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Fiber-Tube Ammunition Container Improvement Study

J. B. Chesser

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

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Ammunition Logistics Program

FIBER-TUBE AMMUNITION CONTAINER IMPROVEMENT STUDY

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CONTENTS

LIST OF FIGURES

ABSTRACT

The U.S. Army is experiencing problems due to moisture absorption and permeation in the fiber-tube ammunition packaging currently used. Deterioration of ammunition caused by moisture and temperature has plagued the Army for many years. Swelling of fiber ammunition storage tubes makes it difficult for users to remove artillery rounds from their containers. Improvement or replacement of the fiber storage tubes would result in longer ammunition storage life and improved ease of use. Several new styles of containers were studied as possible replacement containers. After this initial study, a decision was made to investigate coating materials to improve fiber-tube performance. Four suitable coatings produced by various manufacturers were located; it is proposed that these coatings be tested to determine suitability. In addition, a method was developed to improve the storage tube neck seal and wall design. The proposed neck seal also has the capability to improve ease of use.

1. BACKGROUND

Deterioration of ammunition due to moisture and temperature has plagued the U.S. Army for many years. The problem is exacerbated in the pre-positioning ship environment, where many items became unserviceable within 1 year. The primary ammunition item affected in the pre-positioning ship environment was the 105-mm Howitzer ammunition. The propellant bags had degraded to a zero tensile strength. Tests conducted by the Product Assurance Directorate of Armament Research Development Engineering Center indicate that propellant bag deterioration can be reduced by moisture and storage temperature reductions. Pre-positioning ships have been modified for a temperature and humidity environment, correcting the problem at one location. However, the problem persists in other areas of the ammunition life cycle. Using a sealed container with nonmoisture-absorbing dunnage can significantly improve the life expectancy of ammunition life.

In addition to problems with storage life, end users have complained about the current fiber-tube ammunition packing containers. Users complained that the old 105-mm tank ammunition using fiber tubes packed inside wooden boxes made it difficult to remove end caps from the tubes. In 1986 users of 120-mm tank training ammunition complained that swollen fiber tubes were difficult to remove from end-opening wooden boxes. This swelling is the result of moisture absorption by the container.

Improvements in the current fiber-tube package will have two benefits: (1) improved storage life for the ammunition and (2) improved ease of use for the end user. This study surveyed methods to improve or replace the currently used fiber-tube ammunition container. An industry survey was made of packaging materials and coatings technology to develop a suitable replacement or improved package. The types of ammunition that will benefit from an improved container include 81-mm mortar rounds, hand grenades, and 120-mm mortars. Drawings of the current fiber tube for 81-mm mortar rounds are shown in Figs. 1 and 2.

A key factor in this study was identifying requirements for a replacement tube. The basic requirements for a replacement container are (1) low water permeability, (2) low water absorption, (3) ease of use, (4) ease of resealing, and (5) low cost (not more than $10). Any replacement package must meet Mil-Spec 1904, the basic specification for ammunition packaging. In order to prioritize the importance of competing requirements on packaging, an informal poll was taken to rate the requirements. The poll respondents were PM-AMMOLOG personnel, and the results are presented in Table 1.

This survey shows that the most important requirements are low cost, low water vapor permeability/absorption, and good shock attenuation characteristics. Although ease of use is not as important as the previously mentioned requirements, it is still a significant factor. It should be noted that any replacement container must be accepted by the user community.

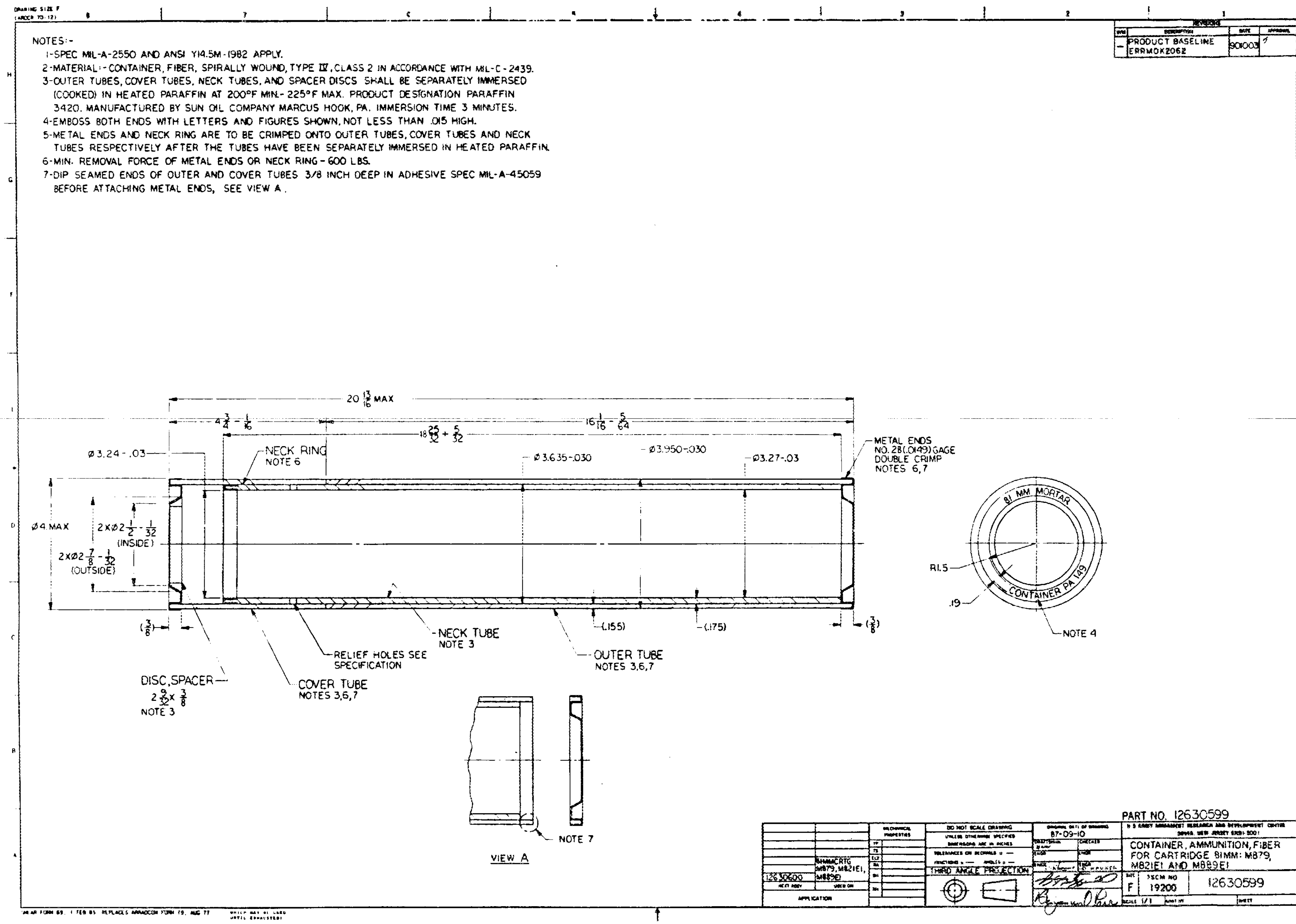
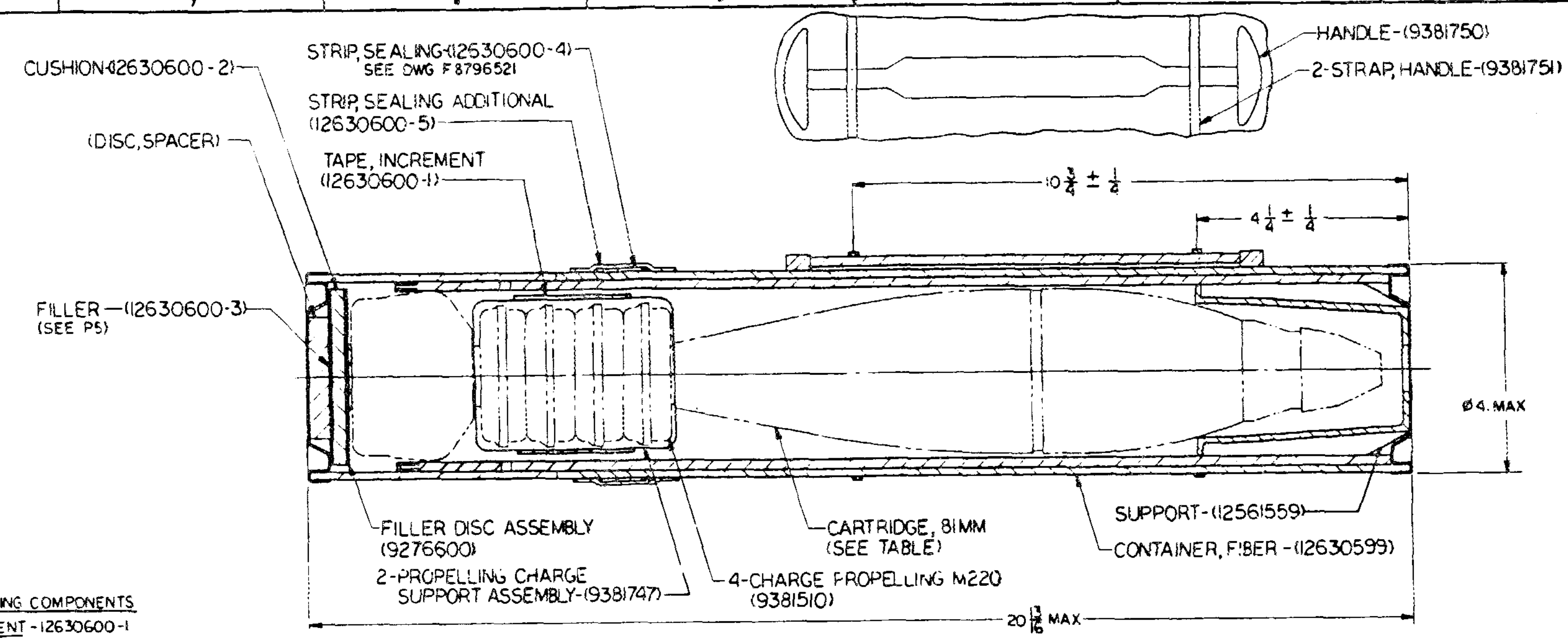


Fig. 1. Container, ammunition, and fiber for Cartridge 81MM: M879, M821E1, and M889E1.



PACKING COMPONENTS

TAPE, INCREMENT - 12630600-1
2. WIDE X 24. LONG ADVISORY
NOTE 6
CUSHION - 12630600-2
3 3/8 DIA X .250±.025 THICK
NOTE 3
FILLER - 12630600-3
3 3/8 DIA X 1/16 THICK
NOTE 2,4
STRIP, SEALING - 12630600-4
1. WIDE X 17. LONG ADVISORY
NOTE 7
STRIP, SEALING ADDITIONAL - 12630600-5
2. WIDE X 22. LONG ADVISORY
NOTE 6

CONTAINER, AMMUNITION, FIBER, PA 149, FOR CARTRIDGE 81MM: M879, M821E1 AND M889E1 - 12630599
SUPPORT - 12561559
FILLER DISC ASSEMBLY - 9276600
2-STRAP, HANDLE - 9381751
HANDLE - 9381750
2-PROPELLING CHARGE SUPPORT ASSEMBLY - 9381747
LABEL, PROPELLANT CHARGE SUPPORT - 12910091

PACKING INSTRUCTIONS

P1-PLACE PROPELLING CHARGES(9381510) ONTO CARTRIDGE, 81MM (SEE TABLE) THEN PLACE PROPELLING CHARGE SUPPORT ASSEMBLIES(9381747)OVER PROPELLING CHARGES
P2-TAPE PROPELLING CHARGE SUPPORT ASSEMBLIES(9381747)WITH INCREMENT TAPE(12630600-1)CENTRALLY LOCATED AS SHOWN. TAPE TO HAVE APPROXIMATELY 1. INCH TAB AT END. NO GAPS ARE PERMITTED BETWEEN PROPELLING CHARGE SUPPORT ASSEMBLIES.
P3-APPLY LABEL, PROPELLANT CHARGE SUPPORT 12910091 SUCH THAT TAB ON END OF INCREMENT TAPE 12630600-1 IS NOT COVERED.
P4-SLIDE SUPPORT (12561559) DOWN NECK TUBE OF FIBER CONTAINER (12630599) AS SHOWN.
P5-PACK CARTRIDGE/FUZE AS SHOWN, ADD FILLER (12630600-3) BETWEEN CUSHION (12630600-2) AND SPACER DISC AS REQUIRED FOR TIGHT PACKING.
P6-CLOSE AND SEAL CONTAINER WITH SEALING STRIP (12630600-4) IN ACCORDANCE WITH DRAWING 8796521. NO TAB IS REQUIRED FOR SEALING STRIP.
P7-APPLY SEALING STRIP ADDITIONAL (12630600-5) CENTERED OVER SEALING STRIP (12630600-4) AND IN SAME DIRECTION AS SEALING STRIP, LEAVING A 1. INCH TAB.
P8-PLACE HANDLE (9381750) AND 2 STRAP HANDLES (9381751) AS SHOWN, NOTE 5.
APPLY STRAP HANDLES WITH CABLE TIE TOOL, SET TOOL TENSION TO THE VENDOR'S SPECIFIED VALUE FOR STRAP HANDLE WIDTH.

MARKING INSTRUCTIONS

M1-MARK CONTAINER IN ACCORDANCE WITH DRAWING 8796521.
M2-FOR ITEM IDENTIFICATION MARKING, SEE TABLE.

LINE NO.	DESCRIPTIVE NOMENCLATURE	PART NUMBER	NSN	DODIC
1	CARTRIDGE, 81MM: HE M821E1 W/FUZE MO M734 FOR MORTARS M252 AND M29	12630535	1315-01-285-6416	C868
2	CARTRIDGE, 81MM: HE M889E1 W/FUZE PD M935 FOR MORTARS M252 AND M29	12630672	1315-01-286-1385	C869
3	CARTRIDGE, 81MM: PRACTICE M879 W/FUZE M751 FOR MORTARS M252 AND M29	9310340	1315-01-200-4223	C875

NOTES:-
1-SPEC MIL-A-2550 AND ANSI Y14.5M-1982 APPLY.
2-AS REQUIRED.
3-MATERIAL:-PADDING MATERIAL, RESILIENT, TYPE I OR II, MIL-P-13607.
4-MATERIAL:-COMMERCIAL CHIPBOARD, DWG 9272315.
5-TO BE APPLIED AFTER CONTAINER IS MARKED.
6-MATERIAL:-TAPE, COLOR OLIVE DRAB, SPEC A-A-1586.
7-MATERIAL:-TAPE, TYPE I, MIL-T-43036.

REFERENCE DATA

FOR CARTRIDGE 81MM: HE, M821E1 W/FUZE MO M734, SEE DWG 12630535
AND 81MM: HE, M889E1 W/FUZE PD M935, SEE DWG 12630672
AND 81MM: PRACTICE M879 W/FUZE M751, SEE DWG 9310340

PART NO. 12630600

PACKING AND MARKING FOR CNTNR, PA149, AMMUNITION FIBER FOR CARTRIDGE, 81MM: M821E1, M889E1 AND M879

87-09-10 | THIRD ANGLE PROJECTION | F | 19200 | 12630600

Fig. 2. Packaging and marking for container PA149; ammunition fiber for Cartridge 81MM: M821E1, M889E1, and M879.

Table 1. Relative importance of ammunition packing tube requirements as rated by PM-AMMOLOG staff[a]

Low cost	19
Easily resealable after opening	15
Low flammability	10
Ease of use	16
Low weight	13
Good shock attenuation characteristics	17
Low water vapor permeability/absorption	19
Low fume toxicity upon burning	12
Stackability	9

[a]Scale is from 0 to 20, with 20 being the most important.

2. INITIAL RESEARCH

Research into alternative ammunition container designs was initiated with the background information discussed in Sect. 1. Consideration was given to how water entered the containers, and three possible routes for water entry were identified. There were some container configurations and material initially considered but then rejected. These configurations are briefly described in Sect. 2.2. Two avenues were considered as possible development paths–plastic containers and coated fiber containers. It should be noted that only changes to the current fiber-tube ammunition container were considered; changes to the current practice of placing the shell package inside an overpack were not considered.

2.1 MECHANISMS FOR WATER ENTRY INTO PACKAGE

Before contemplating any changes to ammunition containers, a starting point is needed to determine the possible routes of water vapor entry into the container. Examination of the container and discussions with technical staff at Oak Ridge National Laboratory (ORNL) revealed three possible routes of water entry into the container: (1) permeation directly through the container wall, (2) permeation through the neck seal, and (3) wicking through the end-cap seal. These mechanisms for water entry are sketched in Fig. 3. A new container design must address these mechanisms for water entry.

Permeation directly through the container wall is judged to be the least likely method for water entry. The aluminum foil used in the wall construction of the containers is an excellent vapor barrier (see Figs. 4 and 5 for current tube wall construction). To enter the tube, water would have to penetrate the foil barrier. The more likely routes for water entry are through the neck seal and the end caps. At the taped neck joints and the crimped end caps there may be microscopic openings in which water could be drawn by capillary action. The fiber tubes are dipped in paraffin prior to container assembly to minimize water absorption by the fiber tube. Although paraffin is a good vapor barrier, it is sensitive to abrasion. If the paraffin does not thoroughly coat the tube at the end cap and neck closure areas, then water can be easily drawn into the cardboard fiber, increasing its water content. After prolonged temperature and humidity cycling, this water can be released into the container interior. The relative importance of these mechanisms with respect to each other cannot be quantified without experimental work.

2.2 PACKAGING OPTIONS EVALUATED AND REJECTED

Several designs were initially considered and rejected from consideration. These designs are briefly described, along with their reason for rejection. These ideas were not developed in detail.

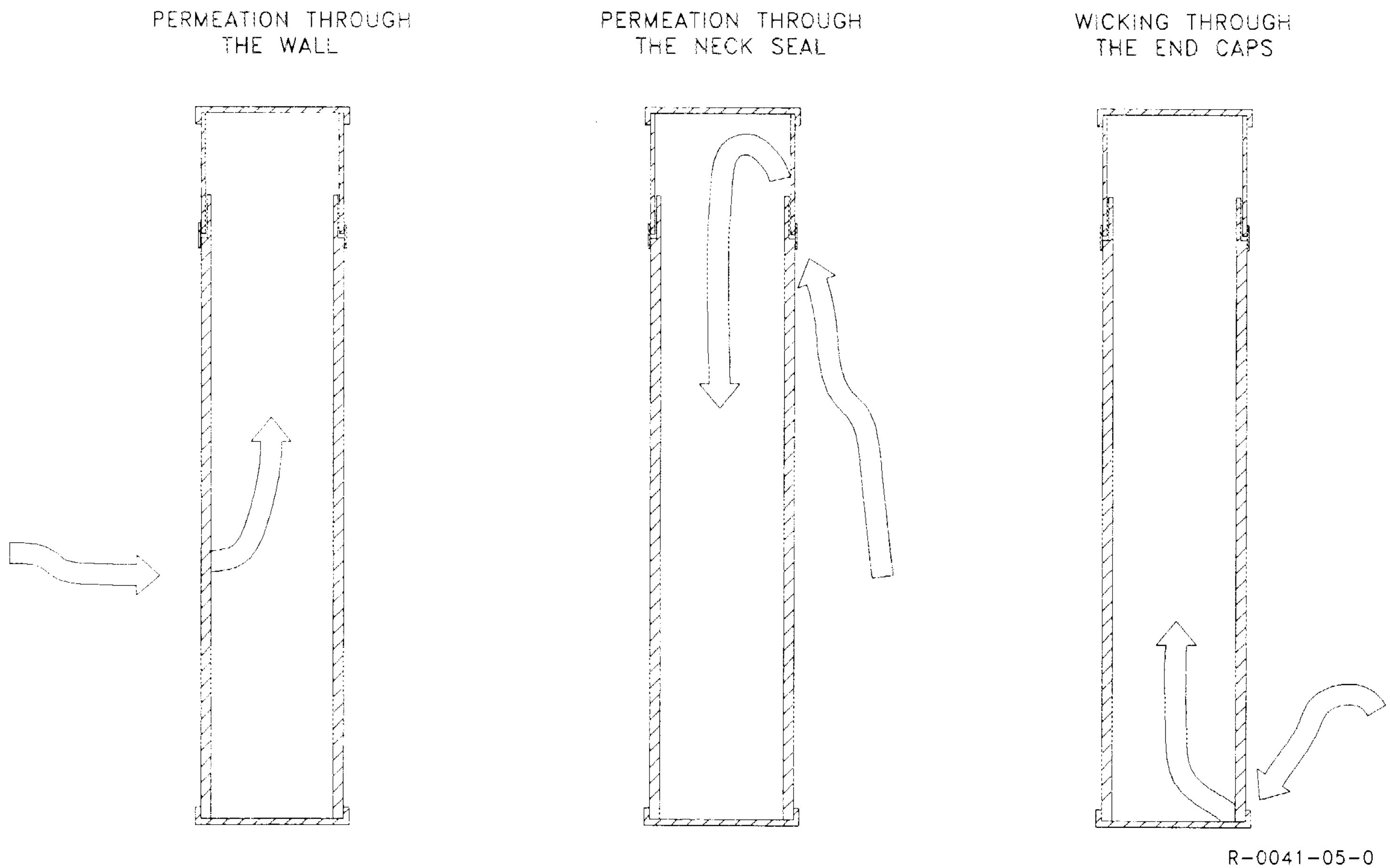
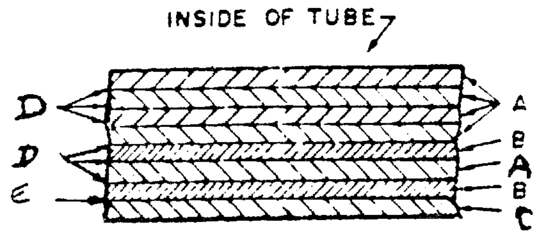


Fig. 3. Possible mechanisms for water vapor entry into fiber-tube container.

MIL-C-2439E

CONSTRUCTION OF OUTER AND COVER TUBES

TYPE IV



A - Ammunition container board, specification MIL-B-20390, as required to provide specified diameter. Use one or more layers of paper of equal or better grade with minimum thickness of .007" to obtain specified diameter.

B - Aluminum foil, specification QQ-A-1876, 0.001" thick. Foil may be partially annealed temper with maximum bursting strength of 45 psi. Lap of foil to be not less than ¼.

C - 7 point lusterless black kraft. Lap shall not be less than 5/16".

D - Glue specification MMM-A-100 (see note F)

E - Polyvinyl acetate adhesive, product no. 53-1430, supplied by United Resin Products Inc., Brooklyn, NY or equivalent.

F - Alternative Adhesive - neoprene latex base adhesive or polyvinyl acetate adhesive meeting requirements of specification MIL-A-45059.

G - Resin is applied to all the outer surfaces of the tubes.

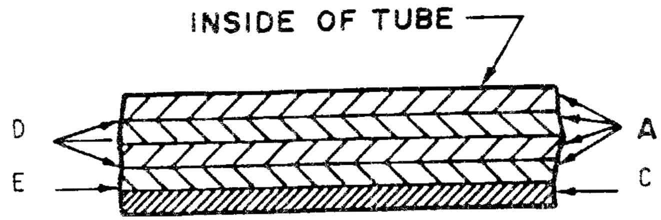
Fig. 4. Construction of outer and cover tubes (copied from MIL-C-2439E).

MIL-C-2439E

CONSTRUCTION OF NECK TUBES

FOR

TYPE IV CONTAINERS



A - Ammunition container board, specification MIL-B-20390, as required to provide specified diameter. Use one or more layers of paper of equal or better grade with minimum thickness of .007" to obtain specified diameter.

C - 7 point lusterless black kraft. Lap shall not be less than 5/16".

D - Glue specification MMM-A-100 (see note F)

E - Polyvinyl acetate adhesive, product no. 53-1430, supplied by United Resin Products, Inc., Brooklyn, NY or equivalent.

F - Alternative Adhesive - neoprene latex base adhesive or polyvinyl acetate adhesive meeting requirements of specification MIL-A-45059.

G - Resin is applied to all the outer surfaces of the tubes.

Fig. 5. Construction of neck tubes (copied from MIL-C-2439E).

1. Fiber tube with inner plastic sleeve: A plastic sleeve is placed inside the outer fiber tube. The upper cap is also fitted with a plastic sleeve designed to seal into the other sleeve. These sleeves serve as a vapor barrier. While this solution addresses vapor entry into the container interior, it does not prevent swelling by the outer fiber tube.

2. Metal tube: The entire container is fabricated of metal, and an inner foam sleeve is placed in the container for shock absorption. For low-cost ammunition, fabricating a metal container is cost prohibitive. A rough estimate is that the container should cost from 5 to 10% of the cost of the ammunition round.

3. Fiber tube with polyurethane coating: The current paraffin coating on the ammunition tube is replaced with a polyurethane coating. There are technical problems with using polyurethane as a coating material. Research conducted at ORNL indicates that it is not resistant to abrasion. Discussions with technical staff at David Taylor Naval Research Center indicate that flammability could also be a concern. The concept of alternative coatings is not rejected; simply the use of polyurethane as coating material.

4. Plastic tube with deposited metal coating: A plastic container is coated with a layer of metal to improve the permeability characteristics of the plastic. Two problems with this approach are (1) the design of an acceptable plastic container and (2) the cost of metal coatings.

2.3 PACKAGING OPTIONS SUBMITTED FOR INITIAL REVIEW

Four different container configurations were submitted for initial review by PM-AMMOLOG staff in March 1991. Plastic containers and coated fiber containers were considered as possible development paths. These containers are briefly described in the following sections. None of these designs were selected for further development; however, they were a useful starting point for discussion and for better determining the needs of the Army.

2.3.1 Fiber Tube With Inner Vapor-Barrier Bag

The basic container is left unchanged from the current design, and the shell is enclosed in a vapor-barrier bag to protect the shell. Aluminized, heat-sealable vapor-barrier bags for the 81-mm mortar will cost $1.50 when purchased in large quantities. The paraffin-dip coating for the container is replaced with an epoxy coating, and the tube wall construction is changed from the current design to minimize moisture transfer through the wall. The coating and tube wall changes are made to minimize tube swelling (see Fig. 6). The advantages of this concept are (1) low development cost and (2) complete protection of the shell. The disadvantages are (1) the container is not easily used–a heat sealer is needed to close the bags after depot inspection and (2) the bag must be removed before using the round in the field.

2.3.2 Fiber Tube With Gasketed Plastic End Caps

A variant of the current fiber tube is shown in Fig. 7. The container is a spirally wound fiber tube fitted with plastic end caps. The tube wall construction is changed from the current design to minimize moisture transfer through the wall. The cut tube ends are sealed to prevent moisture entry into the tube wall, and the removable end cap is gasketed to prevent moisture entry into the container interior. If desired, the inner container wall can be treated with vapor corrosion inhibitors. A key advantage of this concept is incorporation of a gasketed seal. The primary

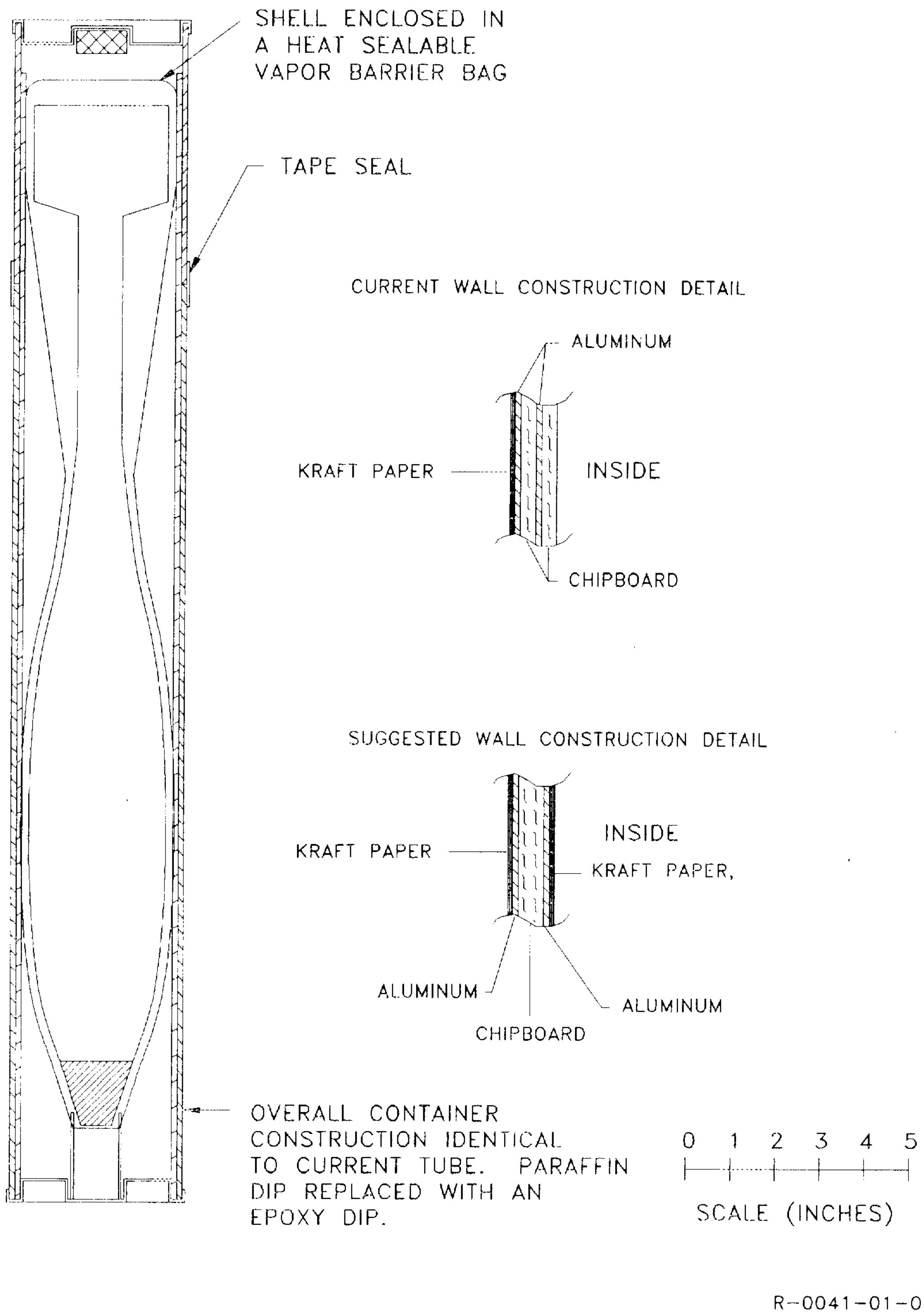


Fig. 6. Fiber tube with inner vapor-barrier bag.

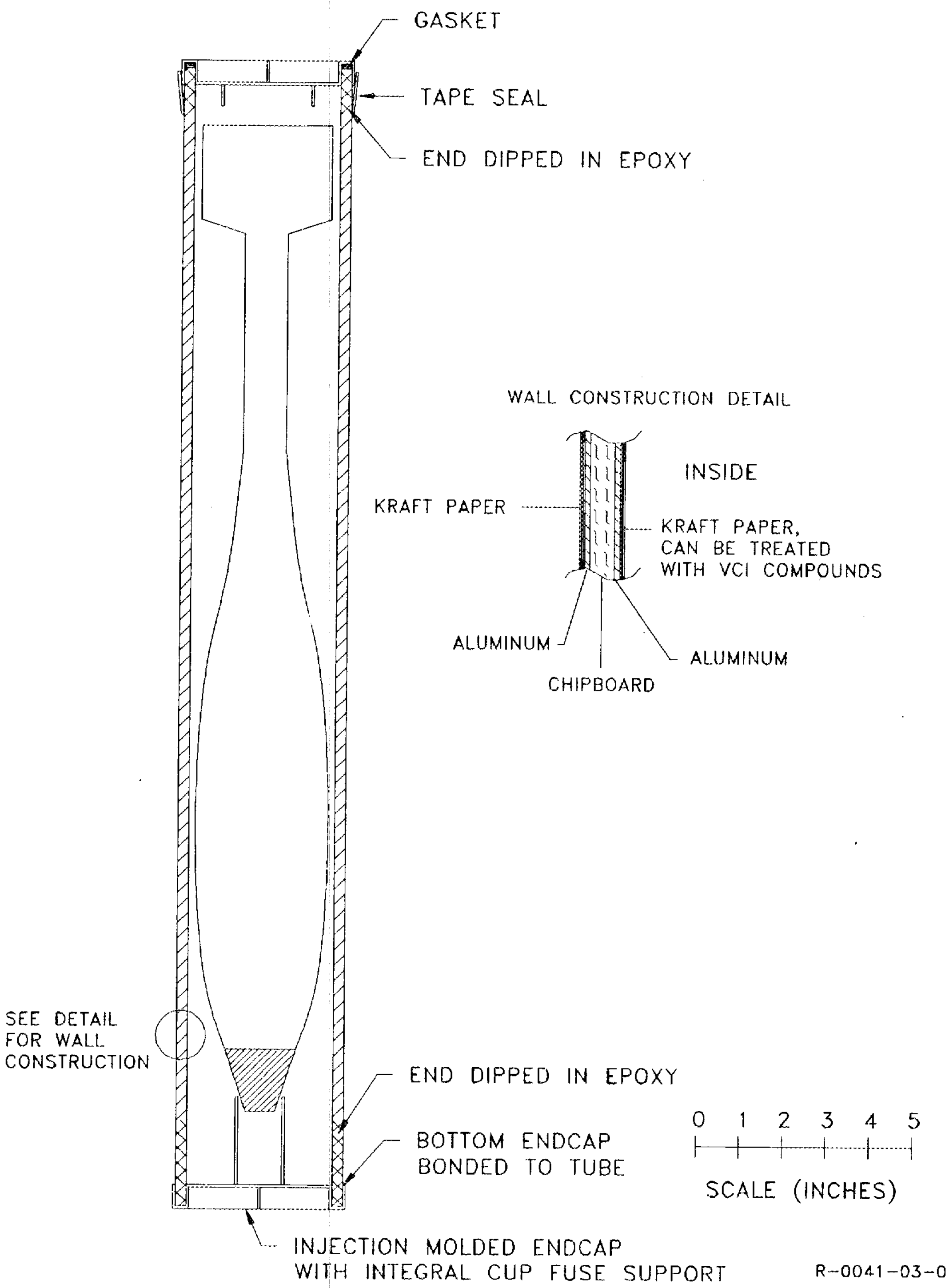


Fig. 7. Fiber tube with gasketed plastic end caps.

disadvantage is potential difficulty in removing the round from the container. In addition, plastic end caps would require considerable testing before acceptance.

2.3.3 Fiberglass Pultrusion Tube With Gasketed Plastic End Caps

The fiber tube used in the previous concept is replaced with a pultruded fiberglass tube, as shown in Fig. 8. An inner, closed-cell foam liner is placed in the tube for shock absorption. In large quantities, a complete container would cost ~$15. The advantages of fiberglass are wide working–a temperature range and mechanical properties that can be adjusted by changing the manufacturing process. Disadvantages of fiberglass are potential difficulty in removing the round from the container, high cost, and considerable development required for an all-plastic container.

2.3.4 Blow-Molded Plastic Tube

Plastic-molded containers had been previously evaluated by the Army. However, a concept for a blow-molded tube was submitted for discussion, as illustrated in Fig. 9. The key advantage of plastic molding is the ease of incorporating features such as gaskets or stiffening ribs into the tube. Unfortunately, testing of plastic-molded tubes has revealed several problems: stress cracking, poor dimensional stability, and poor low-temperature mechanical properties.

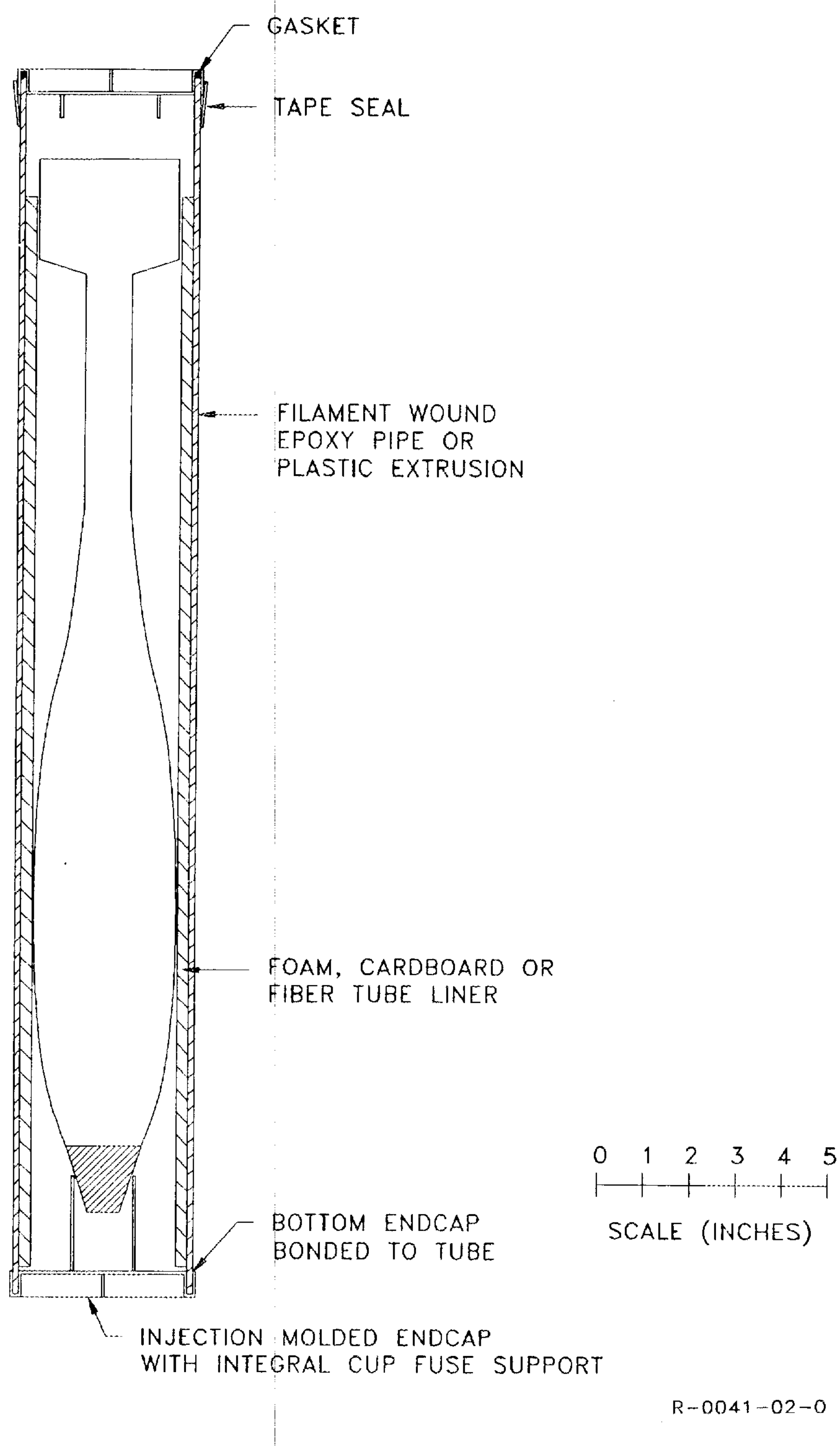


Fig. 8. Fiberglass pultrusion tube with gasketed plastic end caps.

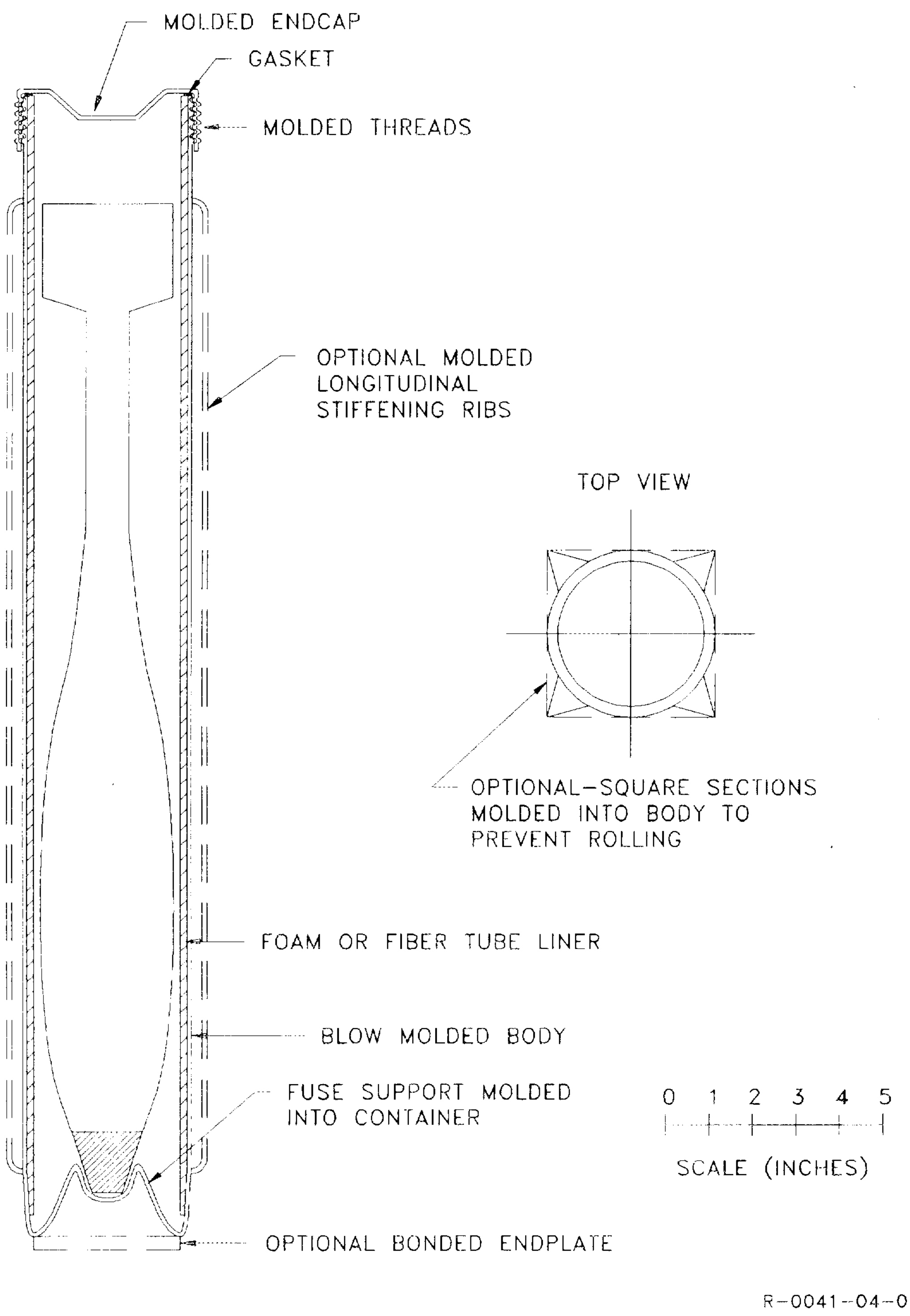


Fig. 9. Blow-molded plastic tube.

3. CONCEPTS FOR CONTAINER PERFORMANCE IMPROVEMENT

After a project review meeting with PM-AMMOLOG staff, it was decided to pursue improving the current fiber-tube container, emphasizing paper coatings and treatments. The new container will be an incremental improvement over the old container, reducing the time needed to introduce a new container into field use. Incremental improvement also has the advantage of being a lower risk approach; the new container is based on the currently used container. Plastic containers have been evaluated in a separate effort and were deemed unsuitable for ammunition packaging (report PMAL01, "U.S. Army Report to the Congress on the Evaluation of Plastic Containers for 81-mm Mortar Ammunition").

Three means of improving fiber-tube container performance with regard to water entry are presented in the following sections. Possible modifications to the fiber-tube ammunition containers are neck seal improvements, wall construction changes, and new container coatings. It is not necessary to introduce all the modifications simultaneously. Any of these modifications should individually produce an incremental improvement in container performance. Again, it should be emphasized that modifications to the current practice of placing the shell package inside an overpack were not considered.

3.1 NECK SEAL IMPROVEMENTS

As noted earlier, one of the mechanisms for water entry is through the neck closure. Reducing container permeability will likely be ineffective if permeation through the neck closure is not addressed. Even if the container body is totally impervious, as with a metal container, the neck closure remains a weak point for water vapor entry. As the path chosen for container development is to improve fiber-tube containers, there is a limited number of options that are applicable for improving the neck-closure seal. Gasketed seals and screw-top closures are not practical for fiber tubes.

A simple solution has been devised to improve the neck seal. The tape seal is overcoated with the tube coating material after the ammunition round is loaded into the canister. This overcoating will create a completely sealed package. A pull tab is placed under the adhesive tape with one free end left hanging to allow easy breakage of the neck seal, much like the pull tabs on consumer product packages. When depot inspection of the round is required, the container is opened, the tape seal is reapplied after inspection, and new coating material is sprayed over the tape seal. Two types of pull tabs (a cord and a thin plastic tape) were tested on an actual container. Using plastic tape as a pull tab produced a better seal. Containers with both cord and tape pull tabs are shown in Fig. 10. The opening of a container with the suggested neck seal is shown in Fig. 11. The pull tab closure required to break the neck seal can also improve ease of opening when the operator wears arctic mittens or an NBC suit.

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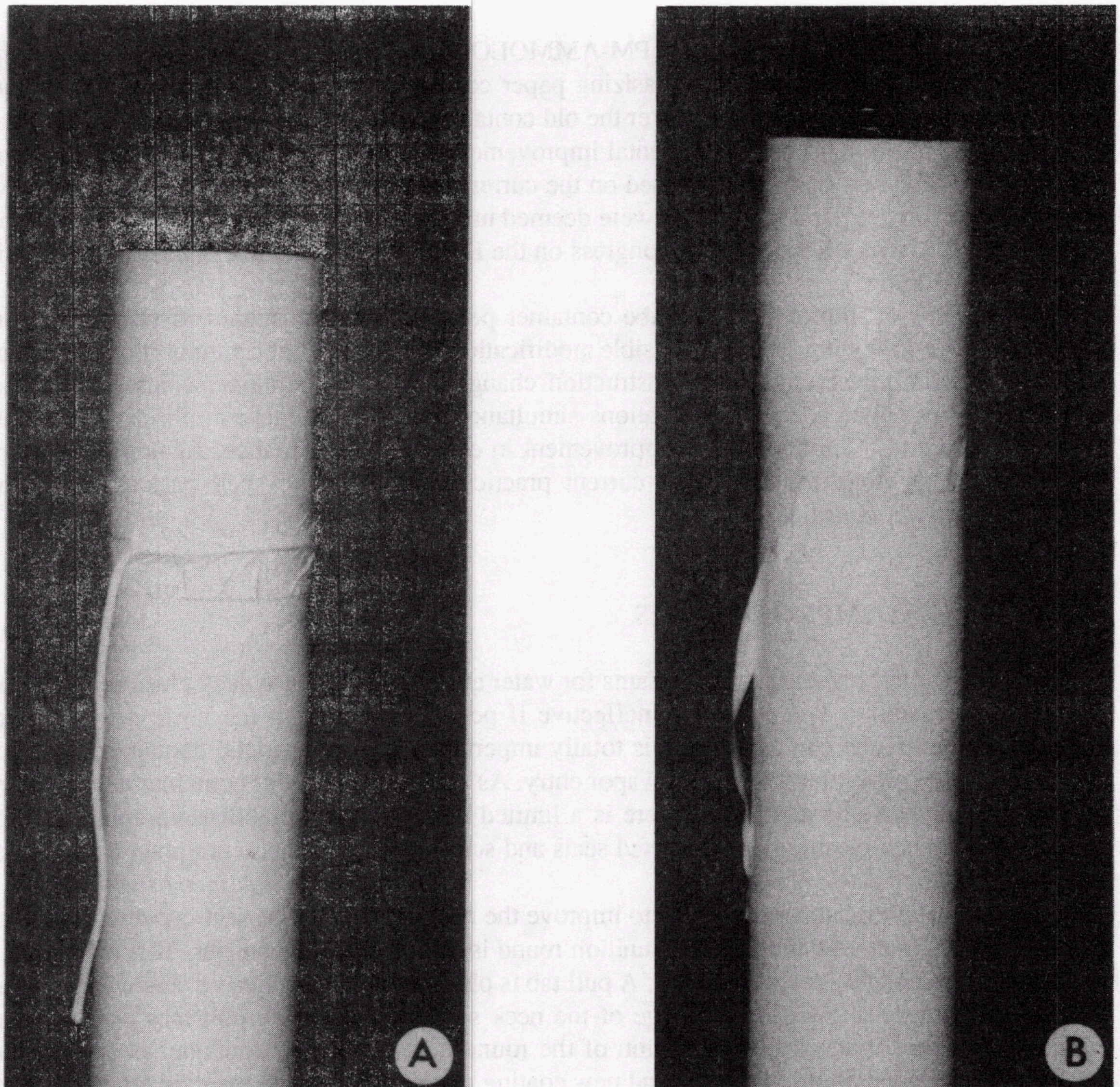

Fig. 10. Containers with sealed neck closure: (a) Container with cord pull tab and (b) container with tape pull tab.

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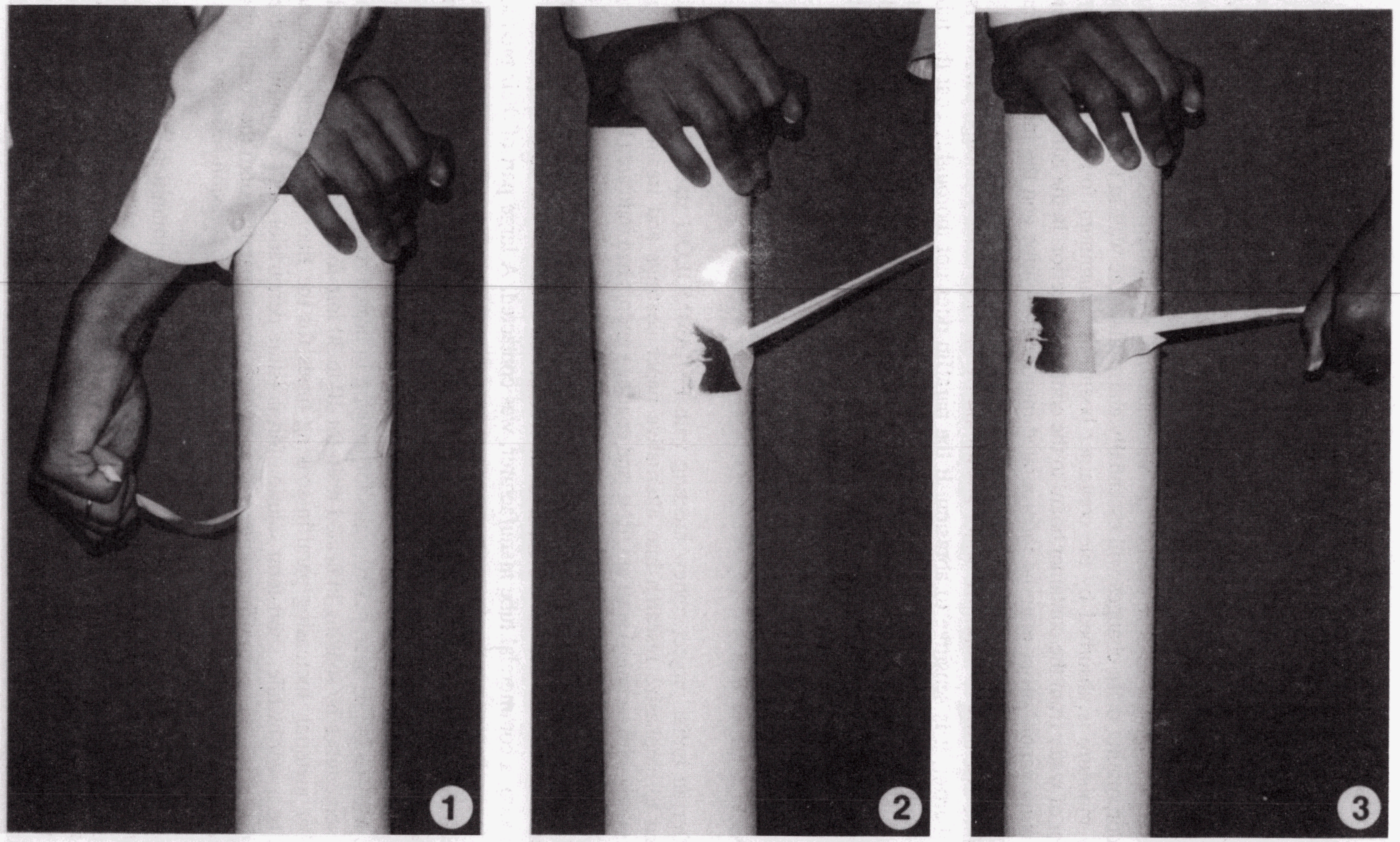

Fig. 11. Opening a container with the sealed neck closure. Notice the uncoated tape after the seal is broken in Steps 2 and 3.

3.2. CONTAINER WALL CONSTRUCTION CHANGES

Although the primary path of moisture entry is not likely by permeation through the wall, some changes could be made to the tube wall to improve tube performance. The current wall construction of spirally wound fiber ammunition containers is shown in Figs. 4 and 5 (excerpted from MIL-C-2439E, "Military Specification: Container, Ammunition, Fiber, Spirally Wound"). These figures show the construction details of the outer tubes and the neck tubes respectively. The suggested wall construction for both outer tubes and neck tubes is shown in Fig. 12. The suggested change involves relocating the aluminum foil vapor barriers in the wall construction.

Incorporating these changes will essentially encapsulate the wall in a layer of aluminum foil. If any moisture is absorbed by the container board, the aluminum foil barrier will hinder the transfer of water from the container board to the container interior. In the current container design, there is no vapor-barrier material incorporated into the neck tube and the innermost four layers of the outer tube do not have a vapor barrier. The fiber tubes are dipped in paraffin prior to container assembly to minimize water absorption by the fiber tube. Although paraffin is a good vapor barrier, it is sensitive to abrasion. If the paraffin does not thoroughly coat the tube at the end cap and the neck closure areas, then water can be easily drawn into the cardboard fiber, increasing its water content. Upon temperature and humidity cycling, water absorbed by the container board can be released into the container interior. Changing the placement of the aluminum foil vapor barriers can hinder the transfer of water into the container.

3.3 NEW COATINGS

After an initial project review meeting with PM-AMMOLOG staff in March 1991, it was decided to emphasize research into alternative paper coatings and treatments for fiber tubes. Discussions with technical staff at ORNL and coating vendors had indicated that although paraffin is a good vapor-barrier material, it is easily damaged. The essential requirements for a replacement vapor-barrier material are low cost, low flammability, and resistance to environmental conditions. The coating material will be subjected to environmental extremes and abrasion.

Sonoco, a commercial tube manufacturer, was contacted. A large part of their product line is tubes for packaging applications. One paper treatment used in their products is urea formaldehyde (phenolic) impregnation of the fiber tube. This technique is not applicable for ammunition shipment containers because it embrittles the tubes. Another technique used by Sonoco that is potentially valuable for ammunition packaging is paraffin soaking. The specification for fiber tubes, MIL-C-2439E Sect. 4.5.10, calls for soaking in heated resin for 3 min. Sonoco, however, treats some tubes by soaking in heated resin for 10 to 30 min to ensure thorough penetration into the fiber material. Increasing paraffin soaking times for the fiber ammunition container tubes might be a worthwhile, short-term solution for moisture penetration into ammunition containers. Georgia-Pacific has a paraffin coating process which sprays paraffin onto the container exterior, producing a water-resistant coating. This coating, however, is not abrasion-resistant so this process is not applicable for fiber ammunition containers.

Four different candidate coatings were located for the ammunition containers. They are manufactured by Rabco (distributed by L&C Associates), Pfizer, Ocean Coatings, and Lummus Pyrotech. All of these coatings have been accepted for use in military applications, although none have been specifically used for ammunition packaging. Rabco and Lummus Pyrotech coatings have been test-applied to containers. Another coating (paralyne) that has good vapor-barrier properties was also located. Its cost of ~$40 per container, however, makes it prohibitive for use on fiber ammunition containers.

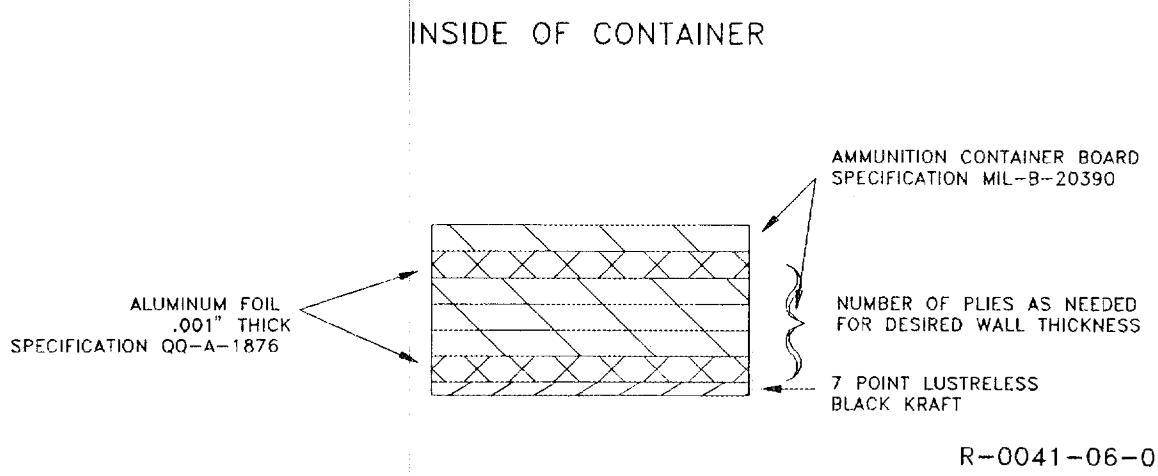

Fig. 12. Suggested wall construction detail.

Coatings can be applied either to the container's exterior alone or to both the interior and exterior of the container. To minimize container swelling caused by water absorption, the container should be coated on both the interior and exterior. The coating should be applied after container assembly to ensure sealing of any gaps around the end caps. Any small gaps can result in water being drawn into the container by capillary action. One problem with coating entire containers is that the clearance between the container body and the cap is altered. This dimensional change was observed in the container coated at ORNL with the Lummus Pyrotech coating. After the coating application, the cap was very difficult to install and remove. An interference fit was caused by the coating layers between the cap and body of the container. If the selected approach is to apply coating material to the entire container, the clearance between the cap and the tube body will have to be modified.

The various vapor-barrier coatings are summarized in Table 2. The information on ingredients is based on data from "Material Safety Data Sheets" and discussions with vendors. Due to the proprietary nature of the ingredient mixture, none of the manufacturers provide full information on the ingredients. The Ocean Coatings product listed below requires an overcoat for weather resistance. Full information on the Pfizer product has not yet been received.

Table 2. Vapor-barrier coatings

Coating manufacturer	Coating	Ingredients	Coverage	Cost ($/gal)
Lummus Pyrotech	Pyroplus ITM	PVDC	224 ft^2/gal 3- to 5-mil dry film thickness	50
Rabco	Protective Sealant System (Cocoon 501)	Vinyl resins Acetone Toluene	413 ft^2/gal @ 1 mil thick	26
Ocean Coatings	Ocean 1001 Vapor Barrier	Vinylidene chloride Ethylene glycol Diethylene glycol	100 ft^2/gal 5 to 6-mil dry film thickness	23
Pfizer	[a]	Polysulfide epoxy	[a]	[a]

[a]Detailed information on the Pfizer coating has not yet been received.

4. CONCLUSIONS AND FINAL RECOMMENDATIONS

The Army is experiencing problems due to moisture absorption and permeation in the fiber-tube ammunition packaging currently used. Deterioration of ammunition caused by moisture and temperature has plagued the Army for many years. Swelling of fiber ammunition storage tubes makes it difficult for users to remove artillery rounds from their containers. Improvement or replacement of the fiber storage tubes would result in longer ammunition storage life and improved ease of use. Several new styles of containers were initially studied as possible replacement containers. After this initial study, a project review meeting was held between PM-AMMOLOG and ORNL. A decision was made to investigate means of improving the currently used, spirally wound fiber ammunition containers.

The majority of effort was spent locating coating materials to improve fiber-tube performance. Four suitable coatings produced by various manufacturers were located. Also, possible methods of improving the storage tube neck seal and wall design were developed. The proposed neck seal also has the potential of improving ease of use.

At this point, actual container testing is needed and it is proposed that entire containers be tested. A test plan for environmental testing is included in Appendix A. This test plan will compare the moisture resistance of containers with the sample coatings. Performance testing of the new neck seal can also be incorporated into this test. The main goal of the initial testing is to reduce the number of candidate coatings. Experimental design and data analysis are addressed in Appendix B. Following environmental testing, flammability testing should be conducted to verify that the new coatings do not increase the fire hazard as compared to the currently used container. A limited number of containers should also be drop tested to verify that the solvents used in the different coatings do not damage the container fibers, thereby reducing their strength. Solvents have the potential of degrading cellulose-based fibers. The manufacturers of each of the coatings presented did not believe that this would be a problem; however, this idea should be verified.

Testing of coupons for water absorption is not recommended in lieu of testing entire containers for water permeability. The problem of water entry into shipping containers is due to the design of the entire container. Coupon testing could address only water permeation in the container wall. It could not address the effect of the neck seal and end caps.

Three methods of improving container performance have been proposed. The possible modifications are new coatings, a better neck seal, and improvements to the wall construction. These changes could be introduced incrementally. Each change could be introduced independently of the others; however, for best performance all changes would be incorporated into a new container design.

The candidate coatings do not significantly raise the container price. For the 81-mm mortar shell container, coating it on the inside and outside with one of the selected coatings will raise the price ~\$2 per container. If the current neck tape seal is left unchanged, there will be no impact on resealability as compared to the current design. With the recommended neck seal design, slight changes in procedure will have to be made if neck seal integrity is to be maintained after opening and closing the container. None of the suggested changes should have an effect on shock attenuation of the container. It is anticipated that a container incorporating the suggested changes would meet the requirements listed in Table 1.

APPENDIX A
TEST PLAN FOR COMPARATIVE TESTING OF NEW FIBER-TUBE AMMUNITION CONTAINER DESIGNS FOR RESISTANCE TO MOISTURE ENTRY

A.1. BACKGROUND

The U.S. Army currently packs certain rounds of ammunition (e.g., the 81-mm mortar round) in fiber containers. These containers, however, are not entirely satisfactory. The current containers have problems with water permeation and absorption, which lead to several other problems: the tube swells (making it difficult to remove a round), the metals in the shell corrode, and the explosive stabilizers deteriorate. The Army wants to develop a new container that will minimize moisture penetration.

A.2. PURPOSE

This test plan was developed to compare testing of ammunition containers based on paper products (i.e., variants of the current fiber-tube container). In order to ensure test repeatability, this test plan is based on American Society of Testing and Materials (ASTM) standards for testing paper products and packaging. Actual service conditions are not simulated in the testing outlined here. The goal of this test plan is to allow qualitative comparison of moisture absorption and permeability of different containers. Determining moisture transport mechanisms will not be possible from the tests presented here. Based on the results of the tests outlined in Sect. A.5, container designs will be either selected for future development or dropped from further consideration.

A.3. DEFINITIONS SPECIFIC TO THIS TEST

1. Sample—a specified number of containers selected to represent containers of a single type or design.

2. Test specimen—a container or a portion of a container upon which a test is to be made.

A.4. TEST SAMPLES

These tests will be repeated both on samples of the current ammunition containers and on samples of the new containers. New container designs could consist of new coatings, containers with new wall construction, or different fabrication methods. The sample size will determine the validity of the tests. A larger sample size would improve confidence in the results, while a reasonable sample size would be ~10 test specimens (i.e., containers).

A.5. PROCEDURES

The test procedures are based on ASTM standard tests. The referenced ASTM procedure is to be followed for testing. Any deviations from the ASTM tests are noted in the following sections. These tests are to be repeated both for samples of the current ammunition containers and the new containers. Test equipment lists are given in the referenced ASTM test procedures.

A.5.1 Preconditioning

The test specimens are to be preconditioned in accordance to ASTM D 685-87 "Standard Method of Conditioning Paper and Paper Products for Testing;" however, it might not be practical to follow Sect. 6.1 in ASTM D 685-87. Section 6.1 references ASTM D 585-86 "Standard Method for Sampling and Accepting a Single Lot of Paper, Paperboard, or Related Product." If Sect. 6.1 is not followed, then the method used to obtain test specimens is to be noted in the test results.

A.5.2 Pretest Moisture Content of Containers

After preconditioning, the moisture content of the container wall is to be determined. Moisture content is to be determined in accordance with ASTM D 644-55 "Standard Test for Moisture Content of Paper and Paperboard by Oven Drying." Section 4 ("Test Specimens") of ASTM D 644-55 is not to be followed. Test specimens are to be selected using the following procedure:

1. Two containers are to be selected from the previously preconditioned sample.

2. At least two specimens are to be removed from each container selected in Step 1 above. The specimens shall be taken from a section at least 2 in. (50 mm) from one end of the container. [The specimens are to be taken from two locations on the container, separated by at least 4 in. (100 mm), and shall weigh at least 50 g.] If the container consists of multiple plies or sleeves inserted inside one another, the specimens are to be taken from a section of maximum wall thickness. The removed specimens shall extend through the container wall to represent a cross section through the container wall.

To prevent the containers from absorbing water from the ambient atmosphere, the total time elapsed between removing the containers from the preconditioning chamber and beginning this step shall be no more than 30 min.

A.5.3 Water Vapor Permeability Determination

Water vapor permeability shall be determined in accordance with ASTM D 1251-79 "Standard Test Method for Water Vapor Permeability of Packages by Cycle Method." While none of the ASTM tests replicate actual field conditions experienced by ammunition containers, this test comes closest to replicating the temperature and humidity cycling experienced in field conditions. The steep moisture concentration gradient caused by the desiccant inside the containers is also not representative of field conditions. Because the goal of this testing is to enable qualitative comparisons of different container types, this situation is acceptable.

To prevent the containers from absorbing water from the ambient atmosphere, the total time elapsed between removing the containers from the preconditioning chamber and beginning this step shall be no more than 30 min.

A.5.4 Posttest Moisture Content of Containers

After completing Step A.5.3, the moisture content of the container wall is to be determined. Moisture content is to be determined in accordance with ASTM D 644-55 "Standard Test for Moisture Content of Paper and Paperboard by Oven Drying." Section 4 ("Test Specimens") of ASTM D 644-55 is not to be followed. Test specimens are to be selected using the following procedure:

1. Two containers are to be selected from the samples in Step A.5.3.

2. At least two specimens are to be removed from each container selected in Step 1 above. The specimens shall be taken from a section at least 2 in. (50 mm) from one end of the container. [The specimens are to be taken from two locations on the container, separated by at least 4 in. (100 mm), and the specimens shall weigh at least 50 g.] If the container consists of multiple plies or sleeves inserted inside one another, the specimens are to be taken from a section of maximum wall thickness. The removed specimens shall extend through the container wall to represent a cross section through the container wall.

To prevent the containers from absorbing water from the ambient atmosphere, the total time elapsed between removing the containers from the test chamber used in Step A.5.3 and beginning this step shall be no more than 30 min.

A.6. FINAL REPORT

The final report will present data required by the different ASTM procedures in such a manner as to allow comparison of performance between the different container designs.

APPENDIX B
EXPERIMENTAL DESIGN FOR TESTING FIBER-TUBE AMMUNITION CONTAINER REPLACEMENTS

B.1. OBJECTIVES

The objectives of this experiment are to determine whether (1) any of the four fiber-tube coatings identified for ammunition containers are >10% less permeable to water than the existing container and (2) coating the tape closure on the container makes them >10% less permeable than when the tape closure is not coated.

B.2. INTRODUCTION TO EXPERIMENT DESIGNING

This section described an experiment designed to detect differences in the various coating methods and between each coating method and the current, military-standard container. In essence, the experiment is an attempt to draw conclusions based on representative subsets of performance drawn from the total population of performance. To support decision making, the design of an experiment must provide a context for precise and accurate performance measurements. These measurements are summarized by statistics, which are estimates of population parameters, and by statistical tests, which are methods for assigning probability statements to statistics and differences among statistics. An efficient experiment is one which provides an appropriate context for data collection and statistical analysis of data with the minimum possible cost.

The effectiveness of an experiment is affected by four critical parameters: (1) confidence level, (2) power, (3) critical engineering increment, and (4) population variability. The confidence level of an experiment is the probability of incorrectly accepting the hypothesis that the performance sampled comes from different performance populations or, in other words, the probability that a conclusion based on the data is a false alarm. This is called Type I error, and the probability of it occurring is called alpha (α). Power is the ability of the experiment to detect differences in criteria that reflect true differences among performance populations. For the purpose of designing experiments, power is not directly considered; instead, the probability of falsely accepting the conclusion that there are no differences is used. This is called Type II error, and the probability of it occurring is called beta (β). Beta is equal to 1 − power. The critical engineering increment is the smallest performance difference which has practical significance. For example, it is possible to design an experiment which will detect differences of 1% in container permeability but given the added cost of the coatings, this difference may be too small to warrant detecting. Population variability is the amount of variation expected within a single performance population, expressed as a standard deviation. For example, if the permeability of 1000 current, military-standard containers was measured, not all of the containers would exhibit exactly the same permeability. The variability that can be expected from containers from the same population is an important experimental design parameter.

Alpha and beta are usually set a priori by the experimenter, based on the desired confidence, power, and standard experimental practices. For this experiment, $\alpha = 0.10$ and $\beta = 0.30$. The critical engineering increment = 10% (i.e., differences of <10% between any two types of coatings will not be considered significant). Population variability is difficult to estimate because no prior data on container permeability are available; however, the ASTM standard for cyclic permeability testing states that estimates of the same material made at the same laboratory should not vary by more than 10%. This figure will serve as an estimate of the population standard deviation.

B.3 PERMEABILITY EXPERIMENT DESIGN

This experiment should be designed as a fully crossed model with two fixed factors. The factors are coating type (five levels) and closure type (two levels). The alpha error level for the experiment (the probability of falsely identifying a difference among the factor levels) will be $\alpha = \leq 0.10$; the beta error level (the probability of failing to find an existing difference) will be $\beta = \leq 0.30$; the practical significance level (the minimum difference in permeability among coatings which is worth detecting) will be 10%; and the estimated standard deviation within a population of coatings of the same type is 10% (from the ASTM Testing Standard D 1251-79 for the cycle method). Given these parameters, the number of cases within each cell of the experimental matrix should be six containers, from the following formula:

$$N = 2(t_\alpha + t_\beta)^2\, s^2/\delta^2 \quad ,$$

where

t_α = t score for the alpha level (taken from a table),
t_β = t score for the beta level,
s = estimated standard deviation within coating conditions,
δ = practical significance level.

Because there will be 9 cells in the experimental matrix (2 closures × 5 containers − 1), the total number of containers required is 54. However, if the critical engineering increment is raised to 15% from the same formula, then the number of containers required per cell of the experimental matrix is 3, for a total of 27 containers. This is a 50% reduction in the number of containers required, at the cost of a 50% increase in the critical engineering increment.

B.4 STATISTICAL ANALYSIS

In the cycle method of permeability testing, a container is exposed to water vapor, weighed, and re-exposed to water vapor, etc., until the weight of the container reaches an asymptotic level. This will provide two criteria for the experiment: the asymptotic weight (a measure of the total permeability of the container) and the rate of weight gain (a measure of the rate of permeability). These two variables will be subjected to multivariate analysis of variance (MANOVA), a statistical test which can simultaneously evaluate the differences among container and closure types on both variables. This will be followed by analysis of variance (ANOVA) conducted on effects found significant in MANOVA. ANOVA is a statistical test similar to MANOVA but limited to one variable. ANOVA will identify which variable (asymptotic weight or weight gain) differs more among containers. Significant differences between individual containers will be evaluated by mean difference tests conducted on the effects found significant in ANOVA.

This cascading approach to significance testing is necessary to guard the overall alpha level of the experiment. The alpha level of a complete experiment is related to the alpha level of individual statistical tests and the number of tests conducted. If 5 independent statistical tests are conducted, each with an alpha level of 0.10, the alpha level for the experiment as a whole will be 5×0.10, or 0.50. In other words, if five independent tests are conducted at that alpha level, the probability of at least one Type I error occurring is one in two. The MANOVA-ANOVA-mean difference test approach prevents this from happening because it combines many independent tests into a single, larger test conducted by MANOVA. At each succeeding level of the procedure, the overall alpha of the experiment is protected by the preceding significance test (e.g., the MANOVA tests for grand differences among coatings and closures). Tests conducted by ANOVA on effects found significant in MANOVA are no longer independent, and the overall experimental alpha remains 0.10.

APPENDIX C
COATING AND PACKAGING PRODUCTS COMPANIES

The following is a listing of companies which were contacted as part of this study. The majority of companies did not have products suitable for application to artillery-shell packaging. Companies whose product lines were investigated but deemed unsuitable sources for packaging solutions before contacting are not listed here. The purpose of this list is to serve as a cross reference for future research into packaging products.

3M Company
St. Paul, Minnesota
(800) 373-7958
Industrial tapes and adhesives

ARDCO
Denver, Colorado
(800) 628-1569
Contract applicators

Carboline
St. Louis, Missouri
(800) 848-4645
Epoxy-based coatings

Container Corporation of America
Chattanooga, Tennessee
(615) 265-8244
Packaging materials

Corrulite
South Bay, Florida
(407) 996-2089
Corrugated plastic

Current, Inc.
West Haven, Connecticut
(203) 469-1337
Paper coatings

Flambeau Corp.
Baraboo, Wisconsin
(608) 356-5551
Blow molding

Geauga Co.
Canton, Ohio
(216) 456-2481
Plastic molding

General Plastics Manufacturing Co.
Tacoma, Washington
(206) 473-5000
Fire-retardant foam

Georgia-Pacific
Atlanta, Georgia
(404) 448-9440
Paper and packaging products

Henkel
La Grange, Illinois
(800) 237-4037
Base resins for coating formulators

L&C Associates
Northampton, New Hampshire
(603) 964-9421
Distributor for Rabco products

Lummus Pyrotech
Columbus, Georgia
(800) 344-0780
Fire-retardant and vapor-barrier coatings

Michelmann, Inc.
Cincinnati, Ohio
(513) 793-7766
Paper coatings

Morrison Molded Fiber Glass Co.
Bristol, Virginia
(703) 645-8000
Fiberglass tubing

Nova-Tran
Clear Lake, Wisconsin
(800) 554-1697
Paralyne vapor deposition coating

Omega Container
Arcadia, Louisiana
(318) 263-8602
Fiber-tube ammunition packaging

P&S Engineered Plastics
Knoxville, Tennessee
(615) 691-0516
Injection molding

Pfizer
Philadelphia, Pennsylvania
(215) 250-3327
Epoxy-based coatings

Rabco
Moorestown, New Jersey
(609) 235-5116
Sprayable coatings

Rust-Oleum Corp.
Vernon Hills, Illinois
(708) 367-7700
Coatings and paints

Sealed Air Corp.
Danbury, Connecticut
(203) 791-3500
Foam-in-place packaging

Sonoco Products Co.
Hartsville, South Carolina
(803) 383-7000
Packaging tubes

Spec-Fab Co.
Riverton, New Jersey
(215) 922-1788
Packaging products, vapor-barrier bags

Stevenson & Lawyer
Dalton, Georgia
(404) 278-2348
Foam molding

T.H.E.M.
Mount Laurel, New Jersey
(800) 322-8436
Packaging materials, vapor corrosion inhibitors

Tnemec
Kansas City, Missouri
(816) 483-3400
Epoxy-based coatings

United Ammunition Container
Milan, Tennessee
(901) 686-8303
Fiber-tube ammunition packaging

INTERNAL DISTRIBUTION

1. S. M. Babcock
2. E. C. Bradley
3. W. D. Burch
4. D. L. Canter
5-9. J. B. Chesser
10-11. R. M. Davis
12. J. V. Draper
13. M. H. Ehinger
14. R. K. Genung
15. M. J. Haire
16. J. H. Hannah
17. J. N. Herndon
18. R. T. Jubin
19. E. H. Krieg, Jr.
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26. K. E. Plummer
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40. Clinton Bastin, Manager, LMR Reprocessing Projects, Division of Fuels and Reprocessing, Office of Facilities, Fuel Cycle, and Test Programs, NE-471, Department of Energy, Washington, DC 20545.

41. L. F. Blankner, Fusion and Nuclear Technology Branch, Energy Programs Division, Department of Energy, X-10 Site, P.O. Box 2008, Oak Ridge, Tennessee 37831-6269.

42. A. Galonski, PM-AMMOLOG, HQ ARDEC, AMCPM-AL Picatinny Arsenal, Dover, New Jersey, 07801-5001.

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

44. V. Khana, Packaging Division, SMCAR-AEP, Picatinny Arsenal, New Jersey 07806-5000.

45. R. J. Kuper, Chief, Packaging Division, SMCAR-AEP, Picatinny Arsenal, New Jersey 07806-5000.

46. J. Miemis, Office of the Project Manager for Ammunition Logistics, AMCPM-AL Building 455, Picatinny Arsenal, New Jersey 07806-5000.

47. J. H. Saling, ORNL/CFRP On-Site Representative, Reprocessing Technology Development Division, Tokai Works, Power Reactor and Nuclear Fuel Development Corporation, Tokai-mura, Ibaraki-ken, Japan Post No. 319-11.

48. J. L. Scott, DOE Representative, Power Reactor and Nuclear Fuel Development Corporation, Sankaido Building, 9-13, 1-Chome, Akasaka, Minato-ku, Tokyo, 107 Japan.

49. Col. T. Tobin, PM-AMMOLOG, HQ ARDEC, AMCPM-AL Picatinny Arsenal, Dover, New Jersey 07801-5001.

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

51-52. Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, Tennessee 37831.