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Light Weight Container For Large Caliber Munitions - Phase II

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Light Weight Container For Large Caliber Munitions - Phase II

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11. Abstract

The Army currently uses a heavy steel rectangular container to store and transport large caliber munitions. This project is focused on designing and testing a new, efficient, light weight container for this purpose. The original metal container was designed to hold 2 munitions and weighed in excess of 100 pounds including the weight of the munitions. The new container, referred to as a monopack due to its design to hold only one munition, is cylindrical in shape and 30.5 inches long and weighs approximately 7 lbs. The preliminary design of the monopack during the first phase of the project incorporated lightweight composite materials for the body and a lightweight damage-resistant polymer for the end caps. A large amount of the Phase I effort was dedicated to prototype testing. For instance, moisture absorption tests, impact tests, and full scale impact drop tests were conducted on these composite cylinder test articles to check for penetration and damage resistance of the container and its endcaps.

A second phase effort was designed to follow up on the recommendations that were proposed after the results of the Phase I tests had been analyzed. Investigation of a higher failure strain polymer for the end caps was the most critical issue going into the second phase of this project. Three possible candidates were chosen based upon the shortcomings of the material that was used in Phase I and several discussions with materials experts about the material properties that were required to surpass the high impact drop tests. Also the thread design and the gasket seal of the top cap were modified such that the top cap could be screwed on with fewer turns and the gasket would seal the container without being damaged during an inadvertent impact. The details of the modifications, fabrication, and testing of the container for the Phase II effort are described in this report.

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CONTENTS

LIST OF FIGURES

ABSTRACT

The Army currently uses a heavy metal rectangular container to store and transport large caliber munitions. This project is focused on designing and testing a new, efficient, light-weight container for this purpose. The original metal container which was designed to hold 2 munitions weighs in excess of 100 pounds including the weight of the munitions, interior packaging and dunnage and requires a two person carry. The new container, referred to as a monopack due to its design to hold only one munition, is cylindrical in shape and 30.5 inches long and weighs approximately 36 lbs including the munition. In a monopack arrangement a single person is able to carry two munitions but this exceeds human factors limits and is not a requirement. The preliminary design of the monopack during the first phase of the project incorporated lightweight composite materials for the body and a lightweight damage-resistant polymer for the end caps. A large amount of the Phase I effort was dedicated to prototype testing. For instance, moisture absorption tests, impact tests, and full scale drop tests were conducted on these composite cylinder test articles to check for moisture penetration and damage resistance of the container and its endcaps.

Investigation of a higher failure strain polymer for the end caps was the most critical issue in the second phase of this project. Based upon the "lessons learned" concerning the shortcomings of the material and design used in the Phase I study, three new candidate materials were chosen for high impact drop testing in Phase II. Also, the thread design and the gasket seal of the cover (closure cap) were modified such that the cover could be screwed on with fewer turns and the gasket would seal the container without being damaged during the seven foot drop. Drop tests were conducted with the monopack at room temperature and at -65 degrees F. Two of the three designs successfully passed the room temperature tests whereas all specimens failed at -65 degrees F.

BACKGROUND

A concept study was performed by the Vehicle Technology Center (VTC) of the Army Research Laboratory (ARL) for the U.S. Army ARDEC at Picatinny Arsenal, New Jersey and the Phase I effort is described in Reference 1. The project was centered upon the development of a new container for large caliber munitions. The current container consists of a rectangular, steel outer container that holds two fiberboard/aluminum foil/asphalt fiber tubes as shown in Figure 1. Each tube contains a munition which rests on a nylon fuze support. The objective for the Phase I effort was to develop a new container concept that is simpler, lighter, and less expensive to manufacture that would be easy to carry and would protect the contents from the environment, as well as from the wear and tear of handling and storage. The new container, unlike the current design, would provide protection against impact damage and moisture at all times. The scope of this activity included the development of a container concept and the subsequent design and fabrication of several containers. New container concepts and the materials used in their fabrication were tested in accordance with the Military Standard Design and Test Requirements For Level A Ammunition Packaging (Ref.2). Much information was gathered from the user community during visits, phone conversations, and user demonstrations. Consequently, many performance requirements were considered before a preliminary design emerged.

The concept of the monopack is simple and efficient. It has only five basic components: the cylinder, cover, bottom cap, fuze support, and propellant charge cover. Figures 2a, b, c, d, and e depict sketches of each component including component dimensions. Figures 3a and 3b are photographs of a prototype container and an exploded view of the container parts respectively. Although the container has a durable exterior, the design takes advantage of the axial load bearing capability of the munition body itself as it has constant contact with the damage resistant end caps of the container and fuze support. The cylinder's (Figure 2a) major function is to create a barrier from the environment and to protect the munition against drops and accidental side impacts.

These munitions may be stored for years and subjected to considerable abuse during transportation. An integral part of the environmental barrier is the cap's seal. The monopack design is required to be airtight and able to withstand a 3 psi pressure differential when subjected to logistical and tactical transportation vibration and normal handling. The end caps (Figures 2b and 2c) must be highly damage resistant with some elastic energy absorbing characteristics as they will experience the impact loads initially. The fuze support (Figure 2d) supports the nose of the munition and keeps the fuze from coming into contact with the container's bottom end cap. In this concept the fuze support is made of the same damage resistant material as the end caps so that the endcap and fuze support can be integrally fabricated. The propellant charge cover (Figure 2e) shields the propellant charges and keeps the mortar centered inside the tube. The original propellant charge cover was slightly modified such that the entire munition fits within the cylinder as shown in Figure 3c. A simple flexible handle (cord) was attached to the charge cover so that the munition could be easily lifted out of the tube as shown in Figure 3d.

During Phase I the containers were subjected to several test procedures and sequences as described in the Military Standard Design and Test Requirements For Level A Ammunition Packaging Manual (Ref.2) in order to determine the container's ability to protect munitions from adversities resulting from normal as well as abnormal handling and storage conditions. The severity of these tests was taken into consideration during the preliminary design stage of the container, particularly in the selection of materials It was anticipated that the most severe structural test that the container would experience was the seven foot vertical drop test. If the endcaps of the container survived this test it was likely that the other tests pertaining to storage and handling abuse of the endcaps would also be survivable. A series of simulated forklift impacts of the tube body were conducted using a drop weight impactor. These tests were successfully satisfied for the wall thickness used in the tubes. These tests and the results are described in detail in Reference 1.

The findings from Phase I of this project led to several recommendations. First and foremost was the selection of material for the end caps and fuze support. The Nylatron GSM which was initially chosen for its damage resistant qualities had to be replaced with a material having a much higher failure strain. The possibility exists that the material for the endcaps may have to be formulated to meet the necessary requirements.

Secondly, the threaded cover design had to be modified such that fewer turns were required to close the container. A wider thread with higher pitch which lends itself to a thinner wall section, hence greater flexibility, is desirable but the dimension of the cap sidewall constrains these parameters to some extent. Finally, further investigation of gaskets, o-rings, and seals that are compatible with the corner radius in the cap was needed in order to provide an airtight container that will pass the pressure retention tests before and after each impact and vibration test.

INTRODUCTION

This report describes the second phase of the lightweight munitions container concept study performed by the Vehicle Technology Directorate (VTC) of the Army Research Laboratory (ARL) for the U.S. Army ARDEC at Picatinny Arsenal, New Jersey. The primary focus of the Phase II effort was to find an appropriate material for the end caps and fuze support. The Nylatron GSM initially chosen in Phase I for its damage resistant qualities was found to be inadequate for the endcap design. A higher failure strain material is needed to meet the 7 foot drop test requirements.

The Phase I cover design incorporated a threaded screw-on cap which was chosen for its simplicity , easy attachment to the container, and easy access to the contents. However, an excessive number of turns was required to apply and remove the cap. The gasket was a thin layer of silicone that was bonded into the cover and was susceptible to being cut by the top edge of the cylinder upon impact. An aluminum simulant of a new cover design was fabricated to demonstrate a new double-lead thread design and sidewall o-ring seal which was used as the model for the new endcaps. Figures 4a and 4b show a close-up of the aluminum cover simulant and a sketch of the sidewall gasket, respectively.

The seven foot drop tests performed in Phase I were repeated for the new materials and designs in Phase II. Also, during the Phase II drop tests the containers were pre-conditioned to -65 degrees F prior to drop testing. The aforementioned drop tests were videotaped and the test results are described in this report.

MATERIAL SELECTION

Based upon the results from the Phase I tests and performance requirements for the monopack, three endcap materials were selected for evaluation in Phase II. The first two material candidates were A-scale and D-scale urethanes. The D-scale urethane is a harder durometer material than the A-scale urethane. Urethane has many desirable properties. It has excellent abrasion resistance and a high load bearing and elastic energy absorbing capacity. It operates in a broad temperature range and has high resistance to sunlight and general weather conditions. It is also easy to injection mold. The third material was the Nylatron GSM that was used in Phase I. The material properties for these three materials are given in Table 1.

FABRICATION

Three sets of container endcaps were fabricated. One set was machined from D-scale urethane, one set was molded from a castable form of the A-scale urethane, and one set was machined from the Nylatron GSM. The urethane caps shown in Figure 5 were based upon the final design described in the Phase I report with the exception of the thread design, the o-ring seal, and a 1/8" radius which was incorporated into the endcaps at the sidewall interface. Due to the brittle behavior that the Nylatron exhibited in the Phase I tests, the Nylatron endcap was designed with a thinner sidewall than the dimension specified in the final design. Conceivably this would allow more flexibility in the sidewalls to reduce the local bending stresses in the cap during a drop test.

An aluminum simulant of a new cover (Figure 6) was fabricated to demonstrate a new thread design and o-ring seal. All covers have a double-lead thread that will require minimum turns to seal and remove. The double lead thread is shown in the photo in Figure 4a and the sketch in Figure 4b shows the new sidewall gasket design. Four new glass epoxy composite cylinders were fabricated for Phase II drop tests. Three test articles with the three different endcap materials are shown in Figure 7.

A square version of the new cover (see Figure 3b) has also been fabricated for demonstration purposes. Basically, the endcaps are still round but the rings that are bonded to the cylinder (the bottom portion of the cover and a portion of the bottom cap) are square. This will provide flat sides to keep the cylinder from rolling in the racks and to provide better stacking stability. Squaring only the ring portion of the endcaps and bonding them to the cylinder prevents any possibilities of misalignment either with the cover and the ring or the top and bottom caps. Figure 3a shows the carrying handle which runs along the length of the container. The handle should be positioned such that the c.g. of the container with the munition inside is centered with the handle. A removable shoulder strap could also be incorporated in order to free the soldier's hands or simply to make the container easier to carry.

TESTING

The impact drop tests of the new endcap materials were performed in the same manner as the tests in Phase I of this project which are documented in Reference 1. Once all the components had been fabricated and bonded to the cylinders the drop tests were scheduled. An initial pressurization test was conducted to insure that the containers were airtight. The containers, loaded with an inert mortar were dropped from a height of seven feet onto a steel plate under ambient temperature conditions. After the loaded containers had passed these tests they were placed in a thermal chamber and cold soaked to a temperature of -65 degrees F. After reaching an internal temperature of -65 degrees F the containers were removed from the thermal chamber and immediately dropped from seven feet onto a concrete floor. All drop tests were videotaped and subsequently studied to understand the response of these materials. The results of all the aforementioned tests are described in this section of this paper.

Pressure Tests

An initial pressurization test of the cylinder was performed. A 1/4 inch hole was machined into the bottom cap in order to secure a pressure tap enabling pressurization of the container and measurement of the amount of pressure inside to see if any leaks existed. Figure 8 shows the pressure test set-up.

The new sidewall o-ring seal was tested prior to the drop test by pressurizing the container to 3 psi and monitoring any changes in the pressure reading. The pressure reading did not vary and the container was considered to be airtight. The pressure seal was tested again after the ambient temperature drop tests and the pressure reading indicated that the container could not hold the 3 psi pressure. The leakage was found to be in the areas where the endcaps were bonded to the cylinder and not associated with the endcaps or the o-ring seal. This result suggests that a more compliant adhesive should be used for bonding purposes.

Room Temperature Drop Tests

After placing an inert mortar inside the containers they were dropped from 7 feet onto a steel plate. The containers with the munition enclosed weighed approximately 36 pounds. Several 12 X 24 inch steel plates were placed side by side on a concrete floor creating a region of 16 square feet.

The first series of drop tests were performed on the monopack whose endcaps were fabricated from the D-scale urethane. This container was dropped three consecutive times without any failure to the endcap. The first drop was from an upright position onto the bottom cap, the second drop was upside down onto the cover, and the third was from an approximate 45 degree angle onto the edge of the cover. This test article performed very well except the cover popped off. The top was undamaged and replaced on the container and the tests continued.

The next two drops were conducted on each end of the A-scale urethane container, an extremely compliant material. In this test the urethane yielded absorbing some of the kinetic energy in the system. It did not rebound as much as was anticipated and the secondary impact did not pop the cover off as it did with the D-scale urethane material. The cover did come off when it was dropped onto the top but again it was not damaged and was immediately replaced.

Finally the Nylatron container was dropped and even though it survived the impact when it was dropped onto the bottom cap, it failed when it was dropped onto its top in spite of making the cover sidewalls more flexible. The drop tests from Phase I and the results from this test ruled out any possibility that the Nylatron GSM material could be used for this application in this configuration.

Cold Drop Test

The survival of the urethane endcaps in the room temperature drop tests instigated the question of what effect temperature would have on the drop test results of these two materials. A thermal chamber was used to bring the cylinders containing the inert munition to -65° F. The thermal chamber, using liquid nitrogen, cooled the containers and inert munition assembly to -65 degrees F. Control of the chamber was provided by a closed loop feedback controller with a thermocouple positioned inside the chamber and a cryogenically rated electrical solenoid to control the liquid nitrogen flow. A single thermocouple to monitor the end cap temperature was applied to the side of the end cap using metallic tape. Initially, the chamber was cooled to approximately -100° F to bring the container to temperature more rapidly. When the thermocouple on the end cap reached -65° F, the chamber temperature was increased to -65° F. The cylinder was held at this temperature for approximately ten minutes to allow the temperatures to stabilize. The total cooling process took about 30 to 45 minutes. The cylinder with inert munition was then removed from the chamber and dropped from a height of seven feet within 60 seconds after removal from the chamber.

The container with the softer durometer (A-scale) performed better than the hard durometer (D-scale) urethane, which was expected. Neither of the containers completely survived the drop. The container with the A-scale urethane endcaps was dropped bottom first. Surprisingly, the bottom survived the initial impact but the top shattered. The cylinder rebounded approximately one foot into the air while rotating 90 degrees. A secondary impact occurred to the bottom cap at a slight angle to the horizontal but no further damage to the container, munition, or fuze support was observed. It is possible that the energy transfer to the top endcap upon impact initiated failure. There could have been motion of the munition within the container due to the high shrinkage of the metal munition when the temperature of the monopack was lowered which caused the top to shatter as the munition rebounded during the drop test. The photograph in Figure 9 shows the brittle fracture pieces of the cover. It should be noted that the only damage during this test was to the cover from the rebound of the munition at the extreme low temperature and that no damage to the contents of the container or the bottom endcap was observed.

The second drop test involved the cylinder with the D-scale durometer urethane endcaps dropped vertically, bottom cap first, in an almost vertical position. This container with the enclosed inert munition was also "cold soaked" and dropped from a height of seven feet.. Upon impact, a portion of the bottom cap was broken but no damage occurred to the cover during the primary impact. The container rebounded into the air approximately three feet and the secondary impact onto the cover induced no damage to the cover but resulted in a total failure of the glue joint between the cylinder, the fuze support, and the bottom cap. The bottom cap did not shatter as was expected. Figure 10 shows a photograph of the detached bottom cap and fuze support after the drop test. Again, this test resulted in no apparent damage to the munition which remained completely inside the monopack. Since the cover survived the first drop, the container was dropped again onto the cover. The cover popped off the container but remained in one piece.

Even though the A-scale urethane has more energy absorbing capabilities at room temperature than the D-scale, it did not perform as well as the D-scale urethane at low temperature. This response is not fully understood and could be attributable to movement of the mortar within the monopack or the impact conditions could be slightly different. For example, the D-scale urethane monopack could have impacted flat on the end cap whereas the A-scale urethane monopack could have impacted slightly on an edge.

The failure at the cold temperature is clearly related to a dramatic change in the change in mechanical properties of the end caps as temperatures decreased. This phenomena is not unlike how strain rate affects the material's response. The failure strain of urethane material during quasi-static testing is much higher than that under dynamic loading conditions. This was evident in the L-section impactor tests that were conducted during Phase I on Nylatron test specimens (See reference 1 for more detail about these tests). The thin wall sections exhibited very flexible behavior under quasi-static impactor loading but had an extremely brittle nature when subjected to dynamic impactor testing. Generally, material properties provided by a vendor are for static loading and room temeprature conditions unless otherwise stated.

SUMMARY

A second phase effort was conducted building upon the recommendations from Phase I of the lightweight monopack container project. Identifying and evaluating a suitable higher failure strain polymer for the end caps was the most critical issue. Two urethane materials of different durometers were used to fabricate endcaps. The thread design and the gasket seal of the cover were modified such that the cover could be attached with fewer turns and the gasket would seal the container without being damaged during an inadvertent impact. Endcaps for a third container were fabricated using Nylatron (Phase I material) where the sidewalls of the endcaps were modified to be more flexible.

The cylinders with urethane endcaps performed very well in the seven foot ambient temperature drop tests with the exception of the covers popping off during impact. Each cylinder was dropped multiple times. No damage to the caps, containers, or the contents occurred, however, the adhesive used to bond the endcaps to the containers locally cracked resulting in the monopack's inability to maintain a 3 psi internal pressure. The container with Nylatron endcaps failed the seven foot ambient temperature drop test and is no longer being considered for this applicaiton.

Finally, the containers were cooled until they reached a temperature of -65 degrees F. The containers were removed from the thermal chamber and immediately dropped from seven feet onto a concrete floor. Both cylinders failed the cold drop tests. The cold temperature and the high strain rate of the drop impact caused the urethane materials to fail in a brittle manner. Materials similar to urethane should be specifically developed that will satisfy all of the diverse requirements of the monopack container.

RECOMMENDATIONS

The overall objective of this program was to develop a new container concept that was lighter and provided superior protection to the munition that could be built at the same or less cost. A monopack concept was produced that met these goals. The proposed concept could be produced in a highly automated environment relieing on established molding technology. Positive feedback from the user was received about the design especially relative to the ability for a single person to now carry two containers. The new concept provides continuous environmental and impact protection to the munition from cradle to grave and the container is readily reuseable. This concept requires less dunage than the existing concept.

The technical issues that still remain to be solved are minor to the point where industry will assume little risk in using this monopack as a starting point for their design. The minor issues that will need to be addressed pertain to thread design and the identification of or the formulation of a suitable material for the end caps. However, this should not posse an impass for industry. The concept is sufficiently mature to warrant going to the next stage of development.

The collaborative effort between the different organizations and the user was a major reason for the success of this program. Each organization brought their expertise to the table as an equal. Future programs should be modeled after this approach .

DELIVERABLES

During this phase of the project three monopack prototypes were fabricated and tested. Photographs of all test set-ups and test specimens and videos of all drop tests at ambient conditions and at -65 degrees F were provided during the course of the project.

The demo container and the final report will be available at the completion of this phase of the project.

Table 1. Material Properties

Mechanical Property (Reference 3)	Nylatron GSM	Urethane A-scale	Urethane D-scale
Specific Gravity	1.16	1.15	1.18
Modulus of Elasticity (psi)	500,000	9,000	12,500
Ultimate Tensile Strength (psi)	12,500	5,500	7,500
Elongation, %	25	320	225
Durometer	D85	95A	75D
Saturated Water Absorption, %	7	1-2	1-2

Figure 1 Metal container showing 2 fiber tubes inside.

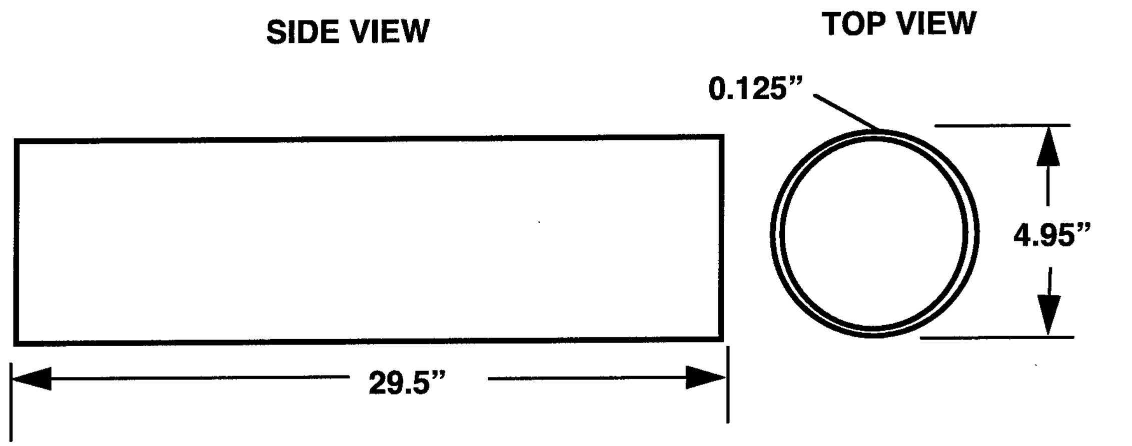

Figure 2(a) Sketch of cylinder.

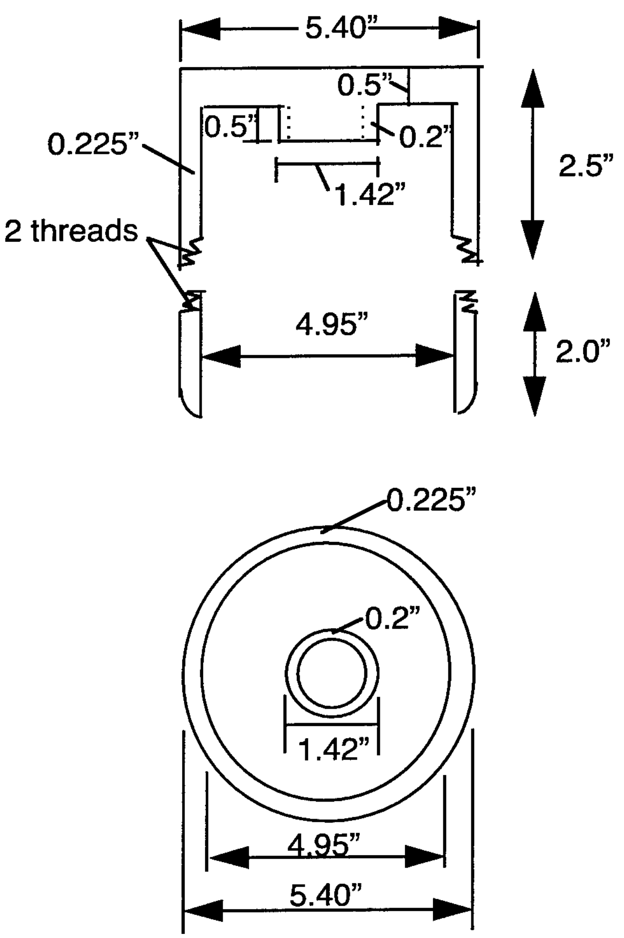

Figure 2(b) Sketch of cover cap.

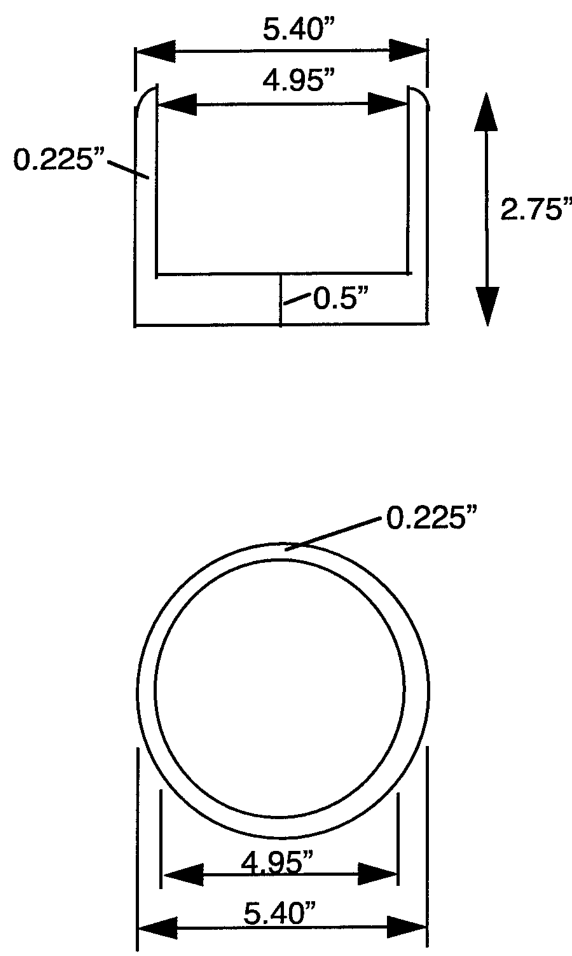

Figure 2(c) Sketch of bottom cap.

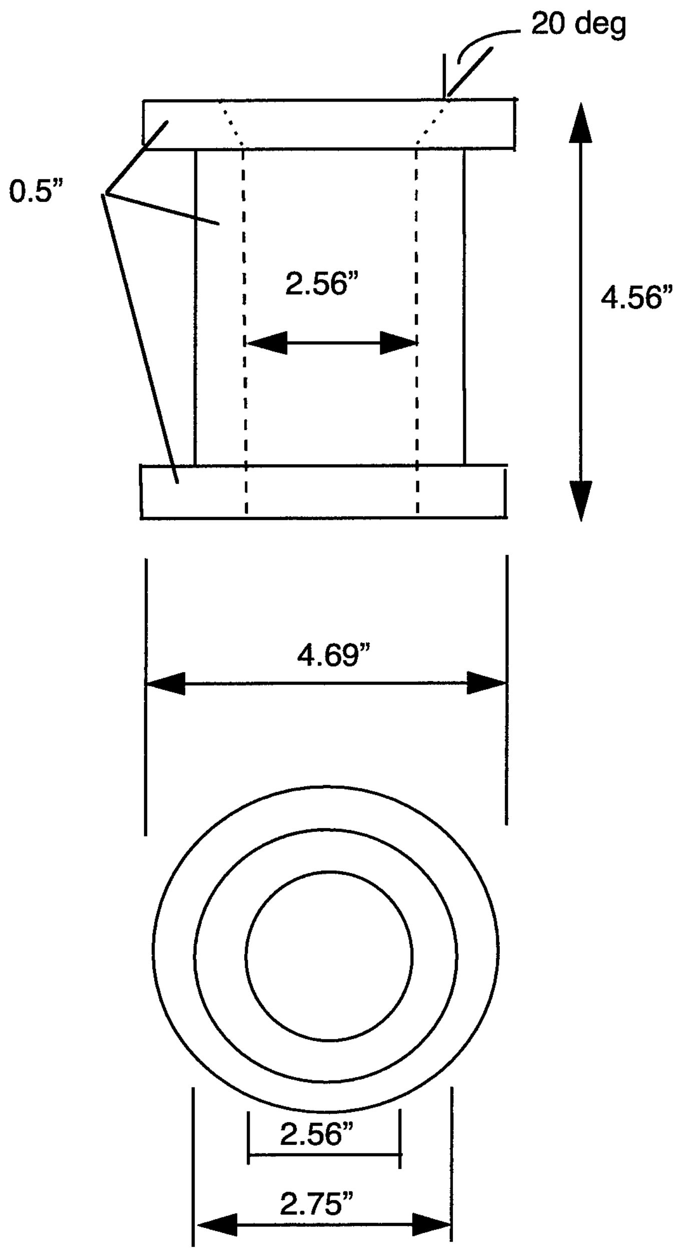

Figure 2(d) Sketch of fuze support

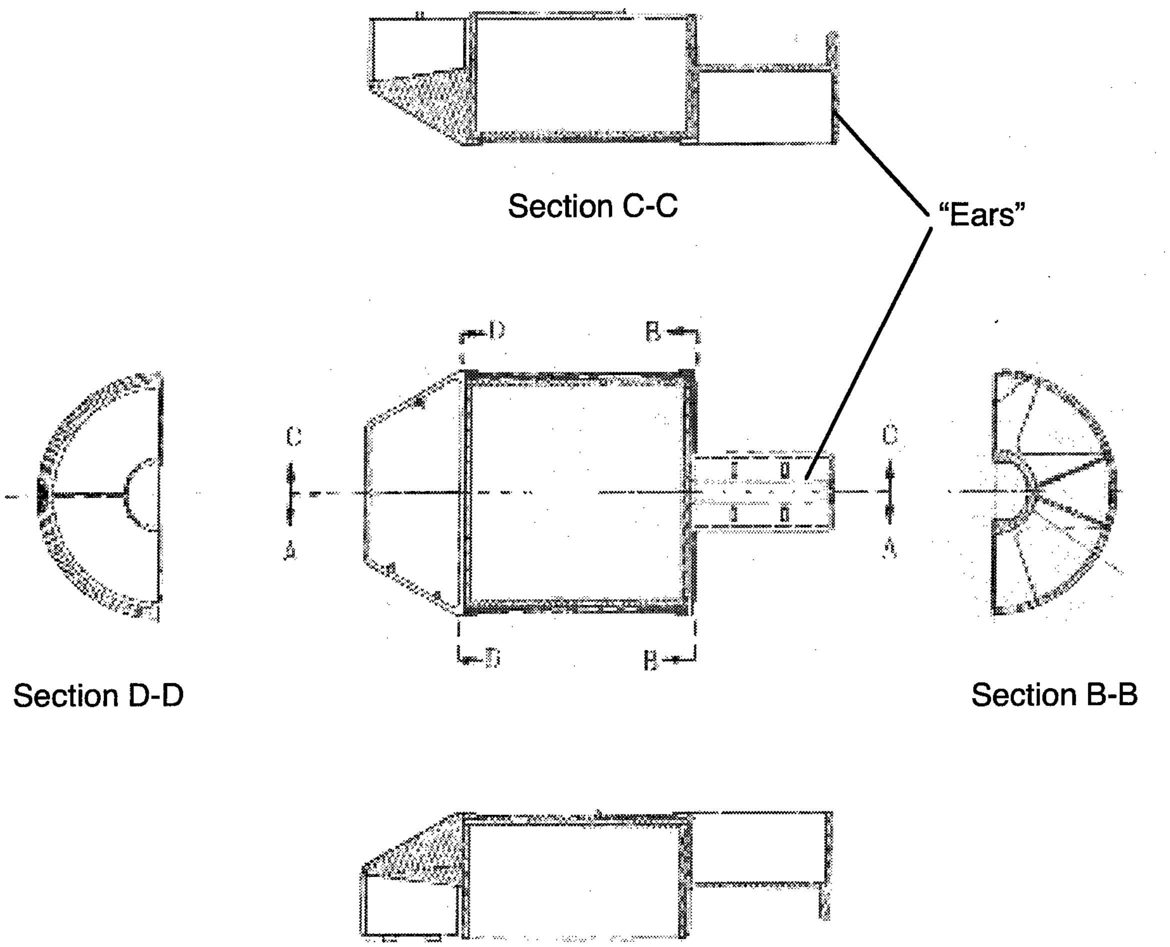

Figure 2(e) Sketch of propellant charge cover

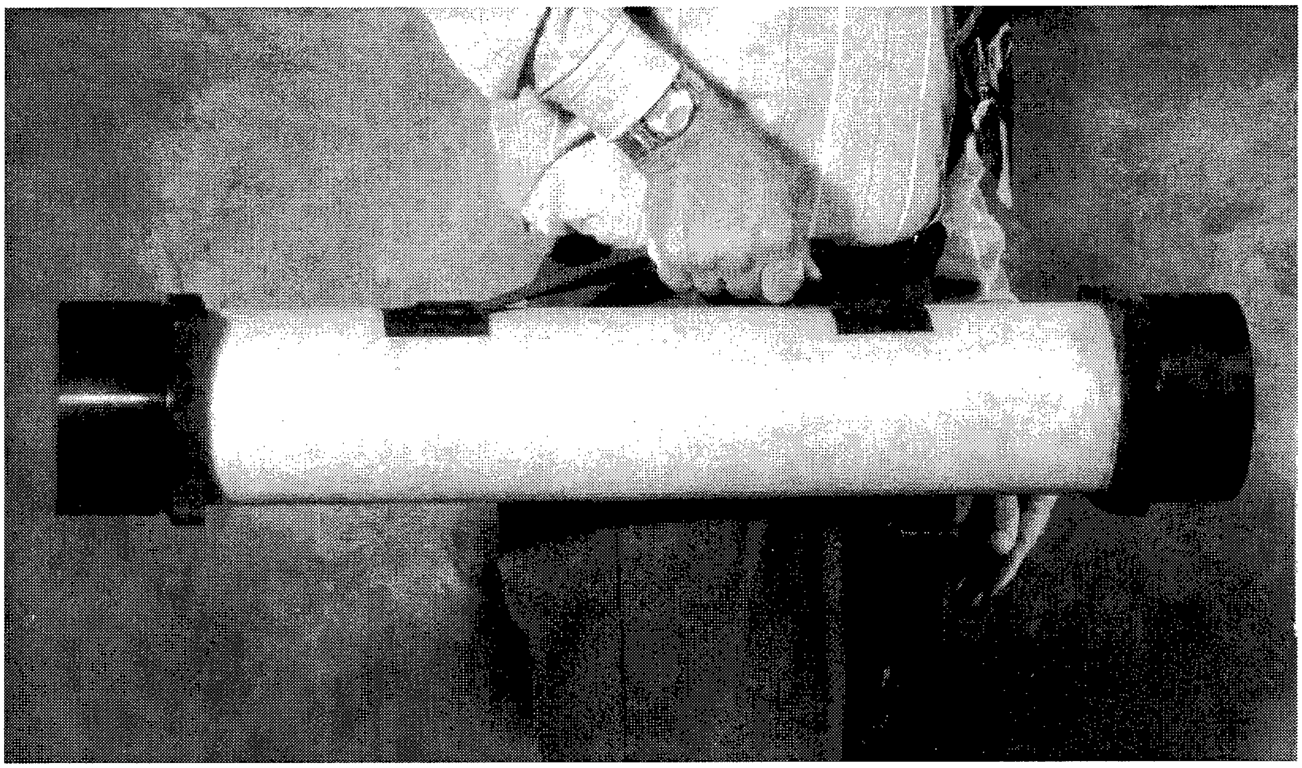

Figure 3(a) - Prototype of monopack container for transporting and storing high caliber munitions.

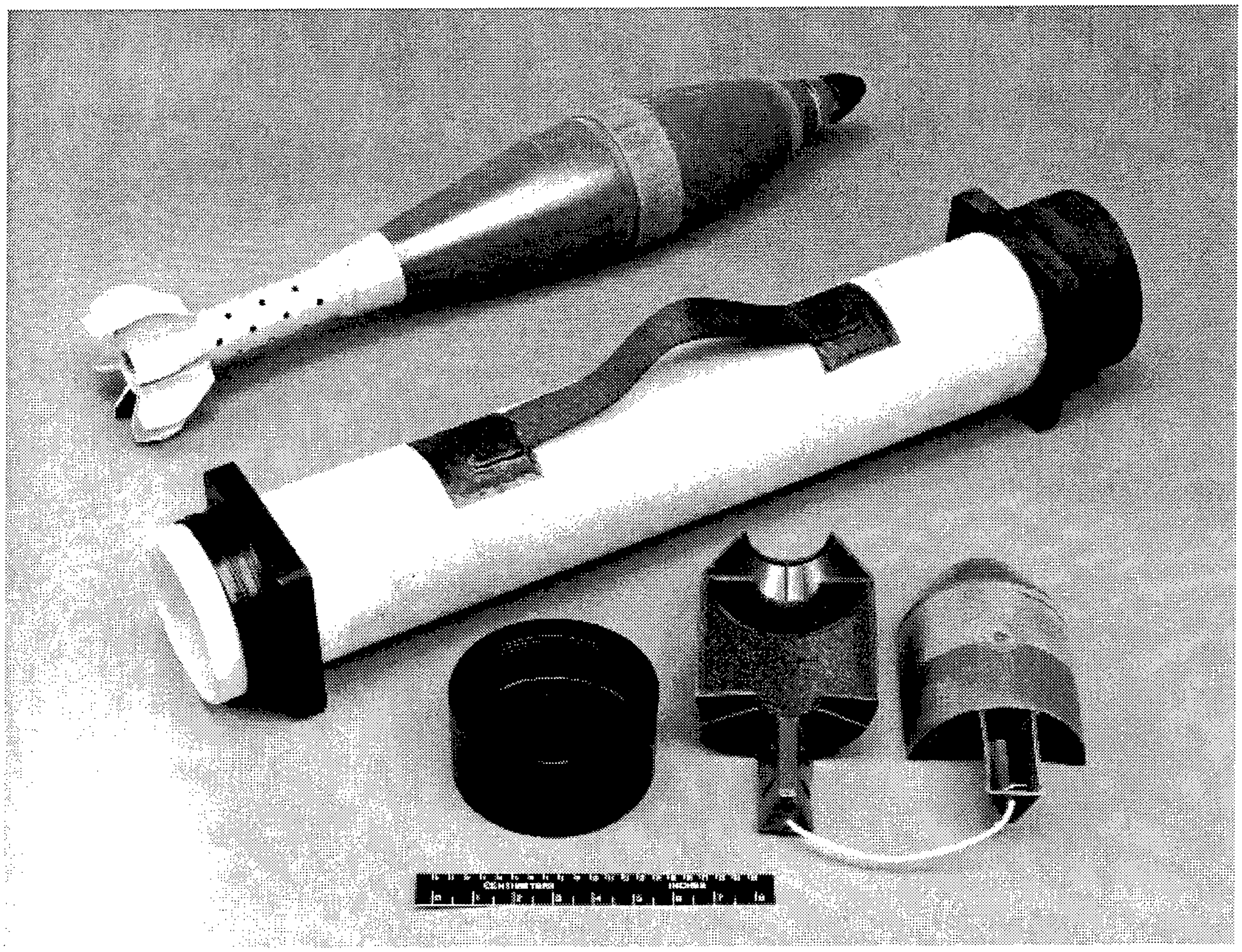

Figure 3(b) - Photograph of the monopack parts and munition.

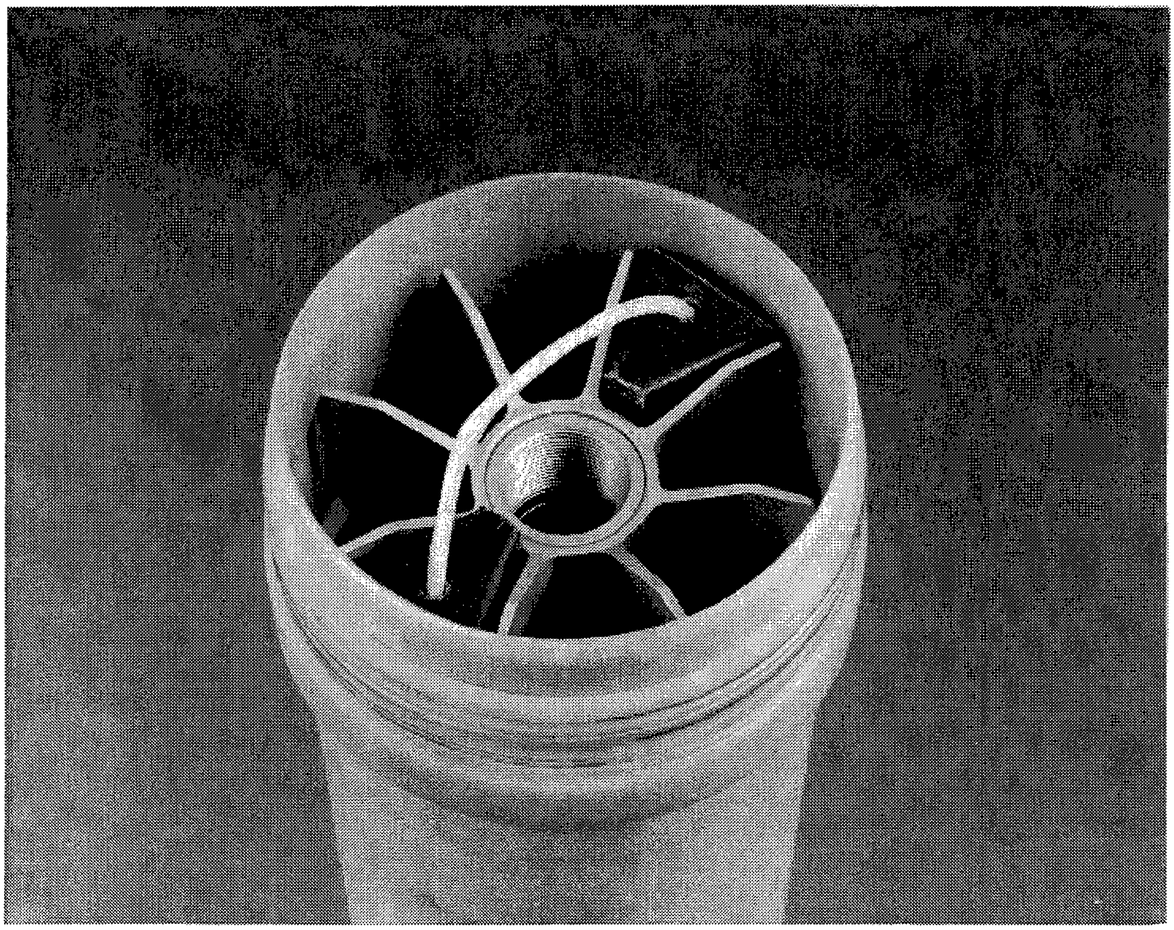

Figure 3(c) - Monopack design showing modified propellant charge cover and handle for easy munition removal.

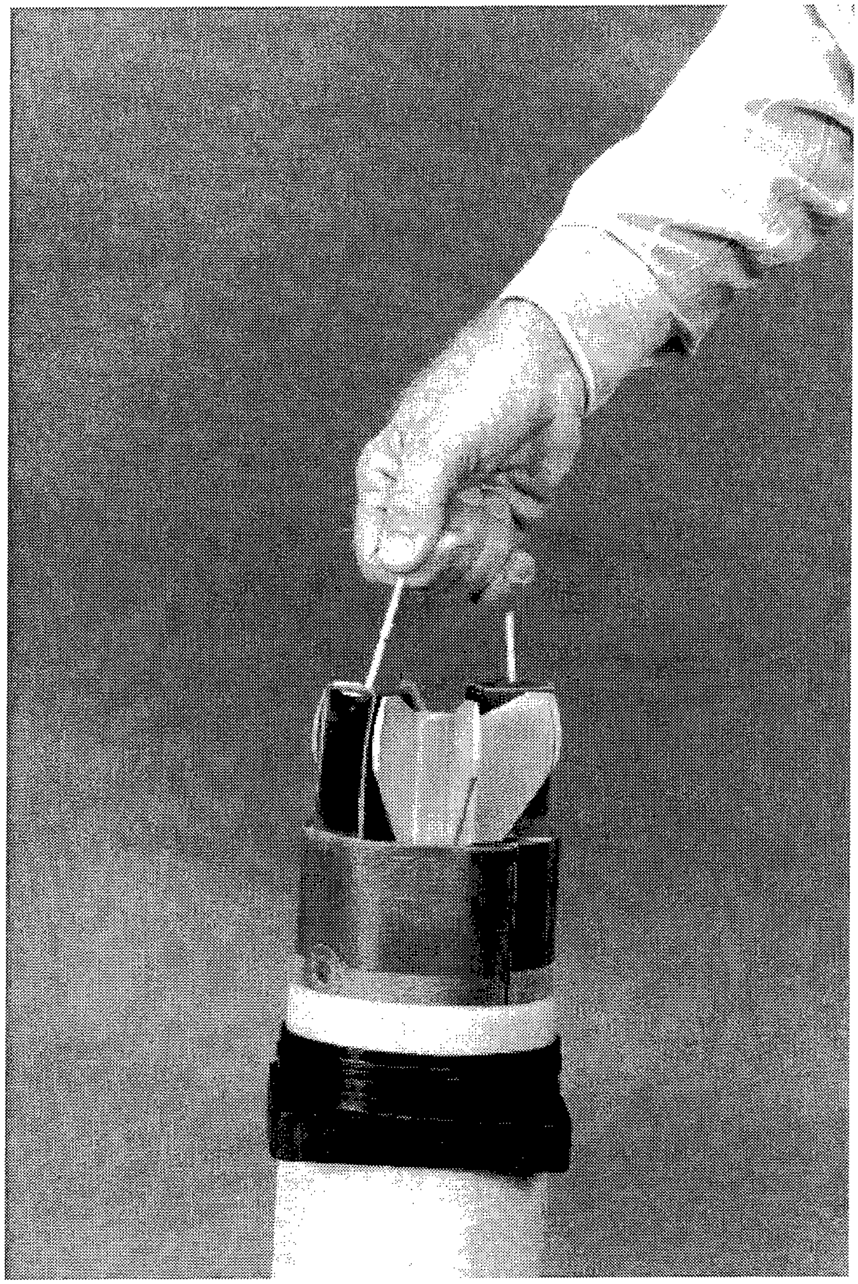

Figure 3(d) - Demonstration of new handle for easy removal of munition

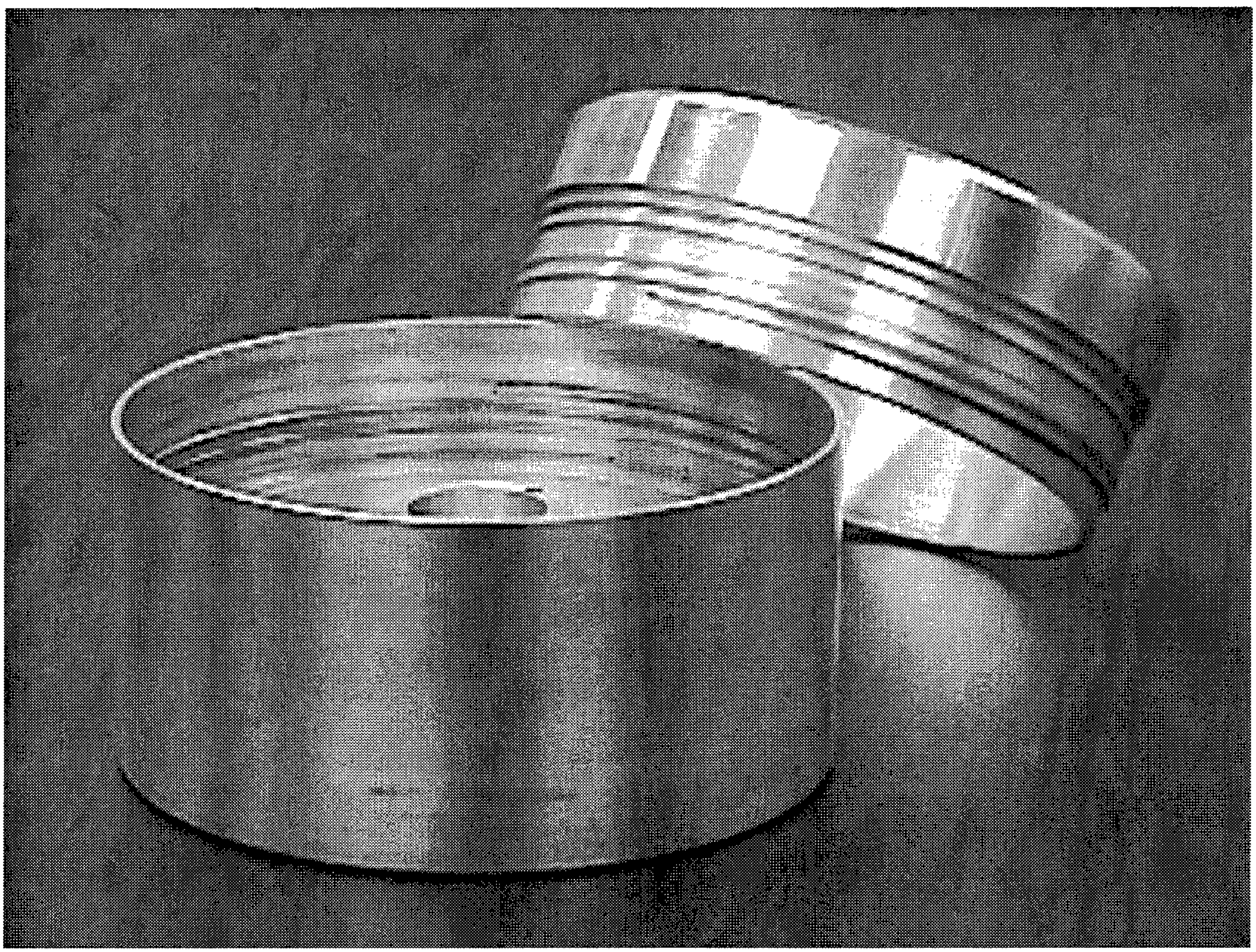

Figure 4a - Close-up of aluminum cover simulant showing double-lead thread design.

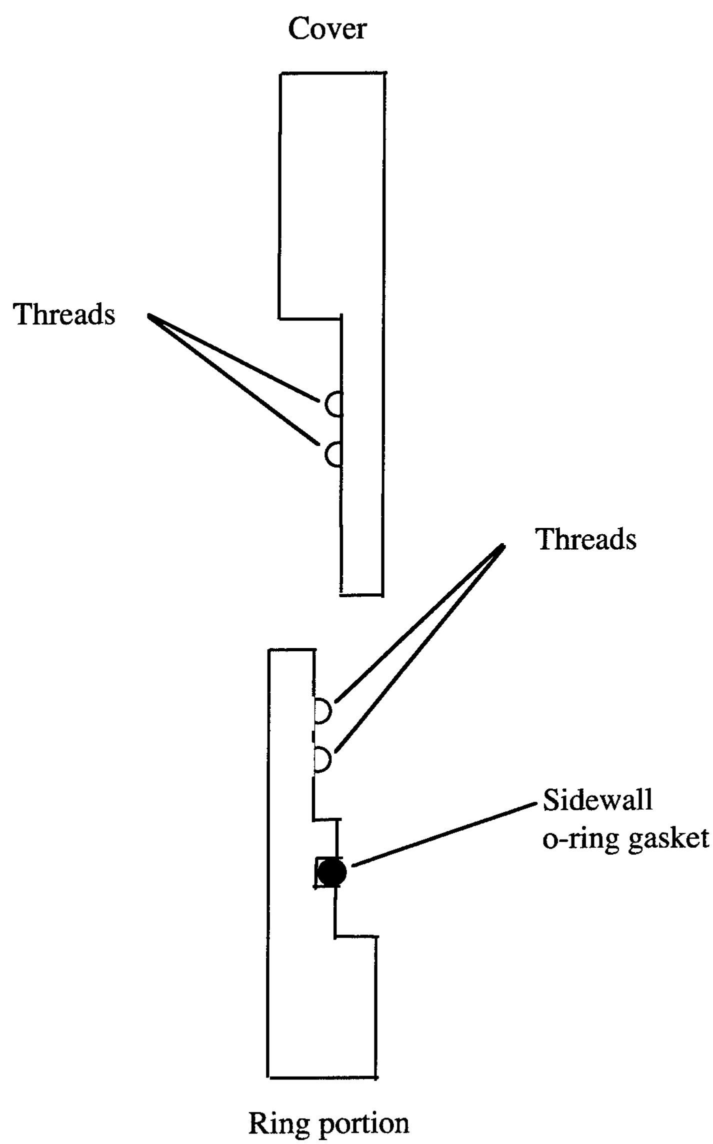

Figure 4b - Sketch of cover cross-section showing sidewall gasket design.

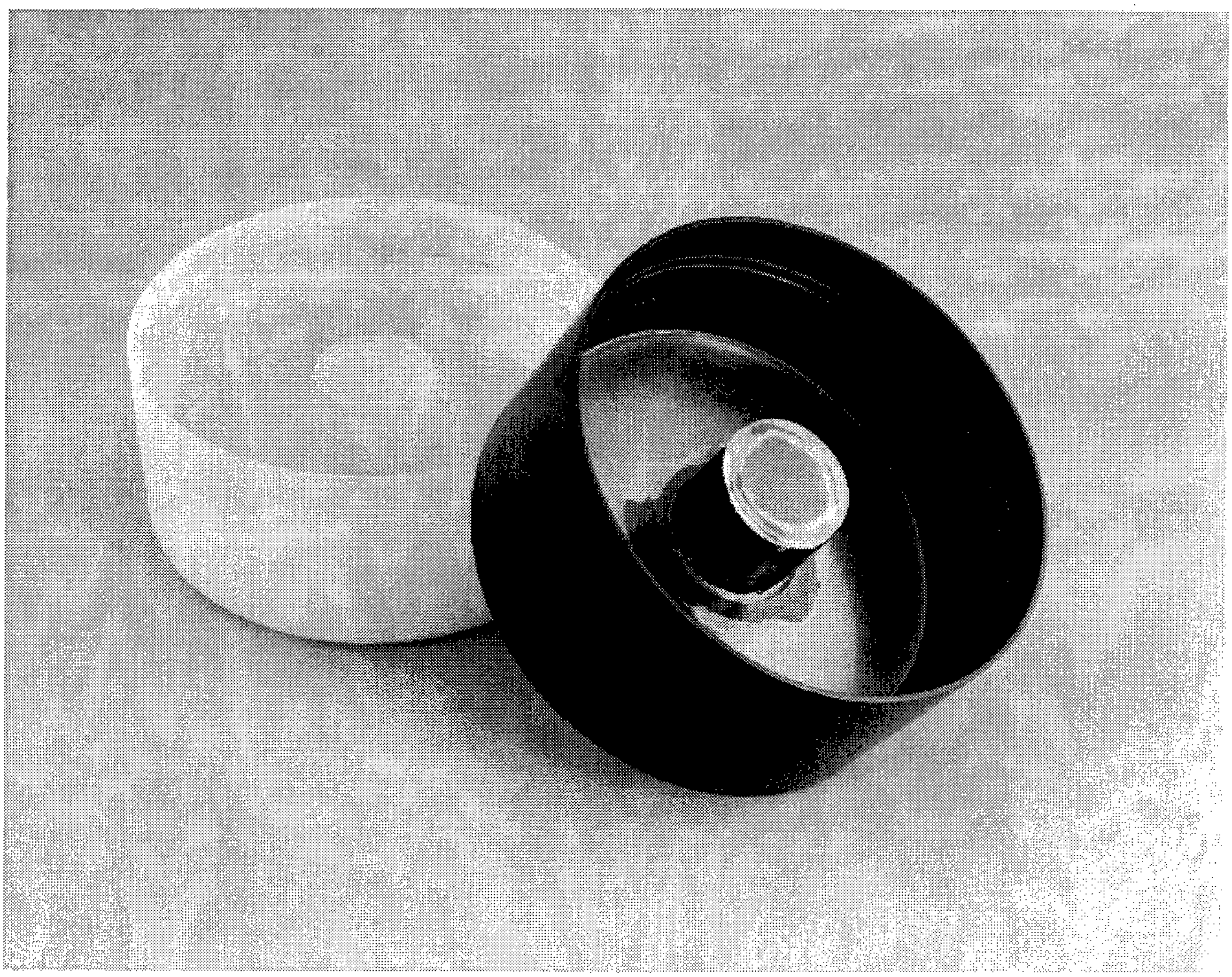

Figure 5 - Covers made of A-scale (black) and D-scale (natural) durometer urethane.

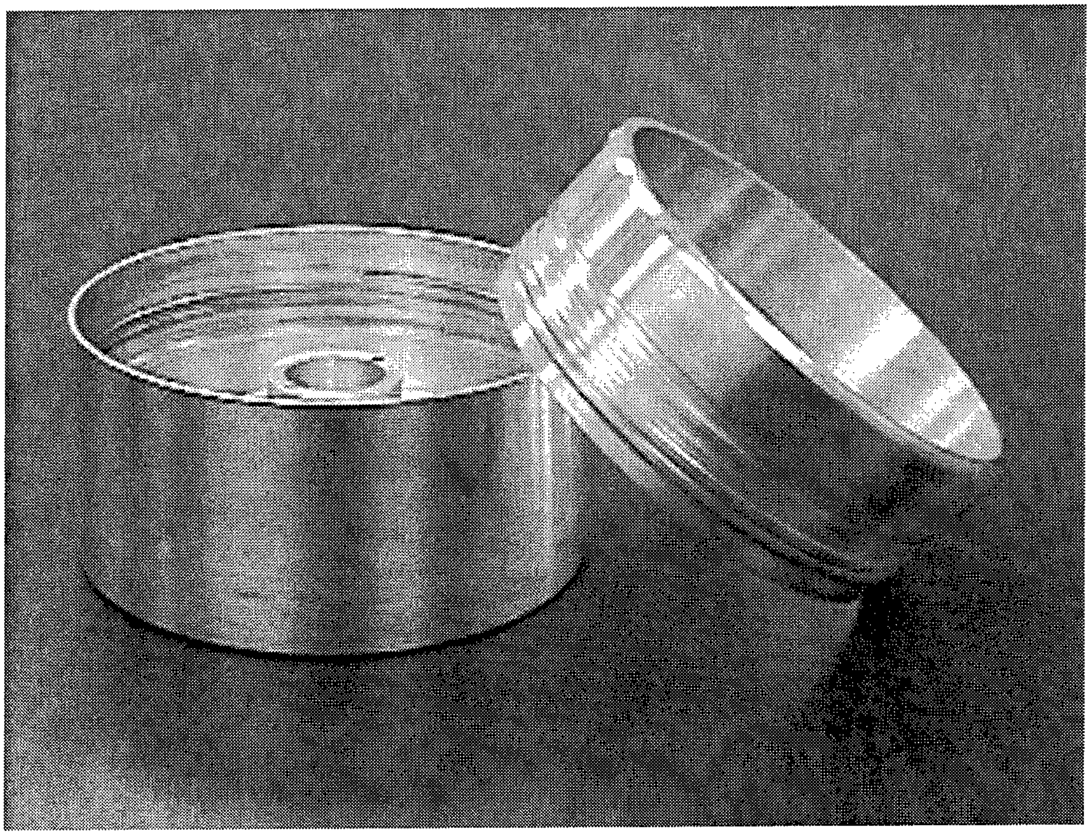

Figure 6a - Aluminum simulant of top cap with new thread and gasket design.

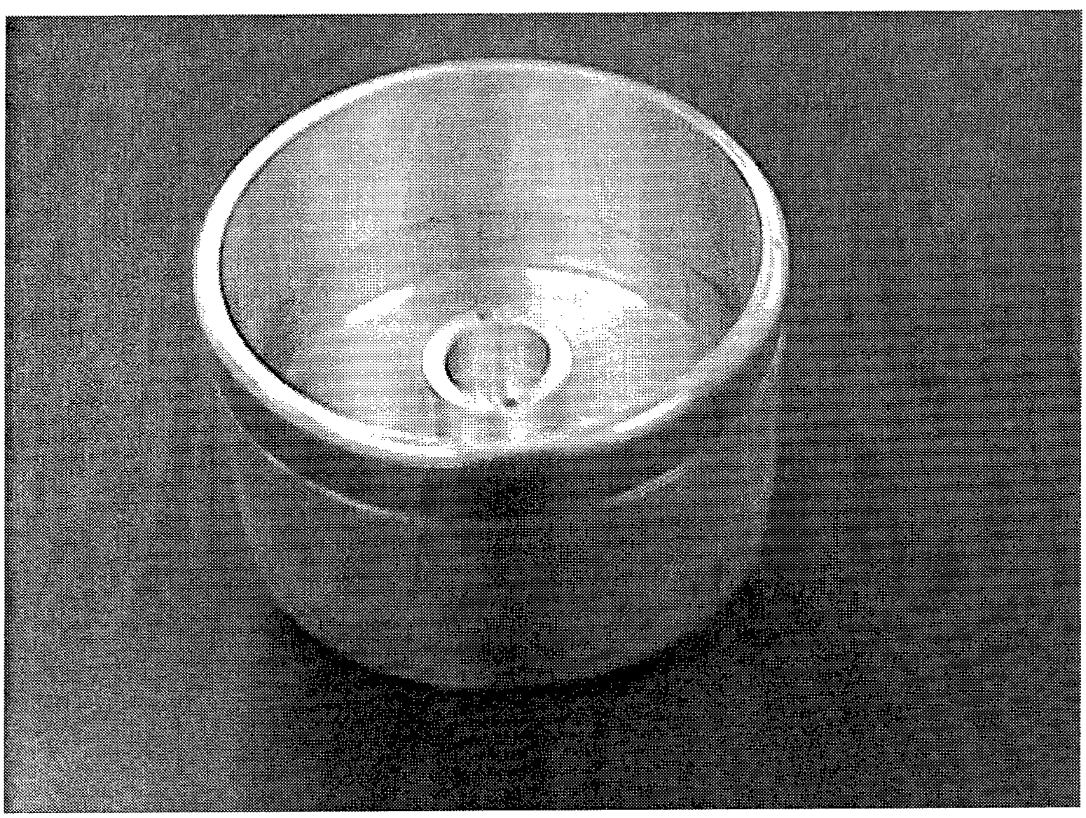

Figure 6b - Assembled view of aluminum cover simulant.

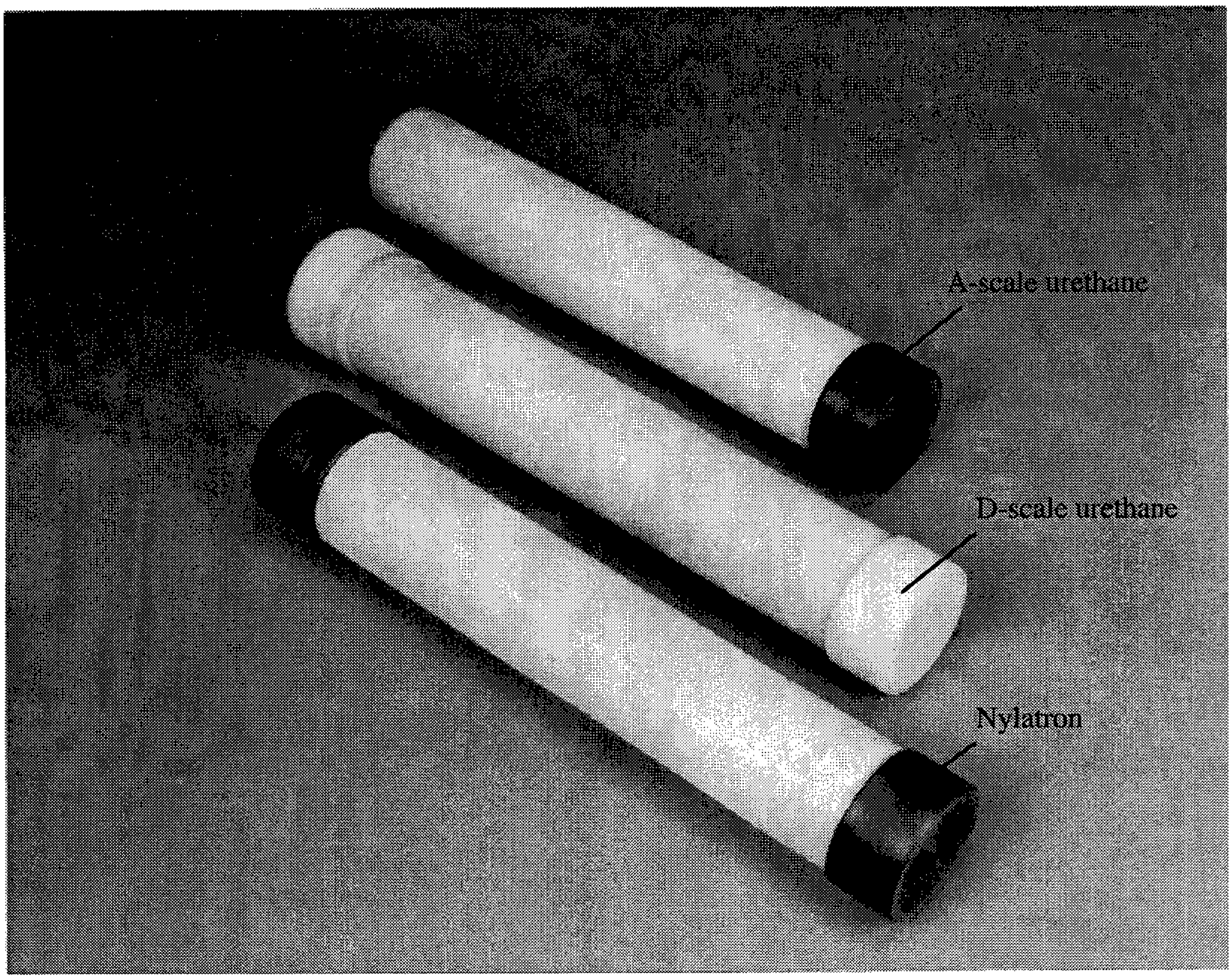

Figure 7 - Three prototypes with different endcap materials.

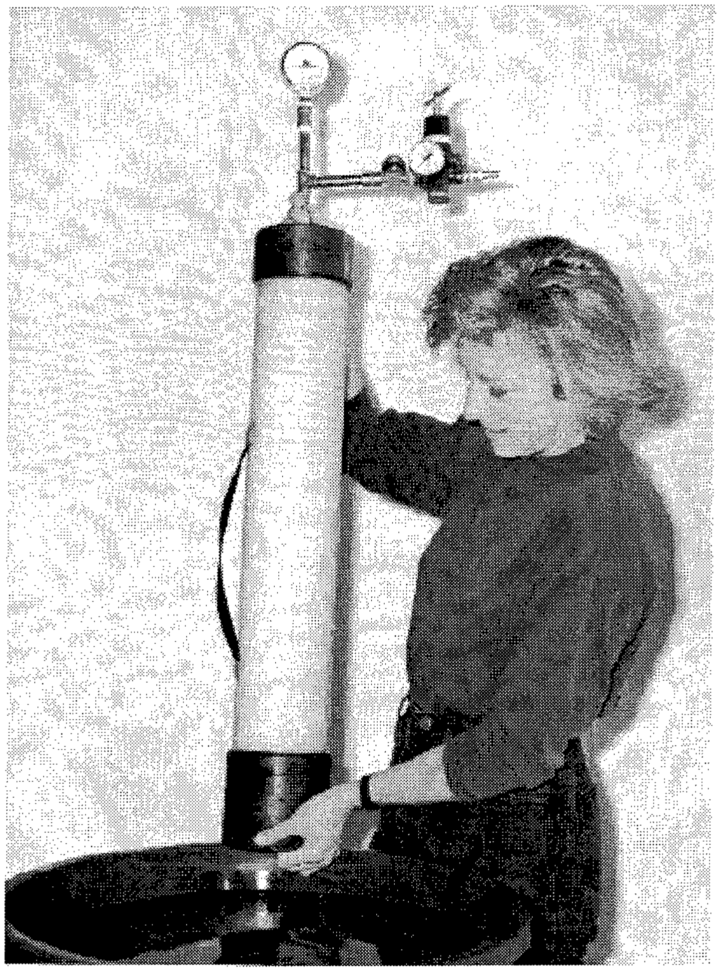

Figure 8 Pressurization/water tank test on container gasket seal.

Figure 9 - The A-scale urethane cover was shattered during the drop test after being cryogenically cooled to a temperature of -65 degrees F.

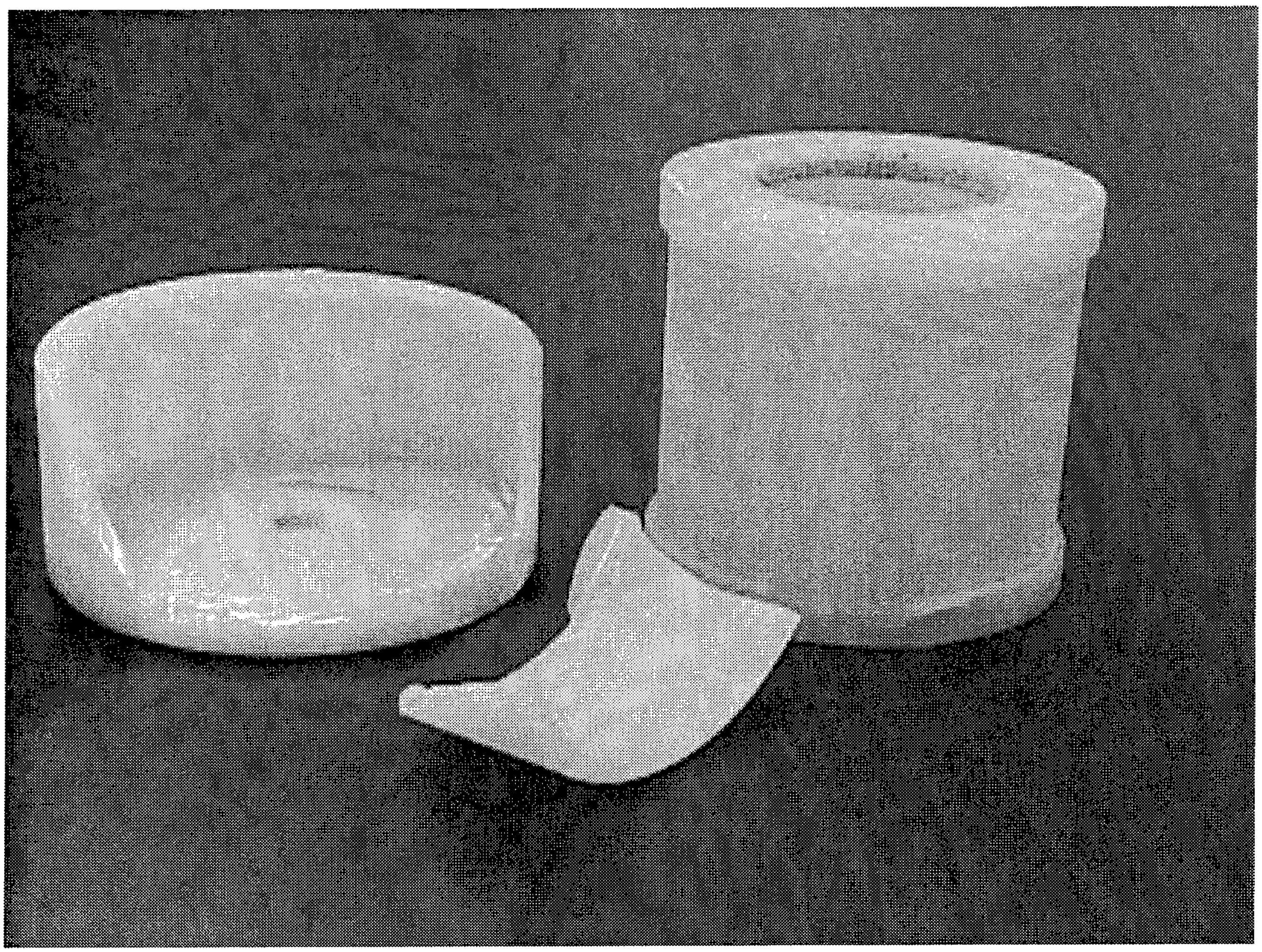

Figure 10 - The D-scale urethane bottom cap after the "cold-soaked" drop test that broke the bond between the bottom cap and the cylinder.

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