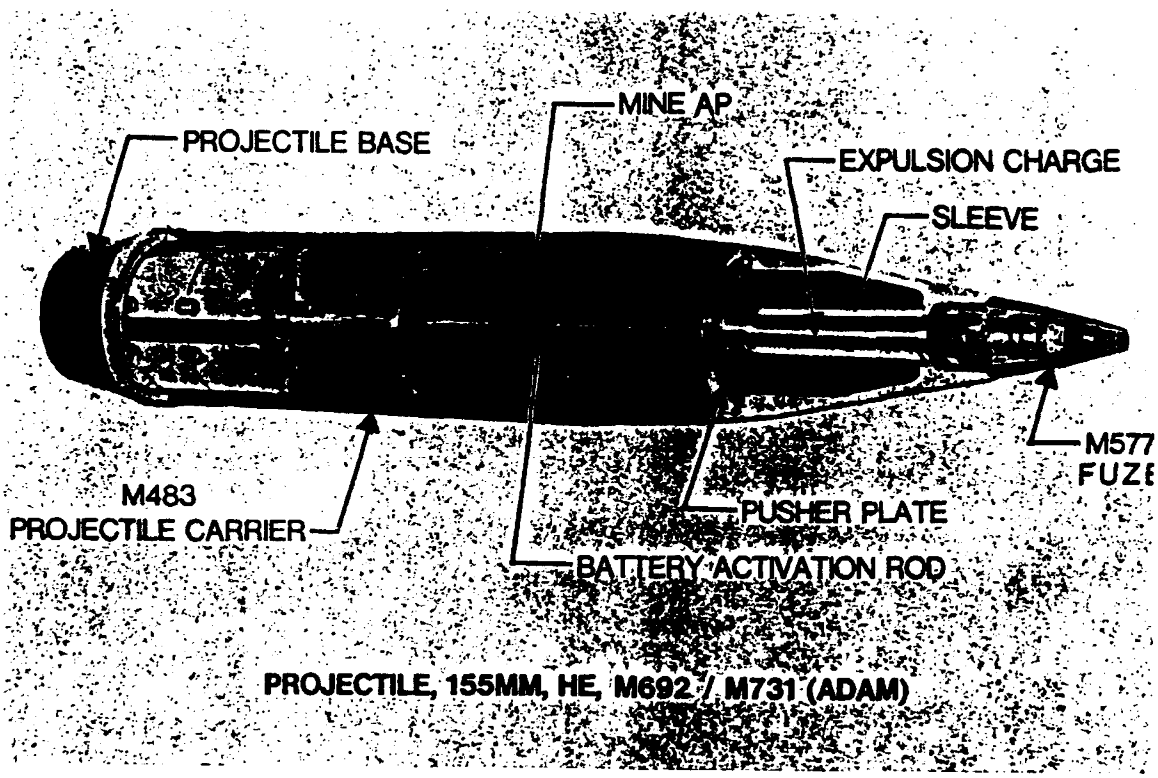


Figure 2. ADAM mine projectile

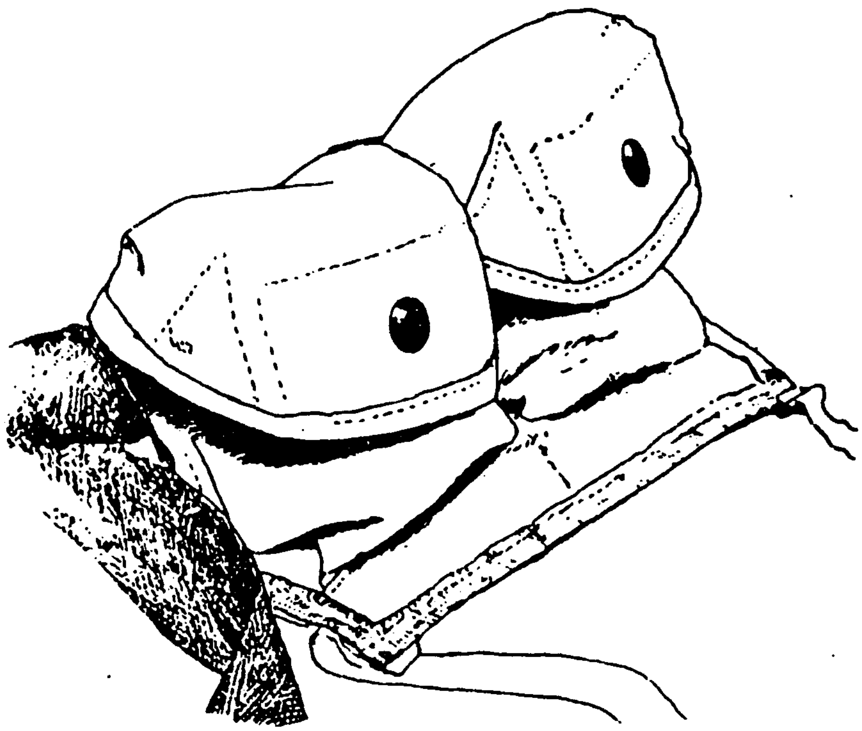


Figure 3. PDM mines in a bandoleer

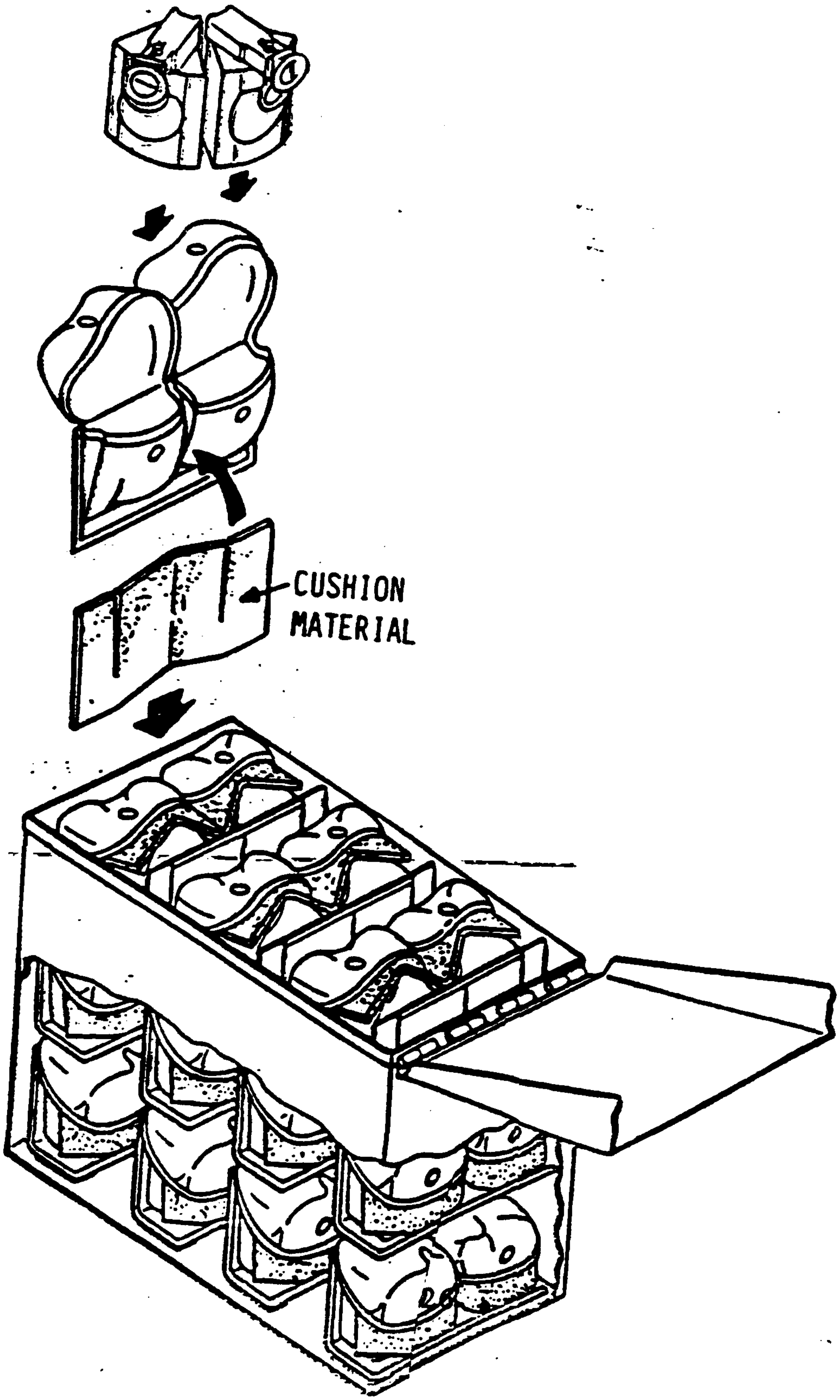


Figure 4. PDM bandoleers in a PA19 container

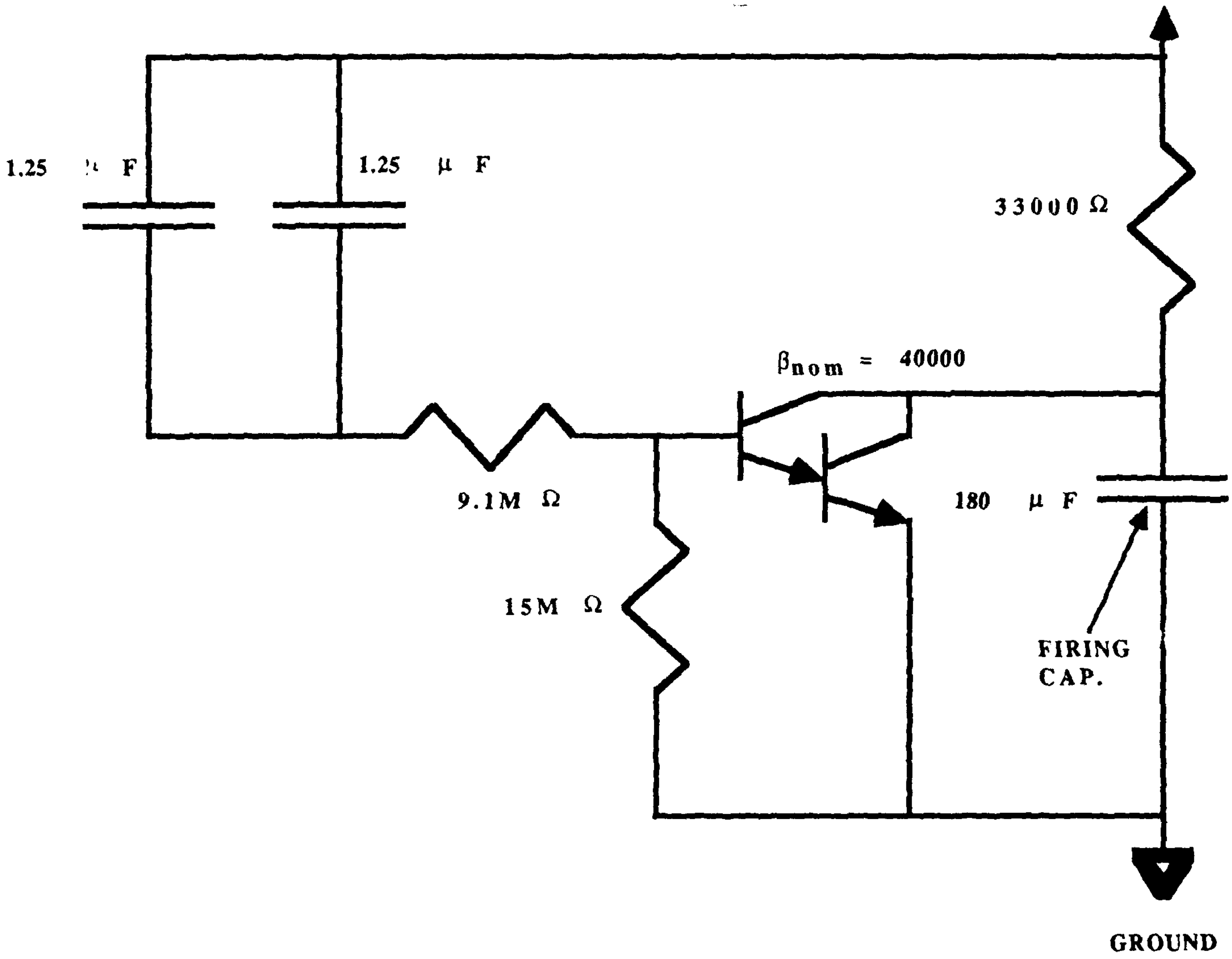


Figure 5. PDM firing capacitor clamp circuit

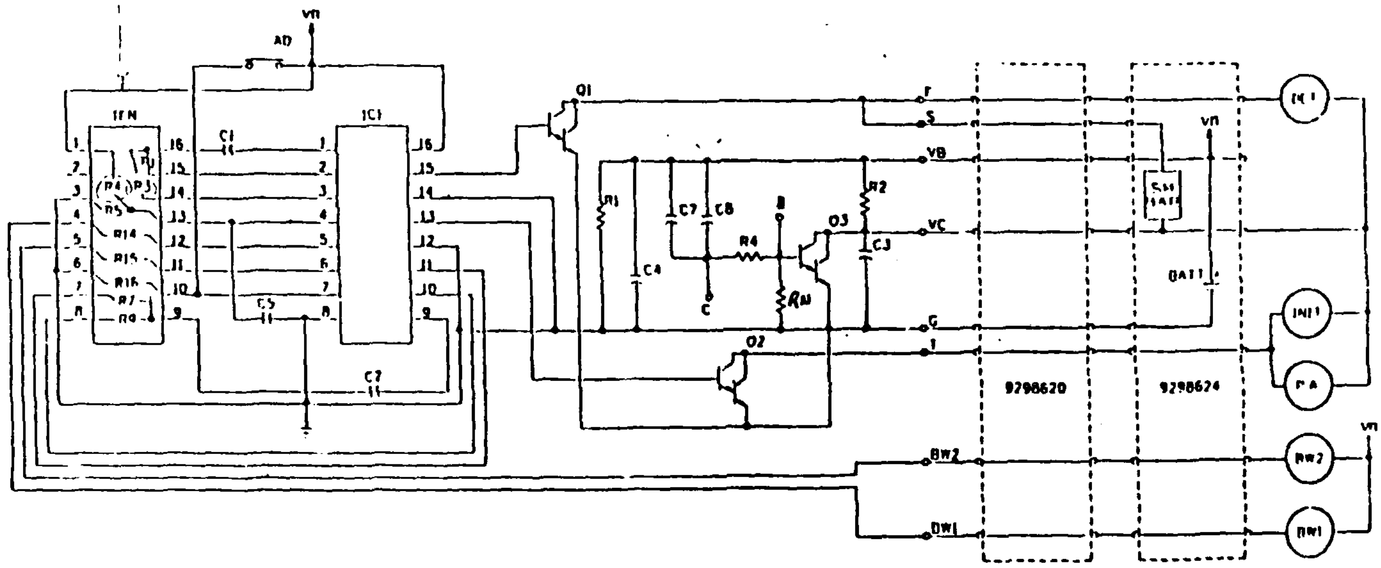


Figure 6. PDM schematic

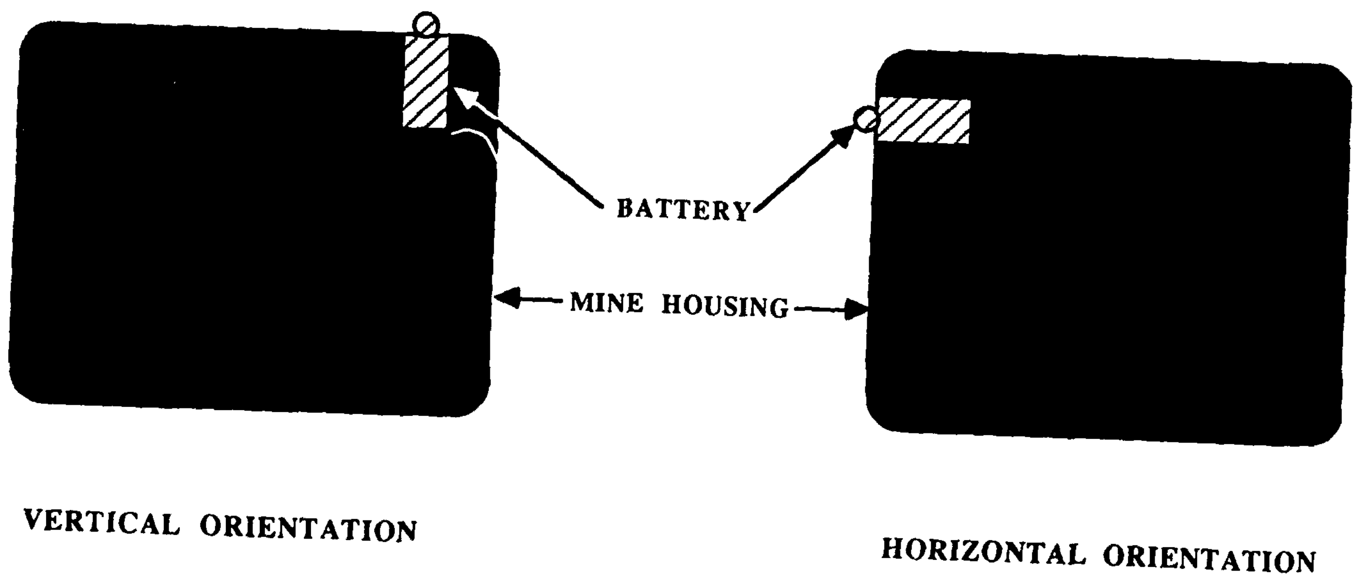
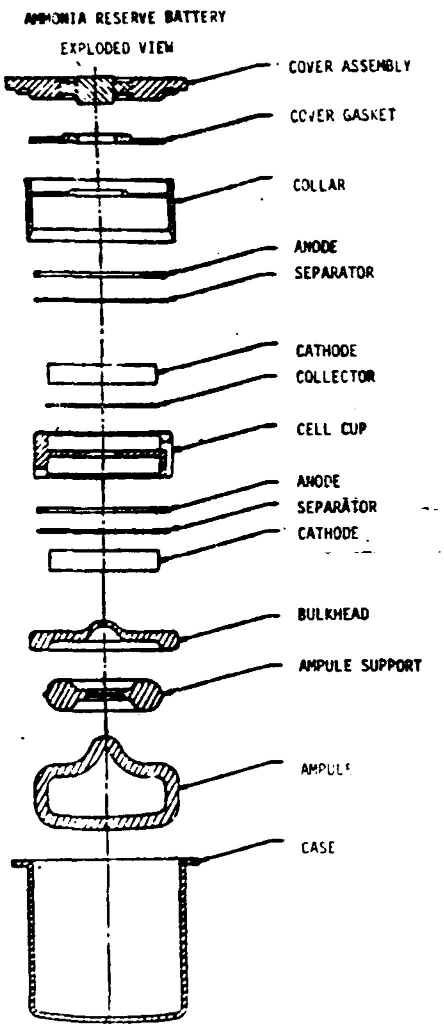
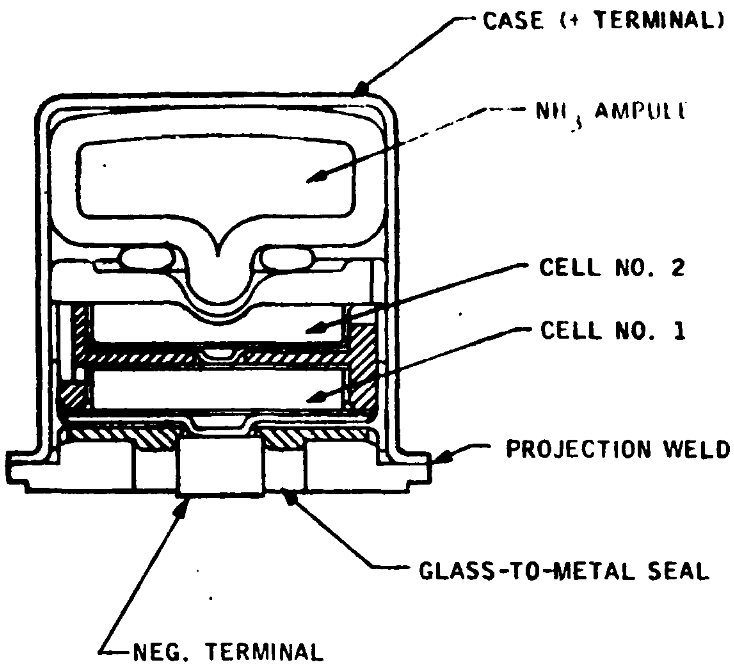


Figure 7. Vertical orientation versus horizontal orientation





G2514 internal construction showing hermetically sealed case, series-connected cells, and glass ampule solvent reservoir.

Figure 8. Ammonia reserve battery

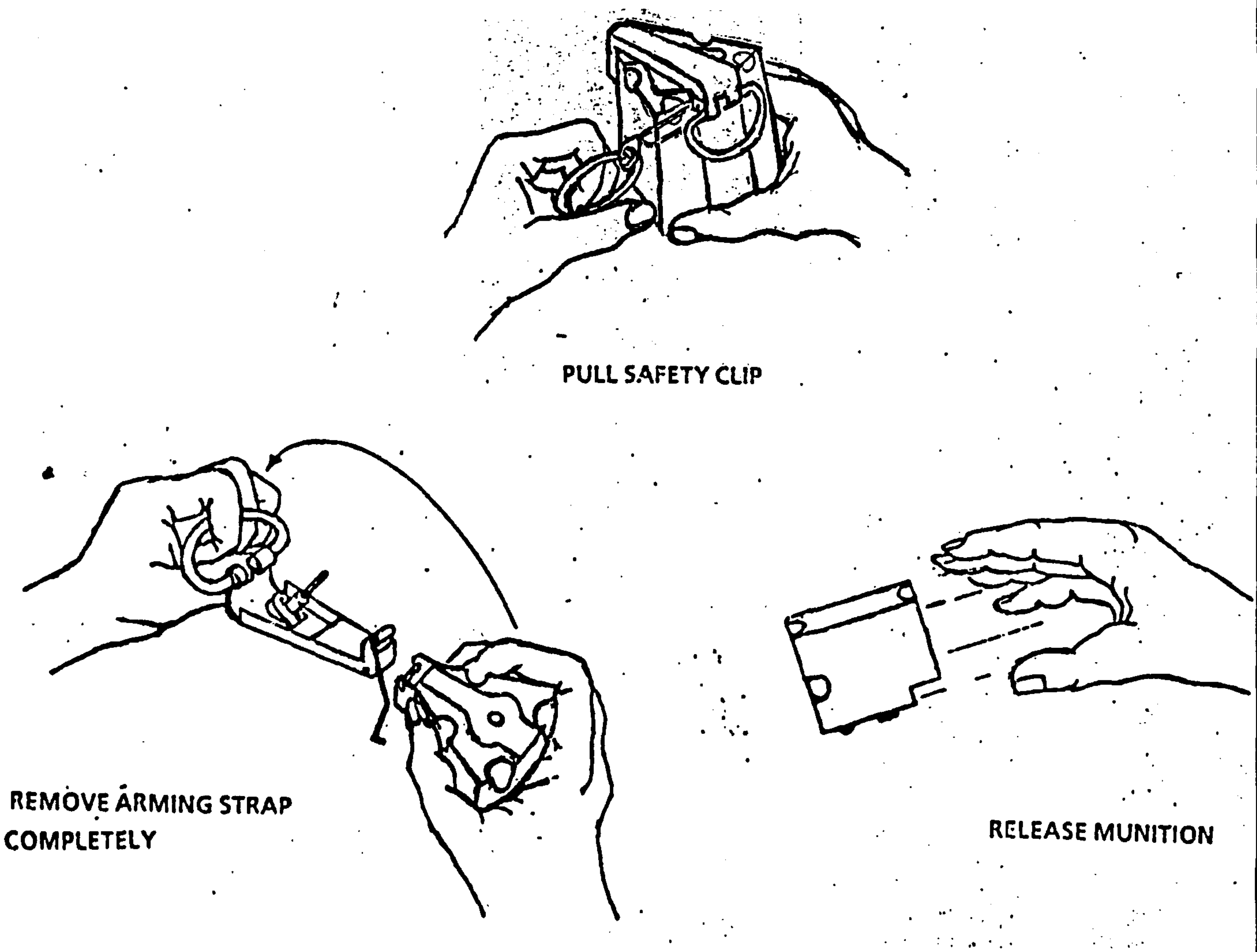


Figure 9. PDM arming sequence

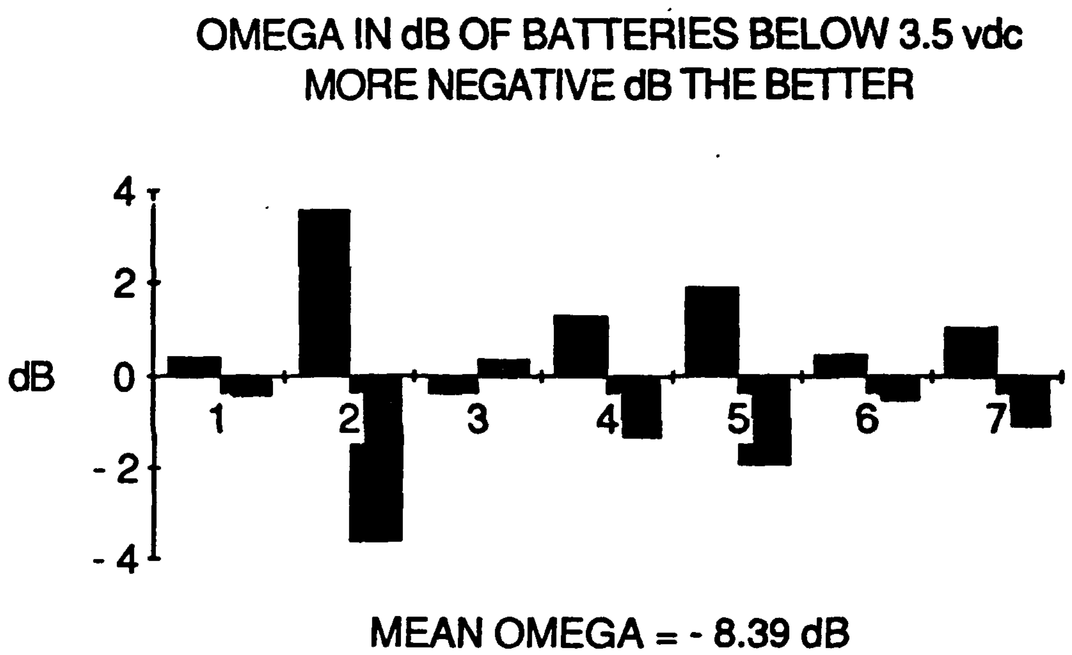


Figure 10. Taguchi battery optimization analysis

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2. Pellen, Robert; Basu, Mihir; Katz, David; and Lau, Steven, "Improper Time of Functioning of Pursuit Deterrent Munition," Technical Report ARFSD-TR-89022, ARDEC, Picatinny Arsenal, NJ, May 1990.

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2. Lange, Norbert Adolph; Forker, Gordon M.; and Burington, Richard Stevens, Handbook of Chemistry, Handbook Publishers, Inc., Sandusky, OH, 1946.

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GLOSSARY

AD	Antidisturbance
ADAM	Area denial artillery munition
AMSAA	Army Material Systems Analysis Activity
ARDEC	Armament Research, Development and Engineering Center
DT II	Development Testing II
FAAT	First article acceptance testing
FSED	Full scale engineering development
FUE	First unit equipment
FY	Fiscal year
IC	Integrated circuit
LAT	Lot acceptance testing
LR	Letter of Requirement
LVD	Low voltage detection
NMRB	New Material Release Board
PDM	Pursuit deterrent munition
S&A	Safe and arming
SAR	Safety assessment report
SD	Self-destruct
SOF	Special Operations Forces
TECOM	Test and Evaluation Command

APPENDIX

TEST PLAN TO DETERMINE THE EFFECTS OF BATTERY PRE-ACTIVATION ON SYSTEM SAFETY AND RELIABILITY OF THE M86 PURSUIT DETERRENT MUNITION (PDM)

1.0: OBJECTIVES. This test will A) Subject the PDM Demonstration Mines to repeated cycles of thermal conditioning to determine the extent of battery pre-activation at varried temperatures, and B) To observe the effects of Battery pre-activation upon the system safety of the PDM.

2.0: BACKGROUND. Based upon Battery pre-activation problems encountered at Honeywell during Battery First Article Acceptance Testing (FAAT), both the extent of Battery pre-activation during thermal cycling, and the effects of Battery pre-activation upon system safety must be quantified.

3.0: TEST PREPARATION.

3.1. Equipment Needed: See Equipment Table.
3.2. Test Location: ARDEC, Bldgs. 1501 and 1530.
3.3. Test Data: The data collected from the testing oulined below will be acquired, tabulated and summarized in a test report.
3.4. Test Criteria:
  3.4.1. The testing outlined below in 4.0. will determine the effects of high-temperature storage upon Battery pre-activation. This testing will be in accordance with MIL-STD-810E, Method 501.3.
  3.4.2. The testing outlined below in 5.0. will demonstrate the effects that Battery pre-activation has upon the system safety of the PDM.
3.5. POC's for this action are David Lavery, X2968 and John Printz, X2669.

4.0: PROCEDURE A.

4.1. 36 Demonstration Mines will be prepared for testing as follows:
  4.1.1. The 36 mines will be marked for identification.
  4.1.2. Each mine will be connected to a compact computer. This device will be operating during the entire duration of the thermal cycling, and record the time that Battery activation occurs, and the Battery's voltage output for the duration of the testing.

4.2. The 36 Demonstration Mines will be thermal conditioned at 150° F for 24 hours. After conditioning, the mines will be cooled to ambient temperature.

4.3. The mines will be thermal conditioned at 160° F for 24 hours. After conditioning, the mines will be cooled to ambient temperature.

4.4. The mines will be thermal conditioned at 170° F for 24 hours. After conditioning, the mines will be cooled to ambient temperature.

4.5. The mines will be thermal conditioned at 180° F for 24 hours. After conditioning, the mines will be cooled to ambient temperature.

4.6. Mines that did not activate will be added to the lot of mines that will undergo the testing outlined in Procedure B.

5.0: PRODEDURE B.

5.1. 14 Demonstration Mines, in addition to those that did not activate during the thermal conditioning test, will be prepared for testing as follows:

5.1.1. The mines will be marked for identification.

5.1.2. Each mine will have the two rivits on the apex of the Arming Strap drilled out and the apex of the Arming Strap removed.

5.1.3. Each mine will have the Shorting Bar removed manually.

5.1.4. Each mine will be connected to a portable digital voltmeter.

5.1.5. The mines will be divided into three lots; Lot A, Lot B and Lot C.

5.2. Strike the Battery balls on the mines in Lot A at the specified force.

5.2.1. Pull arming strap within first 25 seconds of Battery activation.

5.2.2. Record the following data:

5.2.2.1. Whether sensors deploy and the time from Arming Strap removal that sensors deploy.

5.2.2.2. If the mine detonates Anti-Disturbance upon Sensor Enable (78 seconds after Arming Strap removal).

5.2.2.3. If the mine fails to detonate Anti-Disturbance, whether the mine Self Destructs by the maximum Self Destruct time.

5.2.2.4. If the mine fails to Self Destruct, whether the mine detonates following a second Anti-Disturbance attempt immediately following the maximum Self Destruct time.

5.3. Strike the Battery balls on the mines in Lot B at the specified force.

5.3.1. Pull arming strap between 26 and 60 seconds after Battery activation.

5.3.2. Record the results as outlined in Section 5.2.2.

5.4. Strike the Battery balls on the mines in Lot C at the specified force.

5.4.1. Pull arming strap after 61 seconds of Battery activation.

5.4.2. Record the results as outlined in Section 5.2.2.

6.0: REPORTING.

A detailed test report shall be prepared by the POC's for this action.

7.0: EQUIPMENT TABLE.

7.1. 50 Demonstration Mines (M86 PDM's with only the M100 Micro-Detonator in the Explosive Train) with Exposed Leads from V_B and Ground in the Test Pad Area.

7.2. Environmental Chamber(s).

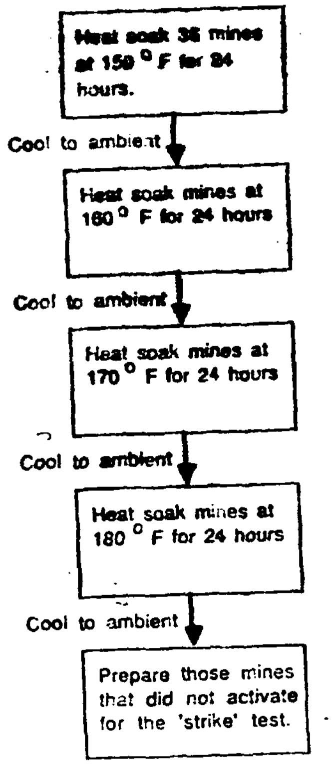
7.3. Digital Thermocouple(s) for the Environmental Chamber(s).

7.4. Portable Digital Voltmeter.

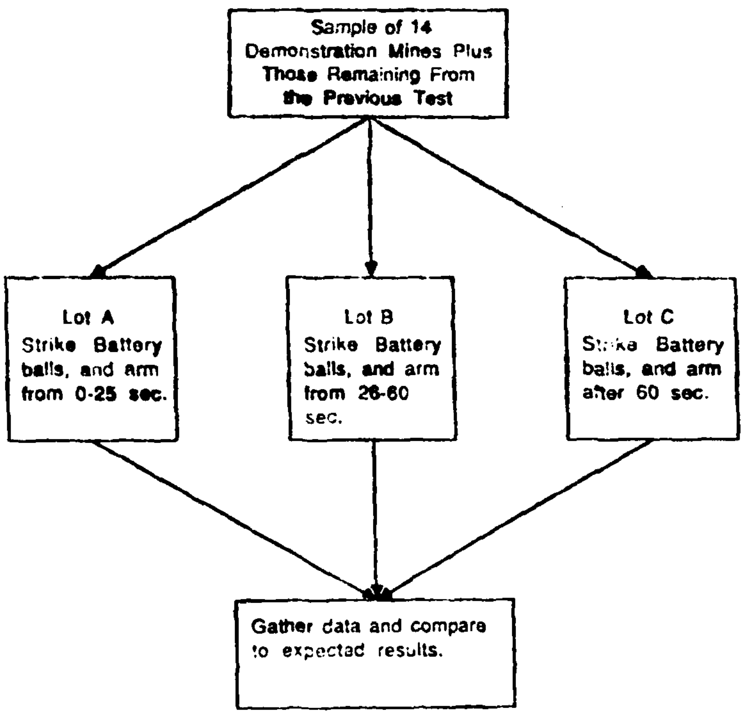
7.5. Adjustable Force Hammer.

7.6. Compact Computer.

8.0: THERMAL CYCLING FLOWCHART



9.0: CONTROLLED BATTERY ACTIVATION FLOWCHART



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