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ELIMINATING PROPELLANT BAG DETERIORATION FOR THE 105-mm M67 PROPELLING CHARGE

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14. ABSTRACT

The rayon propellant bags of the 105-mm M67 propelling charge were observed to deteriorate in short periods of time to the extent that the bags can no longer safely hold the propellant. An engineering study was conducted to resolve this problem by replacing the rayon propellant bags with lightweight acrylic propellant bags.

These acrylic bags have satisfactorily passed material compatibility tests, simulated rough handling and transportation tests as well as ballistic performance evaluations in a 105-mm howitzer at -50°F, 70°F, and +145°F, leaving no residue in the gun tube.

These acrylic bags have also shown remarkable resistance to deterioration (superior to rayon) when in contact with the propellant at elevated temperatures of 149°F, 167°F, 185°F, and 203°F (65°C, 75°C, 85°C, and 95°C) at 75% relative humidity over a 28-week time period. When these high temperature data are extrapolated to ambient service temperature using an empirical (Arrhenius) degradation model, the acrylic bags are expected to exceed the service life requirements of 20 yrs in controlled storage and 2 yrs in uncontrolled storage.

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This acknowledgement does not adequately describe the overall cooperative spirit under which this work and report were done, and for which the author wishes to express her debt and appreciation to all involved.

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ITEM DESCRIPTION

The M67 propelling charge is the primary propelling charge used in a number of semi-fixed cartridges for the standard 105-mm towed howitzers. As shown in figure 1, the M67 propelling charge consists of seven incremental rayon bag charges, which contain varying amounts of M1 propellant. The total propellant weight is approximately 2.83 lbs. Increments 1 and 2 contain single-perforated M1 propellant and increments 3 through 7 contain multi-perforated M1 propellant. The bag charges are numbered from 1 to 7 and are sewn together in numerical order with acrylic thread. The bag charges are stacked around the M28 percussion primer tube in the cartridge case. Increment 1 is placed at the bottom of the cartridge case and increment 7 is placed at the top. Incremental zoning is achieved by removing one or more of the upper zone charges prior to loading the complete round into the gun chamber.

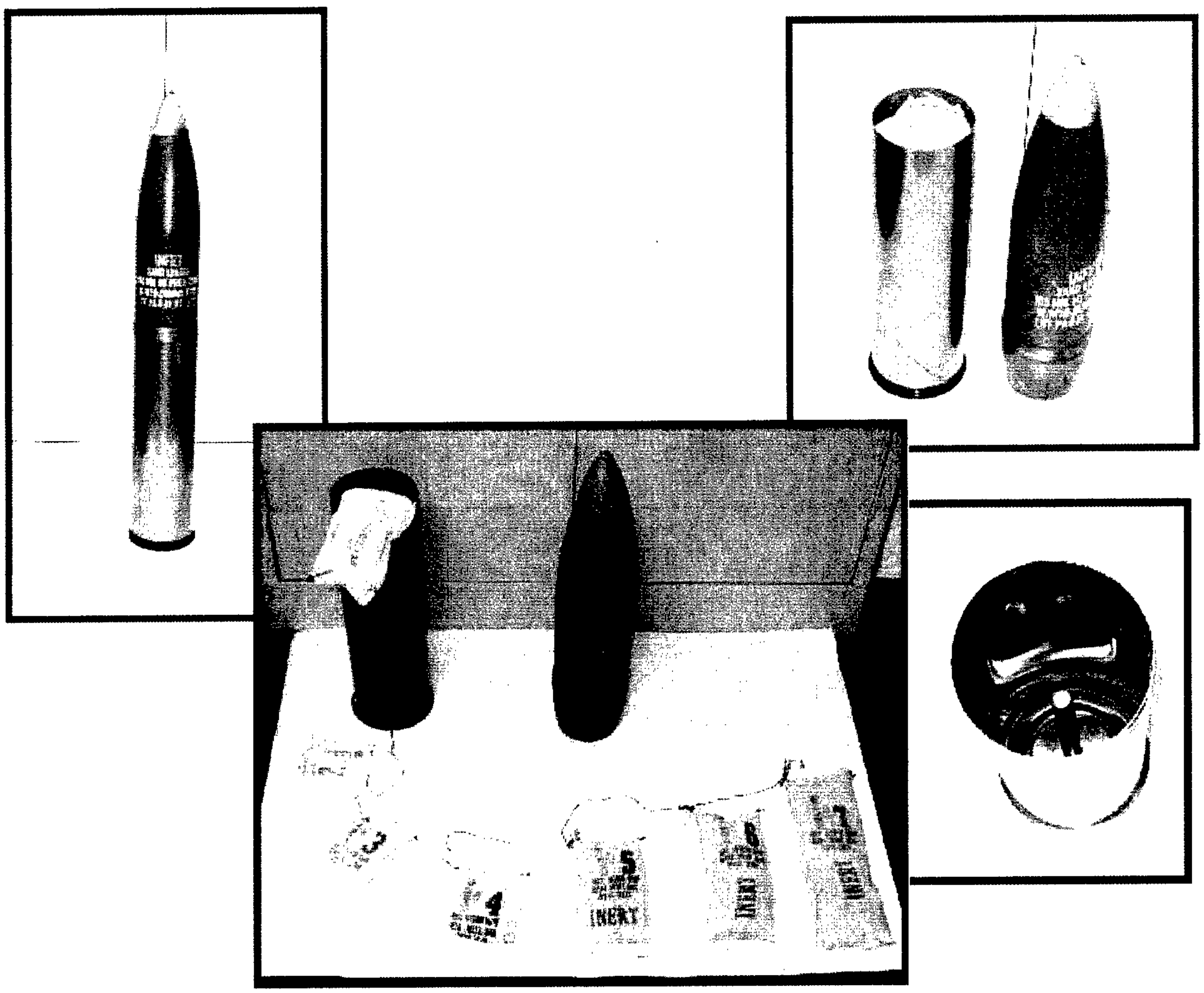

Figure 1
105-mm M67 propelling charge with M1 projectile

BACKGROUND

Currently, millions of stockpiled 105-mm cartridges are in unserviceable condition due to deterioration of rayon propellant bags. Depending on the temperature and humidity of the storage environment, the rayon propellant bags were observed to deteriorate by losing tensile strength within 2 to 15 yrs, to the extent that they can no longer safely hold the propellant (refs. 1 to 3). Also, deterioration was found most pronounced in increment 7 for propelling charges stored inside the cartridge cases as well as propelling charges stored inside the fiber drums.

The consequences of propellant bag deterioration include reduced service life of tactical rounds; expensive maintenance rework that includes cleaning and reloading cartridges with new propelling charges; potential safety and reliability problems if the M67 is no longer zoneable with correct amount of propellant; and impact on war-fighting readiness. Demilitarization of deteriorated lead-containing propelling charges also incurs additional cost and posts environmental and health hazards. For these reasons, the Propulsion Engineering Team at the U.S. Army Armament Research, Development and Engineering Center (ARDEC), Picatinny Arsenal, New Jersey was tasked by DCS Ammo, OSC, and OPM-CAS to initiate an engineering study to resolve this problem immediately.

INTRODUCTION

Gaseous nitrogen oxides given off during propellant deterioration may, in the presence of moisture, form acid that causes the deterioration of the propelling charge cloth. Earlier studies showed that acrylic fabric made of synthetic polymer of acrylonitrile was more acid resistant than rayon fabric made of cotton linters/woodpulp (refs. 4 and 5). Comparison of chemical and physical characteristics between these two types of fabrics indicated that acrylic fabric is equal or better than rayon fabric in terms of acid resistance, tensile strength, and thermal reaction (tables 1 and 2). However, no attempt has been made to predict the long-term performance of propellant bags made of these fabrics.

When selecting fabric for propellant bags, it is required that fabrics used to contain propellant be completely consumed when the gun is fired. If there is any residue, it obviously must not smolder, since smoldering could ignite the propellant charge for the succeeding round before the breech could be closed.

In addition, the Army requires all ammunitions and their components have a minimum service life of at least 20 yrs in controlled storage and 2 yrs in uncontrolled storage. To determine long-term performance (e.g., tensile strength of propellant bag) in a shorter time frame, the concept of an accelerated aging test is used. The objective of accelerated aging is to increase the "stress" on the loaded propellant bag by increasing the influence of one or more environmental factors; e.g., temperature and humidity. In this manner, the propellant bag degrades or reaches its failure point more rapidly than it would under normal conditions. Assuming the mechanism of failure has not changed due to the increased influence of the environmental factor, the results obtained at high temperatures can be extrapolated to ambient service temperatures through the use of a mathematical model to estimate the shelf life of the propellant bag.

Table 1
Properties of rayon and acrylic fabrics[a]

	Rayon properties (high-wet modulus)	Acrylic properties
Resistance to:		
Acids	Poor[b]	Good (weak acids) Fair (strong acids)
Alkalies	Poor[b]	Good (weak alkalies) Poor (strong alkalies)
Sunlight	Good	Excellent
Microorganism	Poor	Excellent
Insects	Poor	Excellent
Thermal reactions:		
To heat	Poor[c]	Good[d]
To flame	Poor and good[e]	Good[f]

[a]From the textbook "Essentials of Textiles;" Fourth edition; Holt, Rinehart, and Winston, Inc.

[b]Generally not good, but under some circumstances it may be acceptable.

[c]Extended exposure to high temperatures will eventually degrade the fiber.

[d]Maintain at temperature below 160°C; do not subject to boiling.

[e]Flame resistant rayon resists burning; other rayons burn.

[f]Burns readily unless specially treated.

Table 2
Weight, breaking strength, and thread count of rayon and acrylic cloths

Cloth type	Weight (oz/yard^2)	Breaking strength (lb/in. minimum)		Thread count	
		Warp	Fill	Warp	Fill
Viscose rayon MIL-C-43157	2.8 - 3.2	35	35	48	48
Acrylic MIL-C-12800	2.3 - 2.7	40	40	58	50

There are two basic approaches for shelf life prediction: accelerated degradation and life tests. A traditional accelerated life test requires testing to continue until the specimens fail. To meet the program's fiscal and schedule constraints, this study employed an accelerated degradation test, since degradation data can be analyzed earlier; i.e., before any specimen fails.

This is done by extrapolating performance degradation to estimate a time when performance reaches a pre-defined failure level. Some of the challenges with the latter approach are that sometimes degradation trend is "reversible" (e.g., units appear to "heal themselves" or get better due to new chemical reaction induced at high temperature) or degradation may vary erratically from unit to unit making it difficult to model.

TECHNICAL APPROACH

Laboratory and ballistic tests were conducted to compare the acrylic propellant bags against the rayon propellant bags (controls) based on the following criteria: (1) chemical compatibility, (2) propellant ballistic performance, (3) cloth residue, (4) safe handling and transportation, and (5) propellant bag shelf life. The overall test plan for this engineering study is summarized in appendix A.

As a safety precaution, acrylic cloth was first tested for its chemical compatibility with its contact material, the M1 propellant. Next, one set of test rounds (acrylic cloth) and one set of control rounds (rayon cloth) were assembled with identical components. These test and control rounds were tested at Yuma Proving Ground (YPG), Yuma, Arizona for charge weight assessment at 70°F; ballistic propellant uniformity at -50°F, +70°F, and +145°F; cloth residue evaluation (including low zone at cold temperature); and simulated rough-handling and transportation at -50°F and +145°F. Accelerated aging tests were conducted at ARDEC to estimate propellant bag shelf life at service temperatures.

EXPERIMENTAL METHODS

Material Compatibility Test

Compatibility of acrylic cloth in contact with M1 propellant was evaluated by subjecting the cloth material to the compatibility test (40 hrs at 100°C for single base propellant) in accordance with the requirements set forth in MIL-STD-286, Method 408.1. This test related the degree of reactivity between propellant and cloth material to the quantity of gas produced under these conditions minus the amount of gas evolved by the propellant and cloth separately. If the difference in gas volume was less than 3 mL, acrylic cloth and propellant are considered compatible.

Loading and Assembly of Test and Control Rounds

One set of test rounds and one set of control rounds were assembled with identical components (e.g., propellant, primer, cartridge case, projectile), with the exception that the test rounds contained M67 propelling charges manufactured with new acrylic propellant bags and the control rounds contained M67 propelling charges manufactured with new rayon propellant bags. The M67 propelling charges were loaded and assembled in accordance with drawing 9205472 and MIL-C-60315 (refs. 6 and 7). The test and control rounds were assembled using M28B2 percussion primers, M14B4 cartridge cases, inert loaded M1 projectiles with inert fuze, and the M67 propelling charges. The total weight of each projectile with inert fuze was 33.00 +/-

0.02 lbs. All test and control rounds were individually packed and sealed in M105A3 fiber containers with the plastic protector tube assembly. Those rounds to be subjected to the sequential environmental tests were further packed in wooden boxes with two fiber containers per wooden box.

Charge Weight Assessment

Ballistic tests were conducted to establish charge weights for both control and test rounds. At the first step, increments 1 and 2, with estimated charge weights, were subjected to ballistic testing. The final charge weights for increments 1 and 2 were calculated from a "velocity versus charge weight curve." At the second step, increments 1 and 2, with final charge weights, and increments 3 to 7, with estimated charge weights, were subjected to ballistic testing. The final charge weights for increments 3 to 7 were calculated from another velocity versus charge weight curve.

When fired from the M101A1 howitzer/M2A2 cannon with at least 75% remaining EFC and with the M1 projectile, the charge weight for each increment was determined to meet the following velocity requirements:

Increment (zone)	Velocity (ft/s)
1	640
2	695
3	765
4	860
5	990
6	1200
7	1525

Propellant Uniformity Tests

Propellant uniformity ballistic tests verified that the M67 propelling charges with the acrylic propellant bags met the following pressure, muzzle velocity, and muzzle velocity variation requirements set forth in MIL-P-60318 and proving ground acceptance test procedure P-105H-2 (refs. 8 and 9). Both test and control rounds were tested along with calibration rounds at -50°F, 70°F, and +145°F, and the following data were recorded: M1 cartridge weight, muzzle velocity, chamber pressure, amount of unburnt cloth residue (if any), and meteorology data. Chamber pressure was recorded by copper crusher pressure gauge, and muzzle velocity was recorded by Terma and Weibel Radar.

Temp (°F)	Sample size	Muzzle velocity (fps)	Velocity std. dev.	Minimum pressure (psi)	Maximum pressure (psi)	PIMP (psi)
-50	7	NA	NA	NA	NA	44,800
+70 (zone 3)	7	765	3.8	9200	10,500	NA
+70 (zone 7)	7	1525	3.4	31,200	39,000	44,800
+145	7	NA	NA	NA	NA	44,800

Sequential Environmental Tests

A series of simulated rough-handling and transportation tests evaluated the effect of the manufacture-to-target environments on both the safety and performance characteristics of the M67 propelling charges assembled with the acrylic propellant bags. For this study, durability of the acrylic propellant bags was compared against durability of the rayon propellant bags based on cloth damage.

Both test and control rounds were subjected to the sequential environmental tests for semi-fixed ammunition in accordance with ITOP 4-2-504 (ref. 10) as shown in figure 2. A visual inspection of the test items was made before and after each sequence of tests and any damage was photographed. A damaged item did not constitute a failure unless there was a safety hazard; e.g., burning and detonation. Only rounds, which were visually judged to be safe for handling and firing, were subjected to ballistic evaluation at -50°F and +145°F.

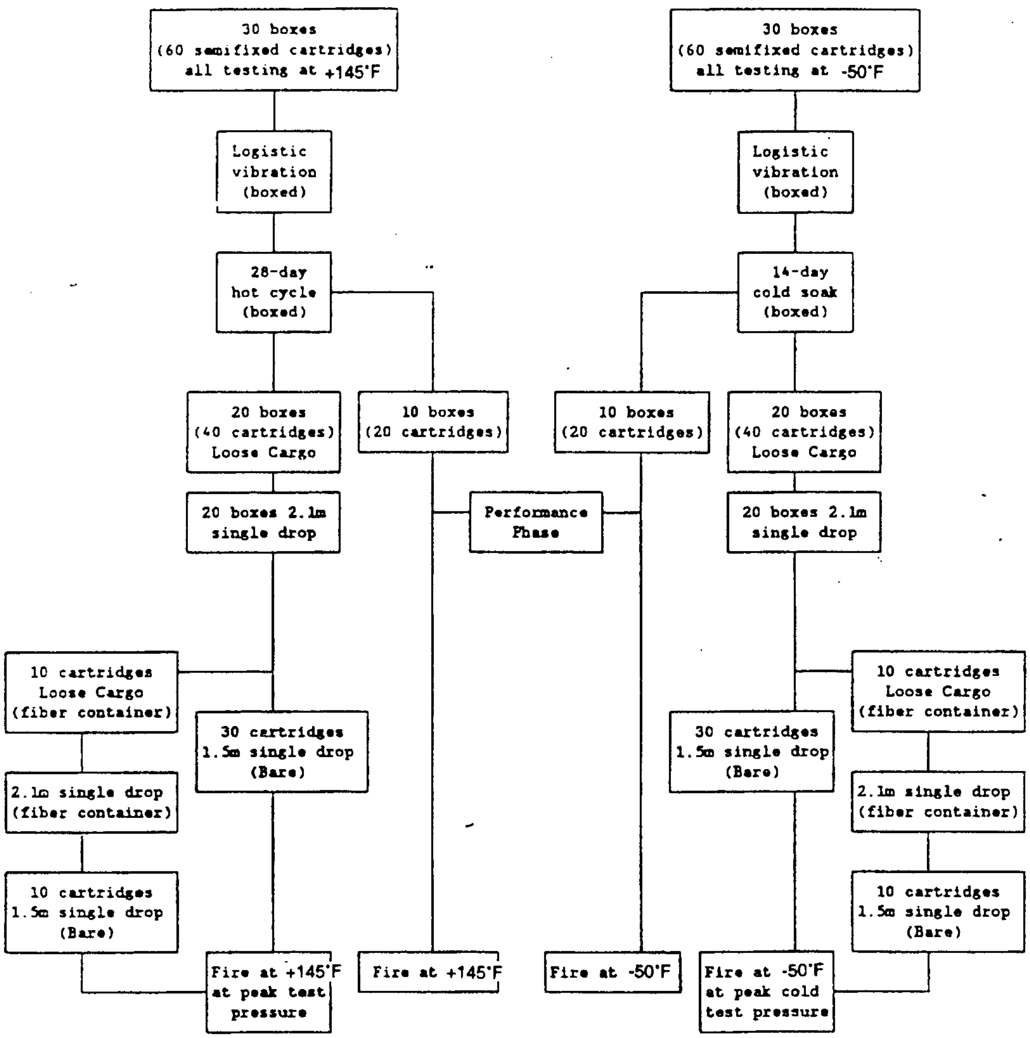

Figure 2
Sequential environmental test for semi-fixed cartridge

Residue Evaluation

A residue evaluation was conducted to verify that the M67 propelling charges leave no unacceptable amount of residue in the gun chamber and cartridge case during any ballistic testing, especially when fired at the lower zones at cold temperature. After each gun firing, the gun chamber and cartridge case were visually inspected for any evidence of unburnt cloth residue. For this study, the amount of acrylic cloth residue is compared against the amount of rayon cloth residue.

Propellant Cloth Shelf Life Study

The long-term compatibility and estimated shelf life for the acrylic propellant bags were evaluated based on accelerated aging testing and mathematical modeling. Both acrylic propellant bags and rayon propellant bags (controls) were tested side by side for comparison. The main experimental design is depicted in figure 3.

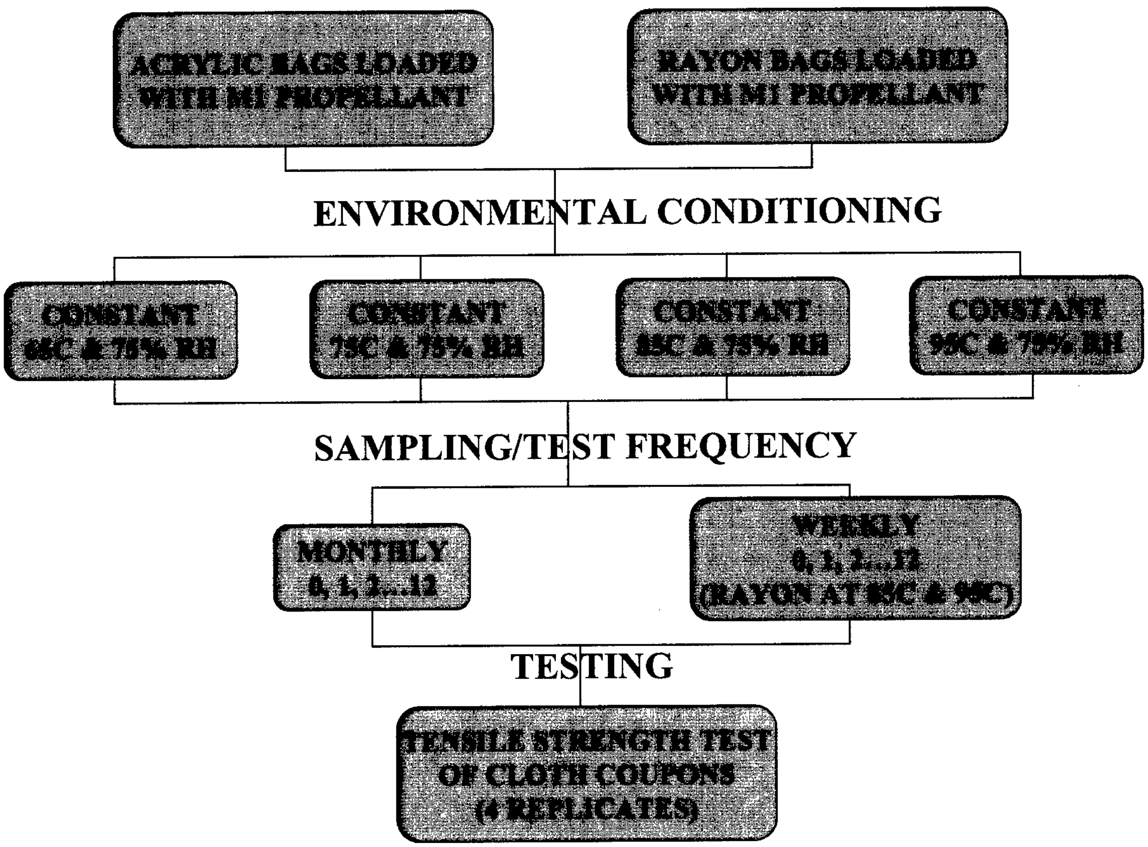

Figure 3
Experimental plan for propellant bag shelf lift study

Four types of propellant bag test samples were prepared as follows: acrylic and rayon fabrics were cut parallel to the fill and warp directions of the cloth, and then were sewn into 4 in. by 10 in. propellant bags. These bags were labeled "acrylic fill," "acrylic warp," "rayon fill," and "rayon warp." Each bag was loaded with M17-perforated propellant. The bag size and ratio of propellant to cloth were designed to simulate increment 7 of the M67 propelling charge. These loaded propellant bags were then placed on stainless steel shelves inside four conditioning chambers with steam injection. These propellant bags were subjected to constant temperature conditioning at 149°F, 176°F, 185°F, and 203°F (65°C, 75°C, 85°C, and 95°C) at 75% relative humidity (RH) for up to 12 months. Periodically, one of each acrylic fill, acrylic warp, rayon fill, and rayon warp propellant bags were withdrawn from each conditioning chamber. All cloth samples were withdrawn on a monthly basis except that the rayon cloth samples conditioned at 185°F and 203°F were withdrawn on a weekly basis. Cloth coupons (3 in. by 5 in.) in replicates of four were prepared from each bag. As shown in figure 4, these cloth coupons were subjected to tensile strength testing in accordance with FED-STD-191, method 5100 (ref. 11).

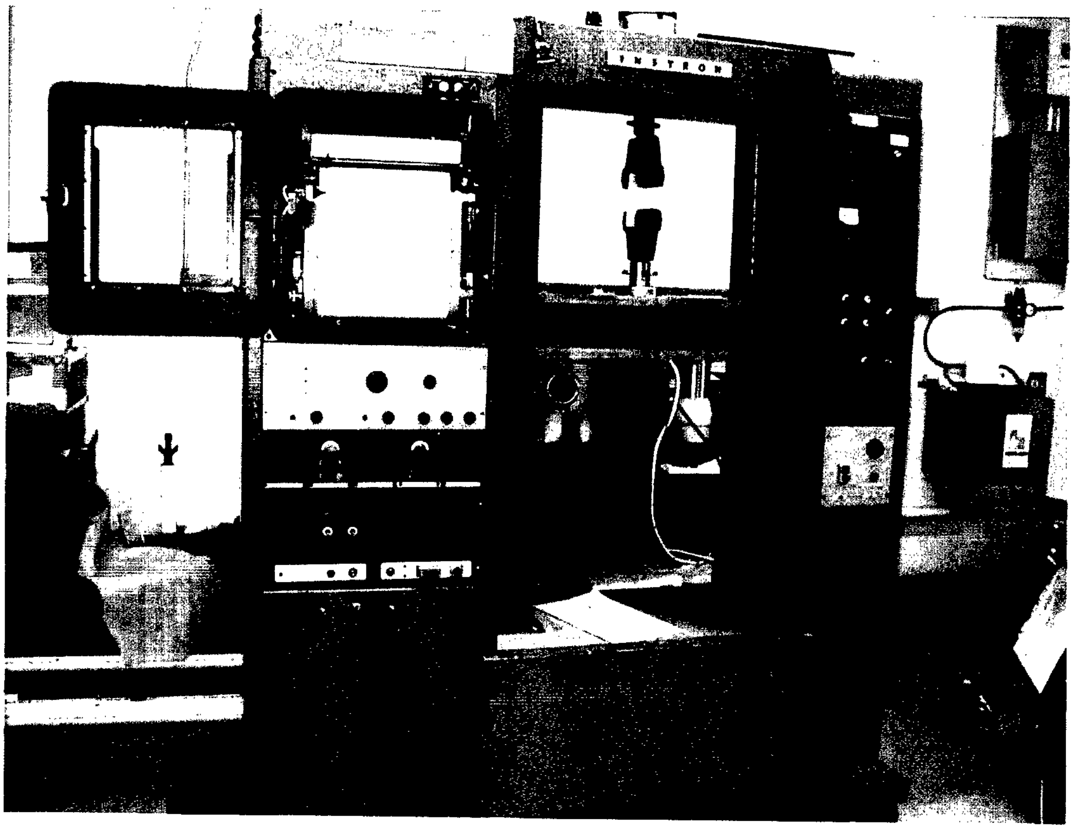

Figure 4
Tensile strength test setup

RESULTS AND DATA ANALYSES

Material Compatibility Test

When subjected to the compatibility test (40 hrs at 100°C for single-base propellant) in accordance with the requirements set forth in MIL-STD-286, Method 408.1, acrylic cloth and M1 propellant showed good compatibility with each other. The amount of gas evolved from the mixture was 6.38 mL. The sum of the amount of gas produced by the ingredients tested separately was 5.90 mL. Since the difference between the two amounts was less than 3 mL, the acrylic cloth was considered compatible with the M1 propellant (app. B).

Propellant Uniformity Tests

Ballistic propellant uniformity results are shown in tables 3 to 5 and figures 5 to 10 (ref. 12). When fired at 70°F, the muzzle velocity standard deviation was 2.3 fps for the zone 3 test rounds, 2.7 fps for the zone 3 control rounds, 3.0 fps for the zone 7 test rounds, and 2.9 fps for the zone 7 control rounds. Both test and control rounds met the muzzle velocity standard deviation requirements of 3.8 fps for zone 3 and 3.4 fps for zone 7. Also, the minimum individual pressure was 9,300 psi for zone 3 test rounds, 9,400 psi for zone 3 control round, 35,200 psi for zone 7 test rounds, and 31,300 psi for zone 7 control rounds. The maximum individual pressure was 9,500 psi for zone 3 test rounds, 9,800 psi for zone 3 control rounds, 36,100 psi for zone 7 test rounds, and 36,600 psi for zone 7 control rounds. Both test and control rounds met the zone 3 minimum and maximum individual pressure requirements of 9,200 psi and 10,500 psi, respectively; and the zone 7 minimum and maximum individual pressure requirements of 31,200 psi and 39,000 psi, respectively.

Table 3
Uniformity test at +70 deg°F

	Test rounds (with acrylic bags)		Control rounds (with rayon bags)	
Zone	Velocity (ft/s)	Pressure (kpsi)	Velocity (ft/s)	Pressure (kpsi)
3	Mean = 760 Std dev = 2.3	Range = 9.3 - 9.5 Mean = 9.3 Std dev = 0.2	Mean = 763 Std dev = 2.7	Range = 9.4 - 9.8 Mean = 9.5 Std dev = 0.1
7	Mean = 1527 Std dev = 3.0	Range = 35.2 - 36.1 Mean = 35.8 Std dev = 0.5	Mean = 1530 Std dev = 2.9	Range = 31.3 - 36.6 Mean = 35.3 Std dev = 1.8

Table 4
Uniformity test at +145°F

	Test rounds (with acrylic bags)		Control rounds (with rayon bags)	
Zone	Velocity (ft/s)	Pressure (kpsi)	Velocity (ft/s)	Pressure (kpsi)
3	Mean = 775 Std dev = 2.8	P_{max} = 10.4 Mean = 10.2 Std dev = 0.1	Mean = 783 Std dev = 3.1	P_{max} = 10.5 Mean = 10.4 Std dev = 0.2
7	Mean = 1571 Std dev = 2.9	P_{max} = 39.6 Mean = 39.4 Std dev = 0.2	Mean = 1577 Std dev = 1.7	P_{max} = 40.2 Mean = 39.6 Std dev = 1.0

Table 5
Uniformity test at –50°F

	Test rounds (with acrylic bags)		Control rounds (with rayon bags)	
Zone	Velocity (ft/s)	Pressure (kpsi)	Velocity (ft/s)	Pressure (kpsi)
3	Mean = 737 Std dev = 2.4	P_{max} = 8.9 Mean = 8.6 Std dev = 0.2	Mean = 744 Std dev = 2.7	P_{max} = 9.1 Mean = 8.8 Std dev = 0.2
7	Mean = 1489 Std dev = 3.9	P_{max} = 32.1 Mean = 31.6 Std dev = 0.5	Mean = 1498 Std dev = 4.6	P_{max} = 33.2 Mean = 32.2 Std dev = 0.7

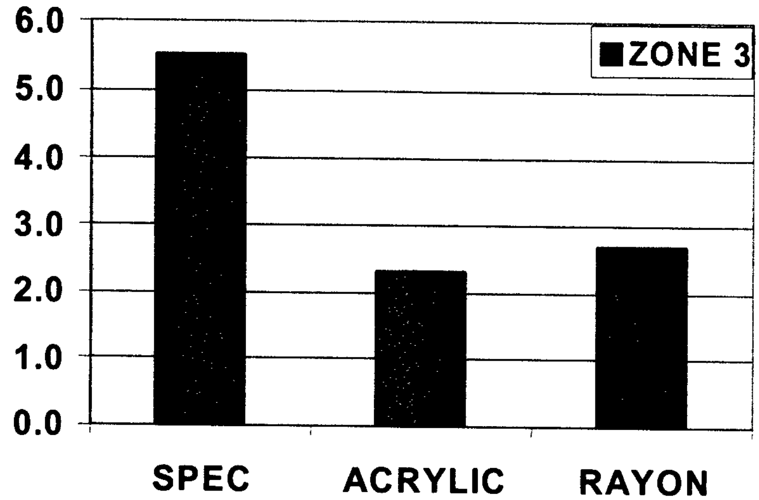

Figure 5
Zone 3 - velocity standard deviation at +70°F

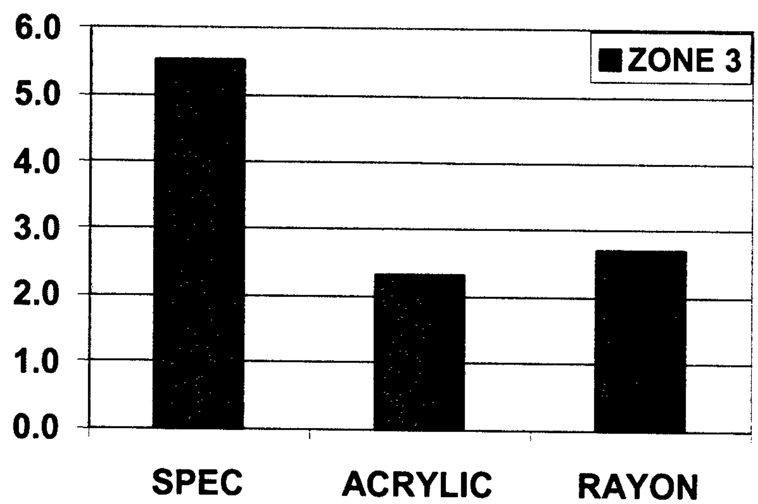

Figure 6
Zone 7 – velocity standard deviation at +70°F

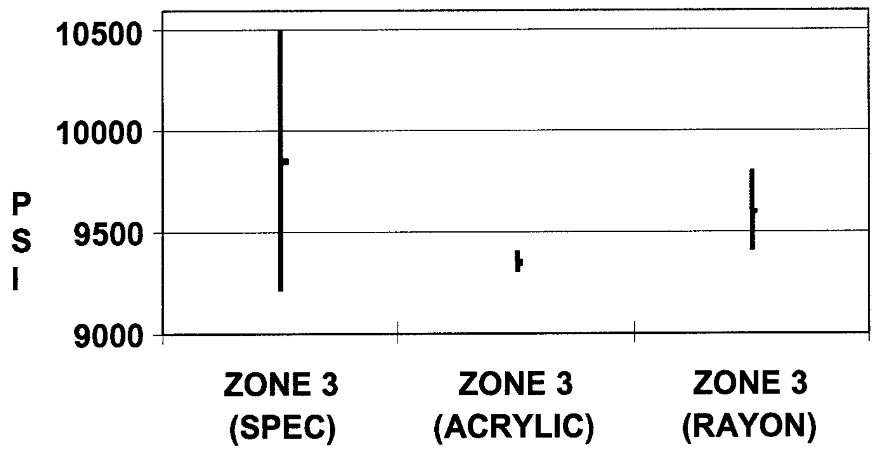

Figure 7
Zone 3 – pressure range at 70°F

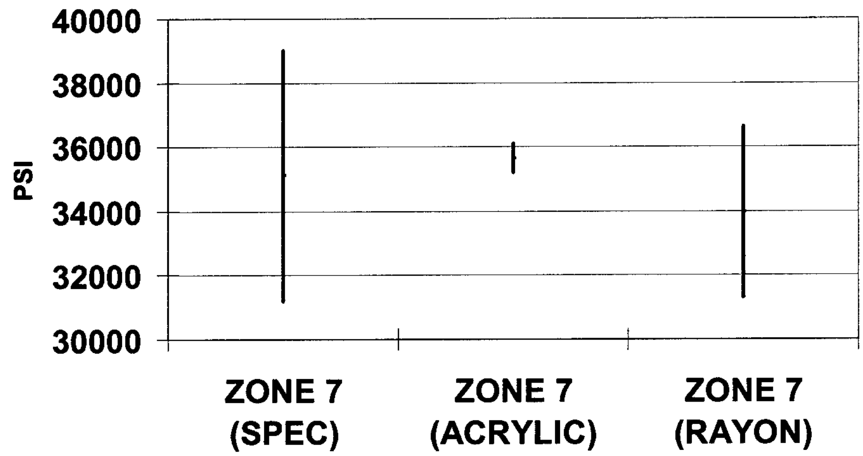

Figure 8
Zone 7 – pressure range at 70°F

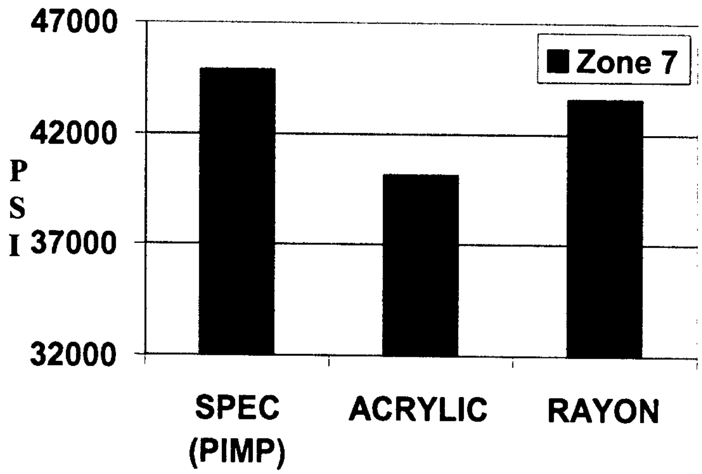

Figure 9
Zone 7 – average pressure plus 4 Sigma at +145°F (propellant uniformity series)

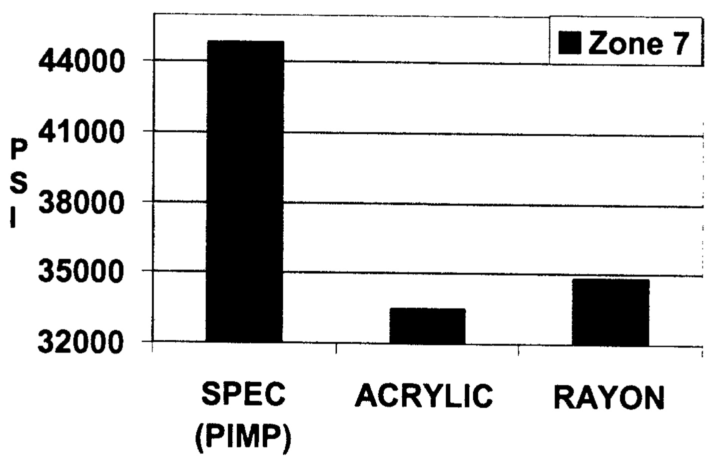

Figure 10
Zone 7 – average pressure plus 4 Sigma at -50°F (propellant uniformity series)

When fired at +145°F, the maximum individual pressure was 10,400 psi for the zone 3 test rounds, 10,500 psi for the zone 3 control rounds, 39,600 psi for the zone 7 test rounds, and 40,200 psi for the zone 7 control rounds. When fired at -50°F, the maximum individual pressure was 8,900 psi for the zone 3 test rounds, 9,100 psi for the zone 3 control rounds, 32,100 psi for the zone 7 test rounds, and 33,200 psi for the zone 7 control rounds. Both test and control rounds passed the tests by not exceeding the permissible individual maximum pressure (PIMP) of 44,800 psi at +145°F and -50°F.

Sequential Environmental Tests

A total of 120 test rounds with acrylic bags, and a total of 120 control rounds with rayon bags passed the sequential environmental test in accordance with ITOP 4-2-504 without any safety hazard (e.g., burning or detonation) during simulated rough handling, transportation, hot and cold storages, and ballistic firing (ref. 12).

Table 6 and figure 11 summarize the number of damaged M67 propelling charges after 120 test rounds and 120 control rounds were subjected to logistic vibrations. After vibration test at +145°F, a total of 14 test rounds and a total of 19 control rounds had bag damages. After vibration test at -50°F, one test round and two control rounds had bag damages. Both acrylic and rayon bags hold up better in the cold temperature than in the hot temperature. However, the acrylic bags hold up better than the rayon bags in both hot and cold temperatures. Approximately 5%, 3%, 24%, and 68% of the damages were found on zone 1, zone 5, zone 6, and zone 7 bags, respectively. It was probably because the upper zone bags had more room to move and rub against the seam of the spiraled cartridge case during vibration.

Table 6
Sequential environmental test: number of damaged M67 after logistic vibrations

Test temperature	Acrylic bags	Rayon bags
+145°F	14	19
- 50°F	1	2

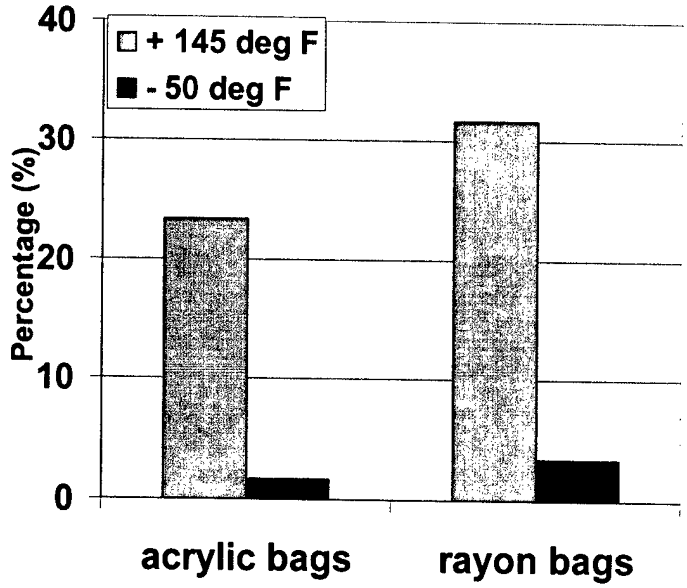

Figure 11
Percent damaged M67 charges after logistic vibration

Table 7 summarizes the number of damaged M67 propelling charges with propellant leakage after logistic vibrations. After vibration at +145°F, a total of four test rounds and a total of nine control rounds had propellant leakage. After vibration at -50°F, no test round and one control round had propellant leakage. It's important to note that the acrylic bags were equal or better than the rayon bags in terms of extent and/or amount of bag damage.

Table 7
Sequential environmental test: number of damaged M67 with propellant leakage after logistic vibrations

Test temperature	Acrylic bags	Rayon bags
+145°F	4	9
- 50°F	0	1

Table 8 and figure 12 summarize the number of damages (holes) found on 20 test rounds and 20 control rounds after loose cargo vibration with fiber containers. After loose cargo vibration at +145°F, a total of 24 holes were found on 10 test rounds and a total of 36 holes were found on 10 control rounds. After loose cargo vibration at -50°F, a total of 15 holes were found on 10 test rounds and a total of 25 holes were found on 10 control rounds. Again, the acrylic bags were more durable than the rayon bags after loose cargo vibration.

Table 8
Sequential environmental test: total number of bag damages after loose cargo vibration (with fiber container)

Test temperature	Acrylic bags	Rayon bags
+145°F	24	36
- 50°F	15	25

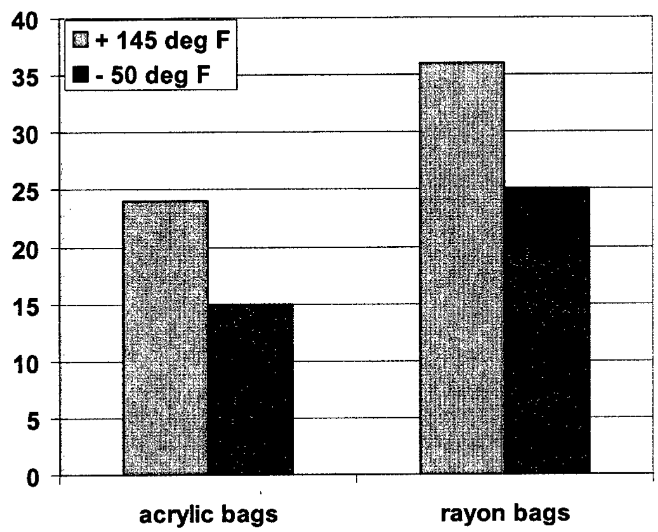

Figure 12
Number of damages after loose cargo vibration

Table 9 and figures 13 and 14 summarize the ballistic test results of 40 test rounds and 40 control rounds, which were subjected to logistic vibrations and temperature conditioning (28-day hot cycle or 14-day cold soak). When fired at +145°F, the maximum individual pressure was 40,700 psi for the zone 7 test rounds and 40,900 psi for the zone 7 control rounds. When fired at -50°F, the maximum individual pressure was 31,900 psi for the zone 7 test rounds and 33,300 psi for the zone 7 control rounds. Both test and control rounds passed the test by not exceeding the permissible individual maximum pressure of 44,800 psi at +145=F and -50=F.

Table 9
Performance phase of sequential environmental test: ballistic test results

Test Temperature	Test rounds (with acrylic bags)		Control rounds (with rayon bags)	
	Velocity (ft/sec)	Pressure (kpsi)	Velocity (ft/sec)	Pressure (kpsi)
+145°F	Mean = 1581 Std dev = 2.3	P_{max} = 41.3 Mean = 40.7 Std dev = 0.5	Mean = 1589 Std dev = 11.0	P_{max} = 42.5 Mean = 40.9 Std dev = 0.7
-50°F	Mean = 1495 Std dev = 3.3	P_{max} = 32.6 Mean = 31.9 Std dev = 0.6	Mean = 1510 Std dev = 3.2	P_{max} = 34.0 Mean = 33.3 Std dev = 0.5

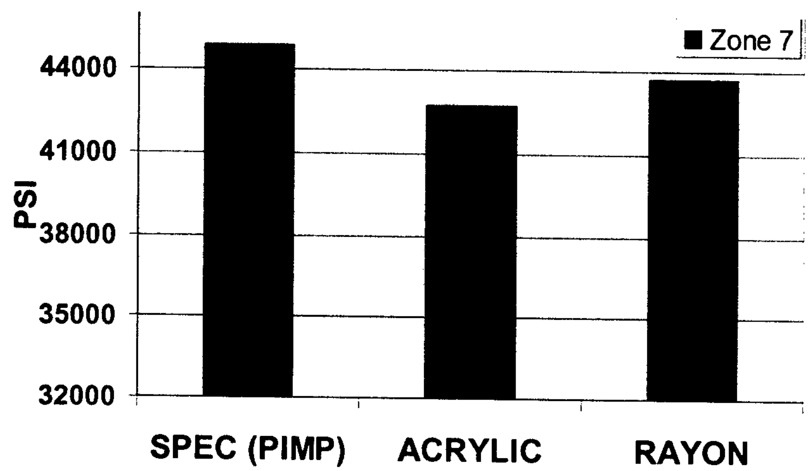

Figure 13
Zone 7 – average pressure plus 4 Sigma +145°F (sequential environmental test)

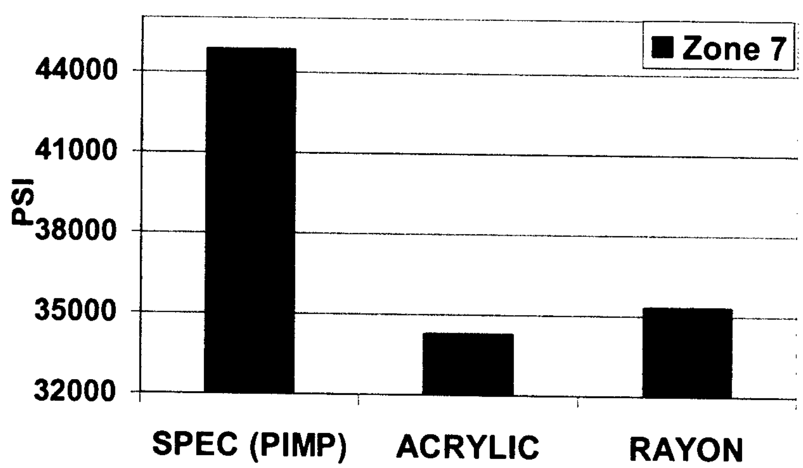

Figure 14
Zone 7 – average pressure plus 4 Sigma at -50°F (sequential environmental test)

Residue Evaluation

As shown in table 10, the acrylic propellant bags left no visible residue during any of the above ballistic tests when fired at zones 1, 3, and 7 at -50°F, 70°F, and +145°F. The rayon propellant bags left trace amount of cloth residue in 25% of rounds fired as shown in figure 15.

Table 10
Performance phase of sequential environmental test: percentage of M67 with recoverable cloth residue after ballistic firing

Test Temperature	Acrylic Bags	Rayon Bags
+145°F	0%	25%
-50°F	0%	55%

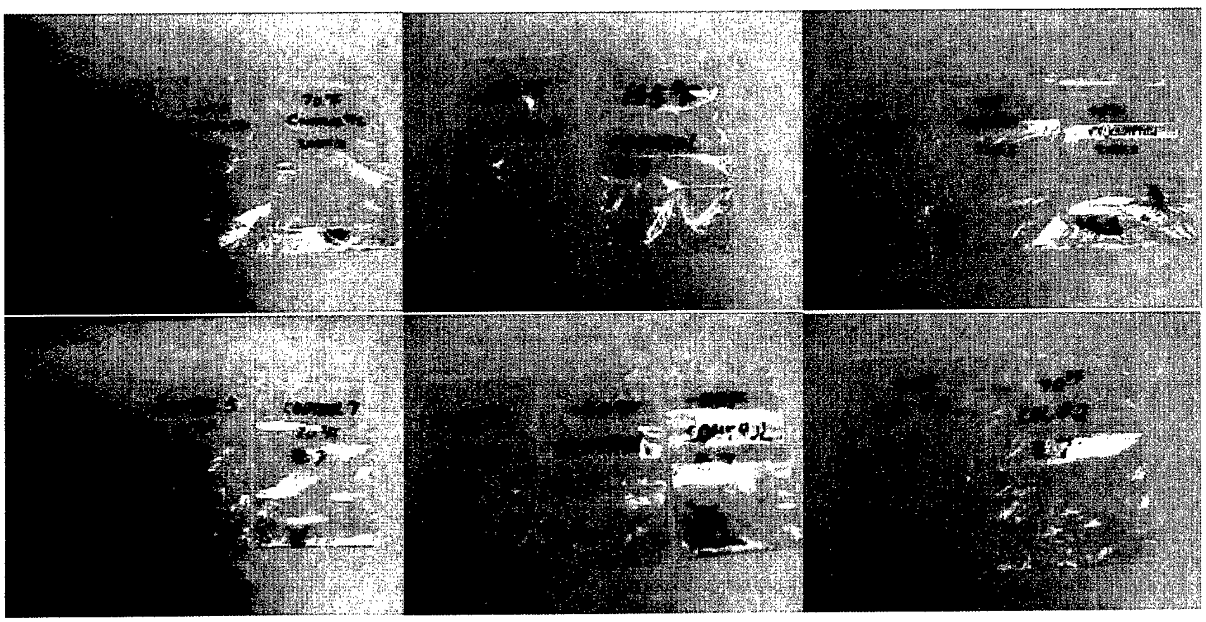

Figure 15
Rayon cloth residue

Propellant Cloth Shelf Life Study

Accelerated aging tests were conducted to measure the tensile strength loss of both rayon and acrylic propellant bags at elevated constant temperatures (149°F, 176°F, 185°F, 203°F) at 75% RH and the results are shown in appendix C. Data collected over a 12-month period indicated that the acrylic fill and rayon fill cloth samples lost their tensile strength more rapidly than the acrylic warp and rayon warp cloth samples. Figure 16 depicts the deterioration of rayon bags after 0, 8, and 12 weeks at 185°F. For a worst-case scenario, only tensile strength data of the acrylic fill and rayon fill cloth samples were fitted to the following Arrhenius degradation model (ref. 13). Once the degradation was fitted, it was used to predict tensile strength loss at the service temperatures of 77°F (25°C) and 95.68°F (35.38°C). The temperature criteria are based on the temperature profiles given in AR 70-38 and MIL-STD-810 (refs. 14 and 15).

$$\text{Log (S)} = \alpha + t\,\beta\,\exp(-\gamma / T)$$

where

S = tensile strength
t = time
T = temperature (absolute)

The coefficients are estimated from regression of the tensile strength data.

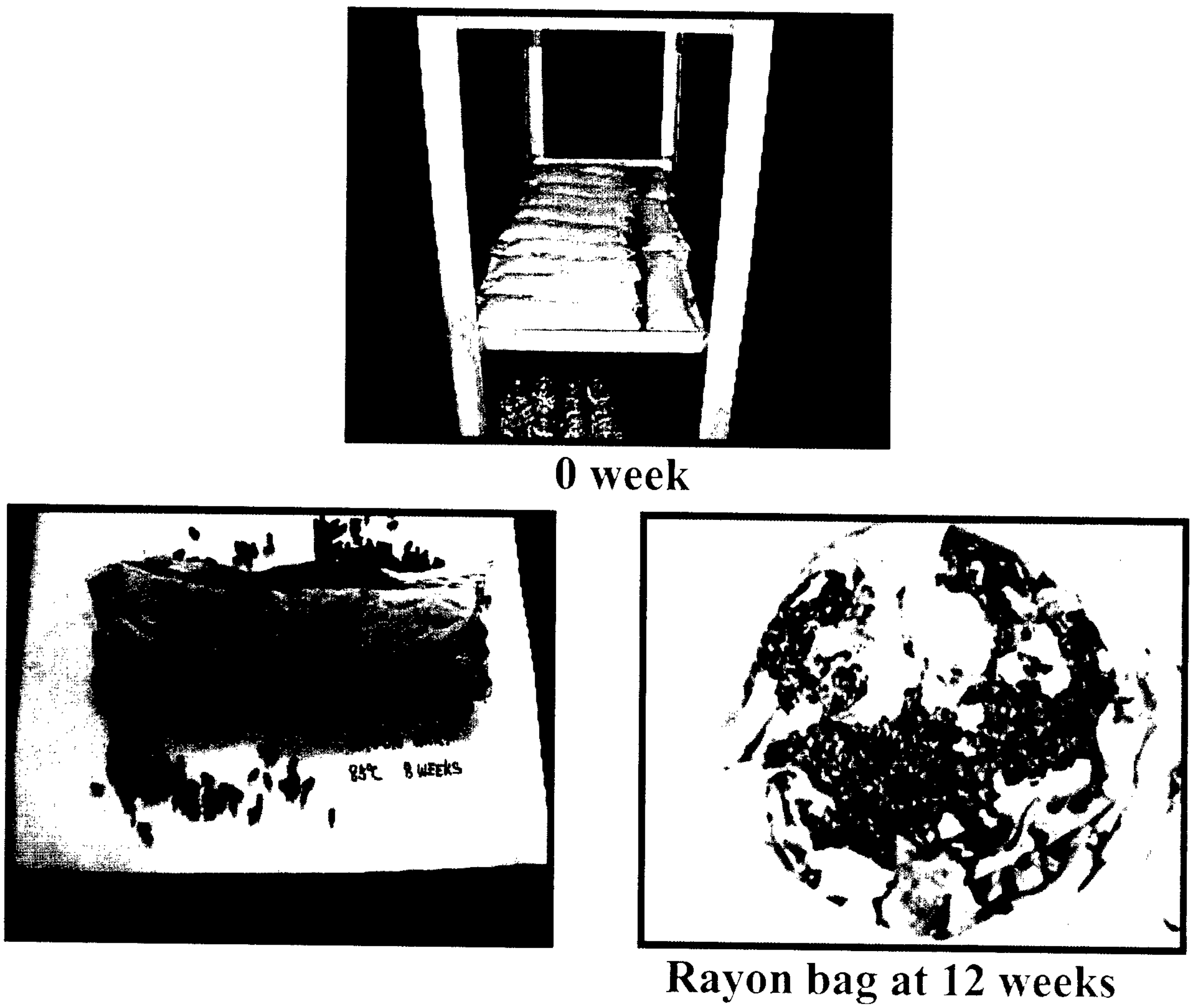

Figure 16
Rayon bags after 0, 8, and 12 weeks at 85°F

Figures 17 and 18 show both the observed and predicted tensile strength data at the elevated test temperatures as well as the estimated parameters (α , β, γ) for the degradation model. Tensile strength data of acrylic cloth were observed to increase slightly over the first few months and therefore were not included for degradation modeling. This phenomenon had also been observed in earlier accelerated aging study and may be explained by chemical addition to the free nitrile groups in the acrylic fiber polymer (ref. 5). In fact, acrylic cloth's resistance to deterioration is an extremely desirable characteristic.

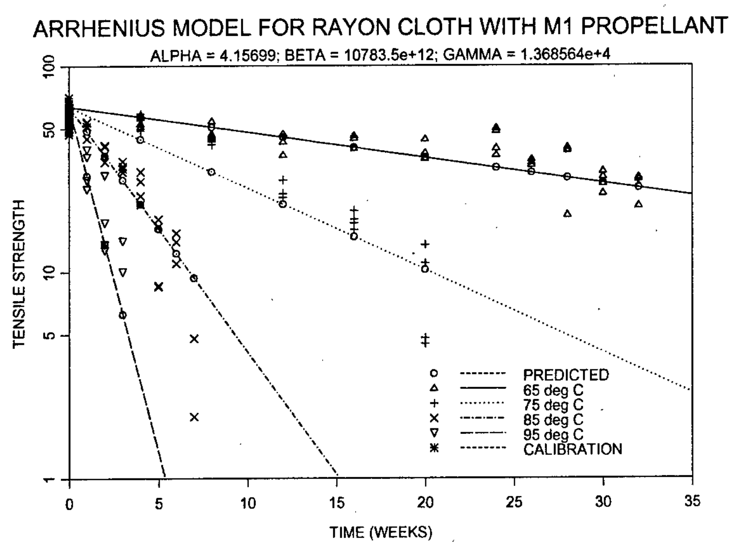

Figure 17
Arrhenius model for rayon cloth with M1 propellant

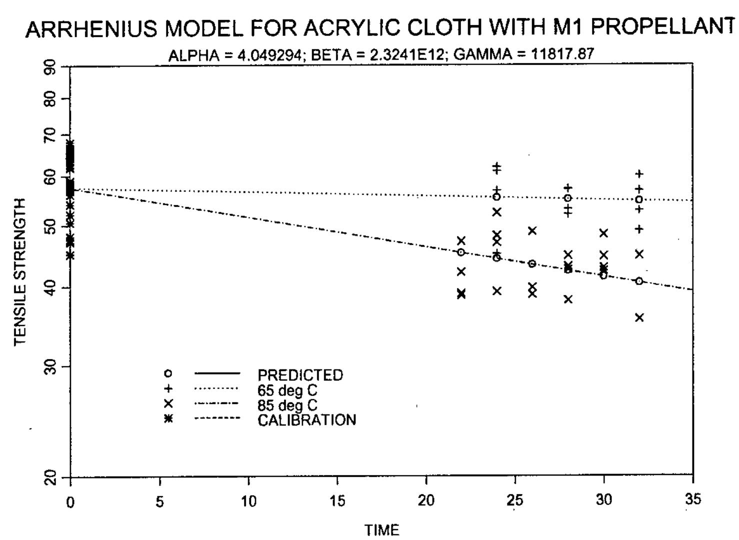

Figure 18
Arrhenius model for acrylic cloth with M1 propellant

Based on this degradation equation and calculated parameters, predicted fraction loss in tensile strength could be calculated for each exposed cloth from the following formula and the results were plotted in figures 19 and 20.

$$\text{Fraction loss} = 1 - T/T_0$$

where T = tensile strength predicted by the Arrhenius degradation equation and T_0 = original tensile strength (intercept of regression line).

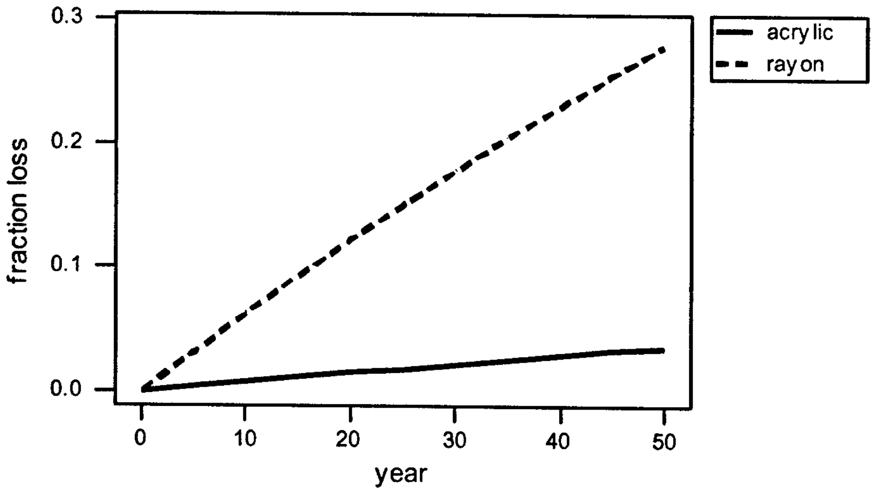

Figure 19
Predicted fraction loss in tensile strength at 77°F (25°C) and 75% RH

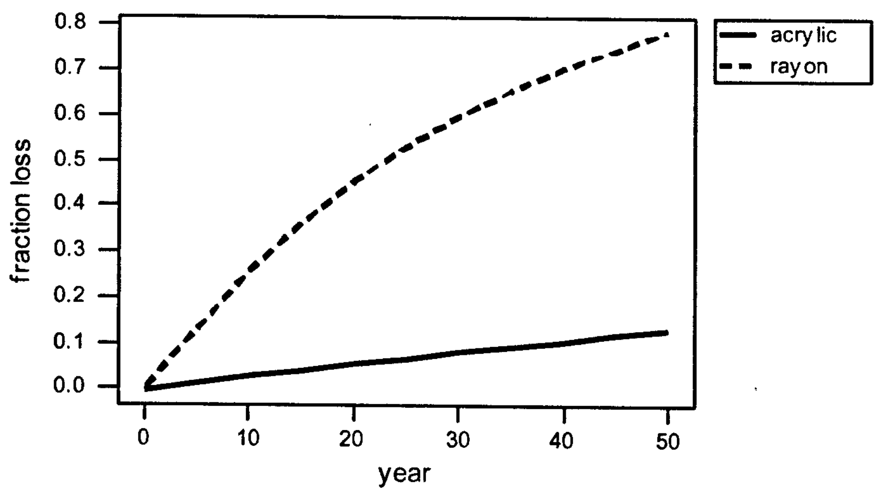

Figure 20
Predicted fraction loss in tensile strength at 95.68°F (35.38°C) and 75% RH

Since the propellant bags should survive rough handling/transportation, it was proposed 10% loss in tensile strength be used as the end point for shelf life prediction. Given this stringent requirement, the medium lifetime of the acrylic propellant bags were expected to far exceed 20 yrs in controlled storage and 2 yrs in uncontrolled storage. The predicted median lifetimes at the service temperatures were shown in table 11. At 77°F (25°C), the acrylic bag and rayon bag have a lifetime of 143 yrs and 16 yrs, respectively. At 95.68°F (35.38°C), the acrylic bag and rayon bag have a lifetime of 37 yrs and 3.4 yrs, respectively. This means the medium lifetimes of the acrylic propellant bags are estimated to be nine to eleven times longer than those of the rayon propellant bags.

Table 11
Predicted medium lifetimes based on 10% loss in tensile strength

	Acrylic cloth	Rayon cloth	Acrylic better than rayon by
25°C and 75% RH	143 yrs	16 yrs	9 times
35.38°C and 75% RH	37 yrs	3.4 yrs	11 times

SUMMARY

The acrylic propellant bags were successfully qualified as a replacement for the existing rayon bags for the 105-mm M67 propelling charge by satisfactorily passing the following laboratory and ballistic evaluations:

- The acrylic cloth material is chemically compatible with its contact material, the M1 propellant.

- The acrylic bags have demonstrated remarkable resistance to deterioration by propellant outgas during the 12-month shelf life study. Based on the Arrhenius degradation model, the shelf life of the acrylic bag was expected to far exceed the minimum requirements of 20 yrs in controlled storage and 2 yrs in uncontrolled storage.

- The M67 propelling charges with the acrylic bags had met all ballistic performance requirements for chamber pressure and muzzle velocity.

- The acrylic bags of various zones left no cloth residue in the cartridge case and gun chamber after ballistic firings at hot, cold, and ambient temperatures.

- The acrylic bags had demonstrated better durability than the rayon bags during simulated rough handling and transportation tests.

The Technical Data Package for the M67 propelling charge was updated to incorporate the use of acrylic propellant bag (ref. 16). Replacement of existing rayon bags with the new acrylic bags will prevent propellant bag deterioration, eliminate expensive rework, and result in substantial cost avoidance in the future.

RECOMMENDATION

Based on the superior properties observed with the acrylic cloth (less residue, increased handling durability, and a long shelf life), all future production of M67 propelling charges should use the acrylic cloth.

REFERENCES

1. Skelton, Don, "The Effects of Simulated PREPO Environments on Ammunition Deterioration rates'" Picatinny Arsenal Technical Report No. QAR-R 93-2, U.S. Army Armament Research, Development and Research Center, Picatinny Arsenal, NJ, 15 April 1993.

2. Skelton, Don and Williams, Janett, "PREPO Cloth Deterioration Study," AMCCOM, Product Assurance and Test Directorate, 15 September 1989.

3. Ammunition Information Notice (Ain) 21-00: Inspection of 105mm Howitzer Cartridges.

4. Nadel, I. G. and Musgrave, J. S., "Develop Substitute Cartridge Cloth Material," Project No. TB4-911E, Picatinny Arsenal Technical Report No. 1916, U.S. Army Armament Research, Development and Research Center, Picatinny Arsenal, NJ, 10 February 1953.

5. Nadel, Isidore G. and Bernstein, Sidney B., "Development of Substitutes for Silk Cartridge Cloth," Technical Report 2683, Feltman Research and Engineering Laboratories, Picatinny Arsenal, June 1960.

6. Drawing 9205472, "Charge, Propelling, M67 Assembly."

7. MIL-C-60315, "Charge, Propelling, M67 for 105mm Howitzer Loading, Assembly and Packing".

8. MIL-P-60318, "Propellant, M1 for Use in Charge, Propelling, M67 for 105mm Howitzer."

9. Supplement P-105H-2, "Proving Ground Acceptance Test Procedure for Artillery Propellants," 28 September 1971.

10. FR/GE/UK/US International Test Operations Procedure (ITOP 4-2-504): Safety Testing of Field Artillery Ammunition.

11. FED-STD-191, "Textile Test Methods."

12. Firing Report No: 03-FP-0620-L5, "M67 Propelling Charge Bag Improvement Study," U.S. Army Yuma Proving Ground, 16 April 2003.

REFERENCES
(continued)

13. Nelson, Wayne (1990), Accelerated Testing: Statistical Models, Test Plans, and Data Analyses, John Wiley & Sons, Inc., New York.

14. AR 70-38, Research, Development, Test and Evaluation of Materiel for Extreme Climatic Conditions.

15. MIL-STD-810, Environmental Test Methods and Engineering Guidelines.

16. Engineering Change Proposal, ECP R2A2031, "Change Propellant Bag Material from Rayon Cloth to Acrylic Cloth," 20 December 2002.

APPENDIX A
SUMMARY OF TEST PLAN

Test Description	Test Quantity	Test Method[1]	Requirement[1]
Compatibility Test: This safety test ensures there will be no reactivity between the acrylic cloth and contact materials.	<u>Small samples taken from:</u> Acrylic cloth M1 propellant	MIL-STD-286, Method 408.1.1.	MIL-STD-286, Method 408.1.1.
Test Hardwares:	**<u>Lot Number:</u>** <u>Warmers (zone 7):</u> TBD <u>Calibration (zones 1-2):</u> Propellant lot# RAD-68108 (SP) <u>Calibration (zones 3-7):</u> Propellant lot# RAD-68051 (MP) <u>Control (zones 1-2):</u> Propellant lot# RAD-68108 (SP) Bag lot# RAD69222 (rayon) <u>Control (zones 3-7):</u> Propellant lot# RAD-68051 (MP) Bag lot# RAD90K-071523 (rayon) <u>Test (zones 1-2):</u> Propellant lot# RAD-68108 (SP) Bag lot# IOW02C-088888 (acrylic) <u>Test (zones 3-7):</u> Propellant lot# RAD-68051 (MP) Bag lot# IOW02C-044444 (acrylic) Projectile: Type: HE, 105mm, M1 Weight: Inert-loaded with dummy fuze to 33.0 +/- 0.02 lbs. <u>Howitzer/Cannon:</u> M101A1 Howitzer/M2A2 Cannon with at least 75% remaining EFC.	Loading and assembly will be proceeded in the following order upon successful completion of each phase: Phase 1: LAP M67 for Zones 1-2 Charge Weight Assessment. Phase 2: LAP M67 for Zones 3-7 Charge Weight Assessment Test. Phase 3: LAP M67 for Propellant Uniformity & Residue Test Phase 4: LAP M67 for Sequential Environmental, and Rough Handling Tests. ***<u>Attention: Each round shall be labeled with respect to type (warmer, calibration, control, test), lot number, zone, temperature to ensure traceability. Proceed to next phase only after approval from Picatinny Arsenal.</u>***	Control and test charges shall have identical component lots (e.g. propellants, primer, cartridge, inert fuze) except the propellant bags. Control charges use rayon bags whereas test charges use acrylic bags.
Charge Weight Assessment: This test establishes charge weight for the M67 prop charge.	<u>Charge weights for zones 1-2 @70°F:</u> 3 warmers (zone 7) 5 calibration (zone 2) 5 test (zone 2) 5 test (zone 1) 5 calibration (zone 1) <u>Charge weights for zones 3-7 @70°F:</u>	Phase 1: Calibration Charge shall be fired alternatively with Test Charge. Require minimum 24 hours temperature conditioning prior to firing. Charge weights for zones 1-2 will be determined from a velocity versus charge weight curve.	Charge weights for each zone will be determined from a velocity versus charge weight curve in accordance with the velocity requirements set forth in para. 5.1.2 of this test plan.

	5 warmer (zone 7) 2 conditioner (zone 7) 5 calibration (zone 7) 5 test (zone 7) 2 conditioner (zone 6) 5 calibration (zone 6) 5 test (zone 6) 2 conditioner (zone 3) 5 calibration (zone 3) 5 test (zone 3)	Attention: Test proceeds only after zones 1-2 charge weights calculated/verified by Picatinny Arsenal. Phase 2: Calibration Charge shall be fired alternatively with Test Charge. Require minimum 24 hours temperature conditioning prior to firing. Charge weights for zones 3-7 will be determined from a velocity versus charge weight curve. ***<u>Attention: Test proceeds only after zones 3-7 charge weights calculated/verified by Picatinny Arsenal.</u>***	
Propellant Uniformity & Residue Test: This test confirms that the M67 will meet the muzzle velocity and pressure requirements at zones 3 and 7, with no unacceptable amount of residue at zones 1, 3, and 7.	<u>70°F:</u> 7 warmer (zone 7) 2 conditioner (zone 1) 7 control[2] (zone 1) 7 test[2] (zone 1) 2 conditioner (zone 3) 7 calibration (zone 3) 7 control (zone 3) 7 test (zone 3)[8] 2 conditioner (zone 7) 7 calibration (zone 7) 7 control (zone 7) 7 test (zone 7) <u>145°F:</u> 7 warmer (zone 7) 7 control (zone 1) 7 test (zone 1) 7 control (zone 3) 7 test (zone 3) 7 control (zone 7) 7 test (zone 7) <u>-50°F:</u> 7 warmer (zone 7)	<u>Performance:</u> P-105H-2[3], para. 3.0, 4.0 MIL-P-60318[4], para. 3.0 MIL-C-60315[5], para. 6.9 ITOP-4-2-504[6], para. 4.2 Test temperatures: -50°F, 70°F, 145°F (-46°C, 21°C, 63°C) <u>Residue:</u> The gun chamber and tube and cartridge case shall be inspected for **cloth and lead foil residue** after each firing. Any residue remaining in the gun chamber or gun tube shall be carefully collected, weighed, and **photographed**. The location of the residue shall be recorded and identified as to cartridge source (warmer, control, calibration or test cartridge and number). ***<u>Attention: A final adjustment on charge weights shall be made based on the Charge Weight Assessment and Uniformity Test Results using linear regression. Test proceeds only after zones 1-7 charge weights calculated /verified by Picatinny Arsenal.</u>***	<u>Performance:</u> Mean velocity, velocity standard deviation, and PIMP[7] at zones 3 and 7 shall meet the requirements set forth in para. 3.0 of MIL-P-60318. <u>Residue:</u> There shall be no residue, or the amount of residue from the test cartridges (with acrylic propellant bags) shall not exceed the amount of residue from the control cartridges (with rayon propellant bags).

	7 control (zone 1) 7 test (zone 1) 7 control (zone 3) 7 test (zone 3) 7 control (zone 7) 7 test (zone 7)		
Sequential Environmental Test: This test determines the effect of the manufacture-to-target environments on both safety and performance of the M67 with the new acrylic propellant bags.	<u>145°F:</u> 7 warmer (zone 7) for hot firing 7 warmer (zone 7) for cold firing 60 test (zone 7) 7 warmer (zone 7) for hot firing 7 warmer (zone 7) for cold firing 60 control (zone 7) 60 new wooden boxes (overpacks) 120 fiber containers (innerpacks) <u>-50°F:</u> 7 warmer (zone 7) for hot firing 7 warmer (zone 7) for cold firing 60 test (zone 7) 7 warmer (zone 7) for hot firing 7 warmer (zone 7) for cold firing 60 control (zone 7) 60 new wooden boxes (overpacks) 120 fiber containers (innerpacks)	ITOP-4-2-504, para. 4.7, Figure 7. Figure 1 of this test plan (test rounds) Figure 2 of this test plan (control rounds) Test temperatures: -50°F & 145°F (-46°C & 63°C) Use "Old" packaging configuration[6]. Each box shall contain two test rounds and two fiber containers. Calibration rounds are to be fired on each day if ballistic test requires more than one day. ***<u>Attention:</u>*** ***<u>Use – 50 deg F (- 46 deg C) for cold temperature.</u>*** ***<u>"bare drop" refers to drop testing on semi-fixed cartridge without fiber container and wooden box.</u>*** ***<u>A visual inspection of the test items shall be made before and after each sequence of tests.</u>*** ***<u>Items not save to be fired shall be downloaded and inspected for damaged propellant bag, propellant, lead foil liner, etc.</u>*** ***<u>Record and photograph any abnormality.</u>***	<u>Performance:</u> The PIMP[7] at zone 7 shall meet the requirements set forth in para. 3.0 of MIL-P-60318B. <u>Safety:</u> There shall be no rupture or leakage from the propellant bags rendering the M67 unsafe for handling and ballistic firing.
Propellant Cloth Shelf Life Study: This test estimates the shelf life of the new propellant bag.	Acrylic cloth Rayon cloth as control M1 Propellant	ARDEC procedure.	Acrylic cloth shall have a minimum of 20 years shelf life.

Notes:

1. If there's a conflict between the item's specification and the ITOP, the item's specification shall take precedence unless otherwise directed by the project engineer.

2. Each round consists of M1 cartridge and M67 propelling charge. The control and test rounds shall be selected from the same and newly accepted lot. Control rounds have the original rayon propellant bags. Test rounds are replaced with the new acrylic propellant bags.

3. Supplement P-105H-2, Proving Ground Acceptance Test Procedure for Artillery Propellants.

4. MIL-P-60318, Propellant, M1 for Use in Charge, Propelling, M67 for 105mm Howitzer.

5. MIL-C-60315, Charge, Propelling, M67 for 105mm Howitzer Loading, Assembling and Packing.

6. The "old" packaging configuration consists of two fiber containers (PA55 or PA105) per wooden box. This old packaging configuration applies to retrofitted items in the stockpile. For new production items, the "new" packaging configuration consists of one fiber container (PA111 for the M927; PA55 or PA105 for M314) per metal container (PA117). The old packaging is expected to provide less protection than the new packaging and, therefore, will represent the worst-case scenario.

7. PIMP stands for "Permissible Individual Maximum Pressure".

8. Comprised of test SP propellant and calibration MP propellant. Charge weights for zones 1 and 2 predicted from closed bomb test.

APPENDIX B
COMPATIBILITY TEST RESULT

APPENDIX B

COMPATIBILITY TEST RESULT

AMSTA-AR-AEE –WECAC
Compatibility Study Report, Analytical Research & Services

DATE March 15, 2002 REPORT NO. EWD- 04 -02/C

CUSTOMER

Requester:	A.Eng
Charge No.:	
Requirement:	Compatibility Study of M1 Propellant, Lot. No. RAD68051 with Acrylic Cloth Material

TEST

Test Performed:	Vacuum Compatibility at 100°C for 40 hours
Method:	Mil-Std 286-C, Method 408.1.1

DATA

Component/Computation	ml gas at STP
Component 1 M1 Propellant	5.55
Component 2 Acrylic Cloth	0.35
Control (1 + 2)	5.90
Mixture (1+ 2) M1 / Acrylic Cloth	6.38
Mixture- Control	0.48

CONCLUSION

(X) Compatible

( ) Marginaly Compatible

( ) Incompatible

Work By Keith Rowe

Approved By

APPENDIX C
PROPELLANT BAG ACCELERATED AGING DATA

pull out date	ID	time (week)	time (day)	tensile coupon 1	strength coupon 2	coupon 3	coupon 4	average
2/20	AW-CAL[1]	4	28	64.0	61.0	66.0	62.0	63.3
3/20	AW-CAL	8	56	65.0	69.3	68.8	63.0	66.5
4/17	AW-CAL	12	84	64.0	64.0	59.0	58.0	61.3
5/15	AW-CAL	16	112	65.0	71.5	67.0	72.7	69.1
6/12	AW-CAL	20	140	70.0	71.3	70.5	66.0	69.5
7/10	AW-CAL	24	168	60.6	58.8	64.0	61.0	61.1
8/7	AW-CAL	28	196	65.8	66.9	58.7	67.0	64.6
9/4	AW-CAL	32	224	64.0	66.0	60.8	67.8	64.7
10/2	AW-CAL	36	252	70.5	71.8	65.0	61.3	67.2
10/30	AW-CAL	40	280	64.0	66.0	59.5	71.0	65.1
11/27	AW-CAL	44	308	68.8	66.6	61.3	70.0	66.7
12/24	AW-CAL	48	336					
Average								65.0
2/20	AF-CAL[1]	4	28	78.3	61.0	48.0	56.0	60.8
3/20	AF-CAL	8	56	56.0	64.5	56.0	67.9	61.1
4/17	AF-CAL	12	84	52.0	59.0	54.0	57.0	55.5
5/15	AF-CAL	16	112	65.5	62.0	66.5	65.3	64.8
6/12	AF-CAL	20	140	59.0	50.5	57.8	63.3	57.7
7/10	AF-CAL	24	168	52.0	45.0	47.0	47.4	47.9
8/7	AF-CAL	28	196	61.8	58.8	58.0	64.3	60.7
9/4	AF-CAL	32	224	58.0	57.0	59.0	66.0	60.0
10/2	AF-CAL	36	252	42.0	40.0	40.0	39.7	40.4
10/30	AF-CAL	40	280	39.5	63.3	36.0	39.0	44.5
11/27	AF-CAL	44	308	65.3	55.8	54.9	56.7	58.2
12/24	AF-CAL	48	336					
Average								58.4
2/20	RW-CAL[1]	4	28	60.0	48.0	61.0	60.0	57.3
3/20	RW-CAL	8	56	66.0	68.0	69.0	66.0	67.3
4/17	RW-CAL	12	84	58.0	57.0	58.0	61.0	58.5
5/15	RW-CAL	16	112	62.5	62.7	56.2	59.5	60.2
6/12	RW-CAL	20	140	62.1	64.3	62.0	60.8	62.3
7/10	RW-CAL	24	168	60.0	61.0	60.0	61.0	60.5
8/7	RW-CAL	28	196	61.0	59.0	61.3	60.8	60.5
9/4	RW-CAL	32	224	46.6	41.5	41.0	37.0	41.5
10/2	RW-CAL	36	252	59.0	62.0	60.0	57.0	59.5
10/30	RW-CAL	40	280	56.0	63.0	60.0	61.8	60.2
11/27	RW-CAL	44	308	57.9	59.0	60.9	61.0	59.7
12/24	RW-CAL	48	336					
Average								60.9
2/20	RF-CAL[1]	4	28	57.5	56.5	51.0	59.0	56.0
3/20	RF-CAL	8	56	63.0	66.0	70.8	66.5	66.6
4/17	RF-CAL	12	84	61.0	62.5	60.0	52.0	58.9

5/15	RF-CAL	16	112	56.0	58.5	58.2	55.0	56.9
6/12	RF-CAL	20	140	58.2	47.0	57.1	56.0	54.6
7/10	RF-CAL	24	168	53.0	53.0	57.9	52.2	54.0
8/7	RF-CAL	28	196	59.1	58.1	57.3	57.1	57.9
9/4	RF-CAL	32	224	50.0	48.5	50.0	53.5	50.5
10/2	RF-CAL	36	252	54.2	55.0	52.0	54.0	53.8
10/30	RF-CAL	40	280	51.6	49.0	50.0	51.8	50.6
11/27	RF-CAL	44	308	57.0	55.5	56.0	57.0	56.4
12/24	RF-CAL	48	336					
Average								57.8
1/23	AW75-CON[2]	0	0	65.0	65.0	65.0	65.0	65.0
2/20	AW75-CON	4	28	73.0	80.5	82.5	61.0	74.3
3/20	AW75-CON	8	56	66.2	64.8	0.0	0.0	32.8
4/17	AW75-CON	12	84	51.5	57.5	56.5	63.0	57.1
5/15	AW75-CON	16	112	64.5	64.5	65.1	66.0	65.0
6/12	AW75-CON	20	140	67.5	61.9	63.8	61.0	63.6
7/10	AW75-CON	24	168	63.8	65.0	65.0	65.4	64.8
8/7	AW75-CON	28	196	64.6	66.5	65.7	66.1	65.7
9/4	AW75-CON	32	224	62.5	59.0	58.0	63.6	60.8
10/2	AW75-CON	36	252	63.6	65.0	60.0	55.3	61.0
10/30	AW75-CON	40	280					
11/27	AW75-CON	44	308					
12/24	AW75-CON	48	336					
1/23	AF75-CON[2]	0	0	58.4	58.4	58.4	58.4	58.4
2/20	AF75-CON	4	28	78.0	74.0	67.0	67.5	71.6
3/20	AF75-CON	8	56	61.0	64.2	56.2	57.8	59.8
4/17	AF75-CON	12	84	48.0	55.0	57.0	54.0	53.5
5/15	AF75-CON	16	112	56.0	61.0	59.1	48.5	56.2
6/12	AF75-CON	20	140	47.5	54.0	42.0	45.0	47.1
7/10	AF75-CON	24	168	48.2	45.6	58.1	46.2	49.5
8/7	AF75-CON	28	196	59.5	53.2	51.3	53.0	54.3
9/4	AF75-CON	32	224	40.0	47.0	52.4	60.3	49.9
10/2	AF75-CON	36	252	48.8	54.9	58.0	57.3	54.8
10/30	AF75-CON	40	280					
11/27	AF75-CON	44	308					
12/24	AF75-CON	48	336					
1/23	RW75-CON[2]	0	0	60.9	60.9	60.9	60.9	60.9
2/20	RW75-CON	4	28	59.0	62.0	67.7	67.5	64.1
3/20	RW75-CON	8	56	64.0	64.0	65.0	58.5	62.9
4/17	RW75-CON	12	84	56.5	49.0	54.0	52.0	52.9
5/15	RW75-CON	16	112	53.0	47.8	46.0	53.2	50.0
6/12	RW75-CON	20	140	58.0	54.0	51.3	49.0	53.1
7/10	RW75-CON	24	168	50.0	51.0	55.2	50.7	51.7
8/7	RW75-CON	24	168	53.0	54.9	52.8	55.9	54.2

9/4	RW75-CON	32	224	50.0	61.3	58.9	65.5	58.9
10/2	RW75-CON	36	252	52.0	50.6	51.0	52.2	51.5
10/30	RW75-CON	40	280	53.0	54.0	54.0	55.0	54.0
11/27	RW75-CON	44	308					
12/24	RW75-CON	48	336					
1/23	RF75-CON[2]	0	0	57.8	57.8	57.8	57.8	57.8
2/20	RF75-CON	4	28	63.0	66.3	64.8	60.0	63.5
3/20	RF75-CON	8	56	60.8	62.0	58.0	61.0	60.5
4/17	RF75-CON	12	84	51.0	49.5	47.0	42.0	47.4
5/15	RF75-CON	16	112	50.2	48.0	50.8	47.2	49.1
6/12	RF75-CON	20	140	46.7	52.0	43.5	44.2	46.6
7/10	RF75-CON	24	168	44.0	41.8	47.0	46.8	44.9
8/7	RF75-CON	28	196	48.7	50.7	50.7	40.2	47.6
9/4	RF75-CON	32	224	43.8	42.5	38.1	38.0	40.6
10/2	RF75-CON	36	252	49.0	47.0	47.0	40.0	45.8
10/30	RF75-CON	40	280	48.7	50.0	49.3	47.3	48.8
11/27	RF75-CON	44	308					
12/24	RF75-CON	48	336					
1/23	M1-AW65-T[3]	0	0	65.0	65.0	65.0	65.0	65.0
2/20	M1-AW65-T	4	28	77.0	73.5	73.0	70.5	73.5
3/20	M1-AW65-T	8	56	67.5	59.6	65.0	62.8	63.7
4/17	M1-AW65-T	12	84	64.0	67.0	60.0	65.5	64.1
5/15	M1-AW65-T	16	112	66.0	64.0	61.3	63.0	63.6
6/12	M1-AW65-T	20	140	63.8	65.6	68.0	64.2	65.4
7/10	M1-AW65-T	24	168	63.8	55.6	56.6	62.7	59.7
8/7	M1-AW65-T	28	196	61.8	63.9	62.0	65.2	63.2
9/4	M1-AW65-T	32	224	61.8	59.0	66.3	56.1	60.8
10/2	M1-AW65-T	36	252	63.0	53.0	63.0	65.0	61.0
10/30	M1-AW65-T	40	280	59.0	55.5	55.0	54.5	56.0
11/27	M1-AW65-T	44	308	67.3	63.5	56.0	62.0	62.2
12/24	M1-AW65-T	48	336	55.0	56.0	56.5	57.5	56.3
1/23	M1-AF65-T[3]	0	0	58.4	58.4	58.4	58.4	58.4
7/10	M1-AF65-T	4	28	43.1	43.0	49.8	44.5	45.1
8/7	M1-AF65-T	8	56	38.1	36.8	42.1	49.2	41.6
9/4	M1-AF65-T	12	84	56.4	59.6	54.9	52.0	55.7
5/15	M1-AF65-T	16	112	40.4	43.0	40.0	47.0	42.6
6/12	M1-AF65-T	20	140	53.7	54.3	44.5	58.1	52.7
7/10	M1-AF65-T	24	168	43.1	43.0	49.8	44.5	45.1
8/7	M1-AF65-T	28	196					
9/4	M1-AF65-T	32	224	56.8	45.0	49.8	55.0	51.7
9/18	M1-AF65-T	34	238					
10/2	M1-AF65-T	36	252	37.0	40.9	40.0	31.9	37.5
10/30	M1-AF65-T	40	280					
11/27	M1-AF65-T	44	308	57.9	47.0	54.0	54.0	53.2
12/24	M1-AF65-T	48	336	41.0	44.0	35.0	35.2	38.8

1/23	M1-RW65-T[3]	0	0	60.9	60.9	60.9	60.9	60.9
2/20	M1-RW65-T	4	28	67.0	77.0	70.5	76.2	72.7
3/20	M1-RW65-T	8	56	61.0	63.6	64.0	60.0	62.2
9/4	M1-RW65-T	12	84					
5/15	M1-RW65-T	16	112	57.2	53.0	42.8	47.0	50.0
6/12	M1-RW65-T	20	140	46.0	40.0	32.0	34.1	38.0
7/10	M1-RW65-T	24	168	29.6	36.0	47.0	34.0	36.7
8/7	M1-RW65-T	28	196	29.6	36.0	47.0	34.0	36.7
9/4	M1-RW65-T	32	224	22.8	41.7	30.5	40.0	33.8
10/2	M1-RW65-T	36	252	33.1	35.5	21.7	23.0	28.3
10/30	M1-RW65-T	40	280	26.8	34.2	32.0	23.2	29.1
11/27	M1-RW65-T	44	308	33.0	22.0	39.5	25.8	30.1
12/24	M1-RW65-T	48	336	30.7	28.0	13.8	12.0	21.1
1/23	M1-RF65-T[3]	0	0	57.8	57.8	57.8	57.8	57.8
7/10	M1-RF65-T	4	28	70.0	72.0	73.0	68.0	70.8
8/7	M1-RF65-T	8	56	44.6	46.8	54.2	45.4	47.8
4/17	M1-RF65-T	12	84	37.0	47.0	43.0		42.3
5/15	M1-RF65-T	16	112	46.0	44.7	40.0	40.0	42.7
5/29	M1-RF65-T	18	126					
6/12	M1-RF65-T	20	140	35.9	44.2	37.9	35.5	38.4
7/10	M1-RF65-T	24	168	35.2	33.1	35.2	34.0	34.4
7/24	M1-RF65-T	26	182					
8/7	M1-RF65-T	28	196	38.9	39.4	40.3	18.8	34.4
8/21	M1-RF65-T	30	210	29.0	26.8	30.8	24.0	27.7
9/4	M1-RF65-T	32	224	28.2	20.8	28.8	26.1	26.0
9/18	M1-RF65-T	34	238					
10/2	M1-RF65-T	36	252					
10/30	M1-RF65-T	40	280					
11/27	M1-RF65-T	44	308					
12/24	M1-RF65-T	48	336					
1/23	M1-AW75-T	0	0	65.0	65.0	65.0	65.0	65.0
2/20	M1-AW75-T	4	28	77.0	74.0	78.0	81.0	77.5
3/20	M1-AW75-T	8	56	68.0	70.0	55.3	61.3	63.7
4/17	M1-AW75-T	12	84	55.0	62.0	59.0	63.5	59.9
5/15	M1-AW75-T	16	112	67.2	61.7	64.0	60.1	63.3
6/12	M1-AW75-T	20	140	65.0	66.8	67.9	69.0	67.2
7/10	M1-AW75-T	24	168	60.2	64.0	65.2	62.0	62.9
8/7	M1-AW75-T	28	196	57.6	62.0	61.2	58.2	59.8
9/4	M1-AW75-T	32	224	54.3	57.4	58.2	50.4	55.1
10/2	M1-AW75-T	36	252	54.0	55.3	57.0	64.0	57.6
10/30	M1-AW75-T	40	280	57.9	57.1	52.8	61.7	57.4
11/27	M1-AW75-T	44	308	48.6	61.7	53.0	60.3	55.9
12/24	M1-AW75-T	48	336	54.5	54.0	58.2	48.0	53.7
1/23	M1-AF75-T	0	0	58.4	58.4	58.4	58.4	58.4
2/20	M1-AF75-T	4	28	63.0	45.0	0.0	53.0	40.3
3/20	M1-AF75-T	8	56	60.0	46.9	43.0	46.6	49.1

4/17	M1-AF75-T	12	84	42.5	40.0	41.5	45.0	42.3
5/15	M1-AF75-T	16	112	51.0	52.7	55.1	50.9	52.4
5/29	M1-AF75-T	18	126					
6/12	M1-AF75-T	20	140	60.2	56.5	51.6	63.0	57.8
7/10	M1-AF75-T	24	168	53.0	57.1	57.0	52.0	54.8
8/7	M1-AF75-T	28	196	38.0	44.7	43.0	42.5	42.1
9/4	M1-AF75-T	32	224	60.0	49.0	52.7	56.7	54.6
10/2	M1-AF75-T	36	252	57.0	54.8	48.0	50.0	52.5
10/30	M1-AF75-T	40	280	36.2	42.3	39.0	39.5	39.3
11/27	M1-AF75-T	44	308	42.0	27.0	39.0	37.4	36.4
12/24	M1-AF75-T	48	336	42.8	39.6	40.0	38.2	40.2
1/23	M1-RW75-T	0	0	60.9	60.9	60.9	60.9	60.9
2/20	M1-RW75-T	4	28	60.0	61.5	65.0	55.0	60.4
3/20	M1-RW75-T	8	56	56.0	47.0	57.0	49.0	52.3
4/17	M1-RW75-T	12	84	36.0	28.5	30.0	23.0	29.4
5/15	M1-RW75-T	16	112	23.0	20.8	28.7	24.0	24.1
6/12	M1-RW75-T	20	140	6.0	11.4	10.6	3.9	8.0
7/10	M1-RW75-T	24	168	End				
1/23	M1-RF75-T	0	0	57.8	57.8	57.8	57.8	57.8
2/20	M1-RF75-T	4	28	59.0	56.0	55.0	49.0	54.8
3/20	M1-RF75-T	8	56	44.8	43.2	41.8	42.0	43.0
4/17	M1-RF75-T	12	84	24.0	24.0	23.0	28.0	24.8
5/15	M1-RF75-T	16	112	19.8	17.2	18.0	16.0	17.8
6/12	M1-RF75-T	20	140	4.5	13.5	11.0	4.8	8.5
7/10	M1-RF75-T	24	168	End				
1/23	M1-AW85-T	0	0	65.0	65.0	65.0	65.0	65.0
2/20	M1-AW85-T	4	28	59.0	54.0	56.0	47.0	54.0
3/20	M1-AW85-T	8	56	67.2	69.2	68.0	67.0	67.9
4/17	M1-AW85-T	12	84	60.0	57.0	58.0	53.0	57.0
5/15	M1-AW85-T	16	112	61.3	55.9	60.9	64.8	60.7
6/12	M1-AW85-T	20	140	58.1	55.7	45.8	40.0	49.9
7/17	M1-AW85-T	24	168	48.4	55.0	48.0	53.8	51.3
8/7	M1-AW85-T	28	196	38.0	44.7	43.0	42.5	42.1
9/4	M1-AW85-T	32	224	48.0	41.0	48.2	47.0	46.1
10/2	M1-AW85-T	36	252	42.0	49.0	41.8	50.0	45.7
10/30	M1-AW85-T	40	280	38.1	40.0	39.2	43.0	40.1
11/27	M1-AW85-T	44	308	30.8	42.7	35.0	43.0	37.9
12/24	M1-AW85-T	48	336	21.0	5.0	27.0	3.0	14.0
1/23	M1-AF85-T	0	0	58.4	58.4	58.4	58.4	58.4
7/10	M1-AF85-T	4	28	43.1	43.0	49.8	44.5	45.1
8/7	M1-AF85-T	8	56	38.0	44.1	43.0	42.5	41.9
4/17	M1-AF85-T	12	84	37.0	43.0	37.5	49.2	41.7
5/15	M1-AF85-T	16	112	48.5	50.0	44.0	41.0	45.9
6/12	M1-AF85-T	20	140	35.7	37.5	40.4	34.6	37.1
7/17	M1-AF85-T	24	168	38.8	48.8	39.8	39.8	41.8
8/7	M1-AF85-T	28	196	38.0	44.7	43.0	42.5	42.1

8/21	M1-AF85-T	30	210	44.6	42.3	48.3	42.8	44.5
9/4	M1-AF85-T	32	224	35.5	44.7			40.1
9/18	M1-AF85-T	34	238	30.0	32.8	31.6	36.0	32.6
10/2	M1-AF85-T	36	252	35.5	27.5	49.0	38.1	37.5
10/30	M1-AF85-T	40	280	24.6	35.8	24.4	27.3	28.0
11/27	M1-AF85-T	44	308	15.2	24.3	22.7	13.3	18.9
12/24	M1-AF85-T	48	336	34.0	9.1	19.7	11.4	18.6
1/23	M1-RW85-T	0	0	60.9	60.9	60.9	60.9	60.9
2/20	M1-RW85-T	4	28	0.0	65.0	71.0	72.0	52.0
3/20	M1-RW85-T	8	56	7.3	5.4	7.6	0.0	5.1
4/17	M1-RW85-T	12	84	End				
1/23	M1-RF85-T	0	0	57.8	57.8	57.8	57.8	57.8
6/19	M1-RF85-T	1	7	51.5	53.6	53.9	44.9	51.0
6/26	M1-RF85-T	2	14	37.5	34.5	41.5	41.0	38.6
7/3	M1-RF85-T	3	21	31.8	32.8	34.7	30.7	32.5
7/10	M1-RF85-T	4	28	23.5	21.3	27.6	30.8	25.8
7/17	M1-RF85-T	5	35	8.5	8.6	16.6	18.0	12.9
7/24	M1-RF85-T	6	42	15.4	14.0	11.0	11.0	12.9
7/31	M1-RF85-T	7	49	0.2		2.0	4.8	2.3
8/7	M1-RF85-T	8	56	End				
1/23	M1-AF95-T	0	0	58.4	58.4	58.4	58.4	58.4
6/19	M1-AF95-T	1	7	70.0	68.3	49.4	64.0	62.9
6/26	M1-AF95-T	2	14	67.1	64.9	53.4	62.0	61.9
7/3	M1-AF95-T	3	21	62.1	66.0	52.3	61.0	60.4
7/10	M1-AF95-T	4	28	57.1	46.5	49.0	42.3	48.7
7/17	M1-AF95-T	5	35	45.7	58.3	53.5	60.1	54.4
7/24	M1-AF95-T	6	42	47.2	57.3	54.1	45.8	51.1
7/31	M1-AF95-T	7	49	55.3	52.4	47.3	58.5	53.4
8/7	M1-AF95-T	8	56	49.8	51.0	37.0	55.1	48.2
8/14	M1-AF95-T	9	63	44.6	36.0	50.0	50.3	45.2
8/21	M1-AF95-T	10	70					
8/28	M1-AF95-T	11	77					
9/4	M1-AF95-T	12	84					
1/23	M1-RF95-T	0	0	57.8	57.8	57.8	57.8	57.8
6/19	M1-RF95-T	1	7	28.0	23.3	39.5	36.3	31.8
6/26	M1-RF95-T	2	14	12.5	13.6	17.3	29.5	18.2
7/3	M1-RF95-T	3	21	14.1	10.0	0.0	0.0	6.0
7/10	M1-RF95-T	4	28	End				

Notes:

1. "AW-CAL", "AF-CAL", "RW-CAL" and "RF-CAL" designate "acrylic warp calibration", "acrylic fill calibration", "rayon warp calibration", and "rayon fill calibration" stored at ambient conditions with the M1 propellant.
2. "AW75-CON", "AF75-CON", "RW75-CON" and "RF75-CON" designate "acrylic warp, 75°C, control", "acrylic fill, 75°C, control", "rayon warp, 75°C, control", "rayon fill, 75°C, control" temperature conditioned at 75°C without the M1 propellant.
3. "M1-AW65-T", "M1-AF65-T", "M1-RW65-T" and "M1-RF65-T" designate "acrylic warp, 65°C, test", "acrylic fill, 65°C, test", "rayon warp, 65°C, test", "rayon fill, 65°C, test" temperature conditioned at 65°C with the M1 propellant.

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