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Two synthetic insulating materials developed for military clothing and sleeping bags by Albany International Research Co. (AIRC) were evaluated by the U.S. Army Natick RD&E Center (Natick). The materials consist of polyester fiber in two forms: a bonded staple-fiber batt, and a spread continuous filament tow. The materials were evaluated for thermal, compressive, and water repellent properties. Laundering durability was also assessed. A commercially available synthetic insulation and waterfowl down were evaluated at the same time to allow a direct comparison. The bonded staple fiber insulation performed very well in all laboratory testing, but suffered a significant degradation in properties after 10 cycles of military field laundering. The continuous filament insulation performed well in all areas except for deficiencies in water-repellent properties. The continuous filament insulation suffered less of a degradation from military field laundering than the bonded staple fiber insulation.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

PREFACE

This study was conducted to evaluate two new thermal insulation materials intended for use in military clothing and sleeping bags. These materials were developed by the Albany International Research Company (AIRC) under contract to the U.S. Army Natick RD&E Center (Natick). Mr. Stephen Fossey and Ms. Peggy Goode of the Materials Research and Engineering Division, Individual Protection Directorate, served as project officers. Ms. Deidre Rapacz, also of the Materials Research and Engineering Division, provided technical assistance and guidance throughout the program.

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LABORATORY EVALUATION OF TWO NEW HIGH-PERFORMANCE POLYESTER BATTING THERMAL INSULATION MATERIALS

1. INTRODUCTION

This report summarizes the performance properties of two new synthetic insulating materials, developed by the Albany International Research Company (AIRC) under contracts funded and monitored by the U.S. Army Natick Research, Development, and Engineering Center (Natick)[1,2,3].

Developed to duplicate the insulation and compressional properties of waterfowl down in a form suitable for military clothing and sleeping bags, the materials approach, or surpass, down's properties. They also cost less per pound than waterfowl down, although they do cost more than other commercially available polyester batting insulation materials. They avoid down's major deficiencies, which are moisture retention and loss of insulating value when wet, high cost, variable quality, and reliance on foreign supply sources.

Both of the two new polyester batting insulators are based on concepts outlined in a patent granted to AIRC[4]. The fiber size distribution in AIRC's "Synthetic Down" mimics the fiber size distribution of waterfowl down. Relatively large diameter fibers support a much larger number of very fine fibers. The large diameter fibers are equivalent to the main quill and branches of a down cluster. The small fibers simulate the fine fibrillae and filaments near the end of down cluster branches. The very fine fibers (less than 12 μm diameter) in both down and the new synthetic insulation provide the bulk of the insulating performance by minimizing convective and radiant heat transfer. The large diameter fibers provide the mechanical properties necessary for high loft and recovery from compression.

The two insulator battings developed by AIRC (and evaluated in this report) consist of 100% polyester fiber in two batting forms; a bonded staple-fiber batt, and a spread continuous filament tow. A short description of each type of insulation is given in the next section. Further details may be found in a series of technical reports published by Natick[1,2,3].

2. MATERIALS AND METHODS

MATERIALS

Bonded Staple-Fiber Batt

The bonded staple-fiber batt insulator developed by AIRC has been given the trade-name Primaloft®. This insulator has generated the most interest as a direct replacement for waterfowl down. Primaloft® is now being produced commercially by Albany International.

Primaloft® consists of 85% 0.5 denier (7.7 μm diameter) polyester cut staple fibers and 15% of a 4 denier (20 μm diameter) bi-component polyester/binder fiber. The bi-component polyester fiber, when processed through a bonding oven, serves to bind the fibers together as well as stiffening the fibrous matrix. A polydimethylsiloxane finish aids in water repellency and laundering durability. The Primaloft® supplied to the government also included a 0.3 to 0.5 oz/yd² non-woven scrim. The bonded staple-fiber batt is referred to hereafter in this report as "Primaloft® ."

Spread Continuous Filament Tow

AIRC also produced a quantity of batting formed from continuous polyester filament. This batting performed quite well in laboratory testing, but commercial development of the continuous filament insulator has not been pursued to date.

The spread continuous filament tow consists of 100% 1.2 denier (11.5 μm) continuous polyester filaments. A silicone finish was applied to the fiber for water repellency and launderability. A curable methylacrylate surface bonding agent was also sprayed on the continuous filament batt to provide some stabilization of the fibrous structure. The adhesive required curing in an oven after the batt was manufactured. The spread continuous filament tow insulation is referred to in this report as "Albany International (A.I.) Continuous Filament."

Continuous filament insulation is preferable for sleeping bags with a shingle-construction design. In these bags, panels of insulation overlap each other like the shingles on a roof, and are secured at several stitch lines to the next overlapping shingle as well as the shell and liner fabric of the sleeping bag. This is in contrast to conventional quilting in which insulation is locked into place by a stitched pattern which extends entirely through the insulation and the shell fabric. Shingle panels are quite free to move during laundering and handling. Since continuous filament insulation is more durable, it is preferred over the staple-bonded type insulation for applications of this sort.

Two other high performance insulation materials were tested at the same time as the Albany International materials to allow a direct comparison with commercially available materials. Water-repellent-treated waterfowl down provided one standard of comparison.

Polarguard® provided another standard. A short description of each type of standard insulation follows.

Waterfowl Down

The waterfowl down used in this study is the standard Tan-O-Quil-QM water-repellent-treated down[5]. Waterfowl down is used in two military sleeping bags. The sleeping bag for the cold weather aircraft survival kit (MIL-S-44220(GL)) contains a 100% waterfowl down fill. The U.S. Army's extreme cold sleeping bag (MIL-S-43880) uses a combination of waterfowl down and polyester cut staple insulation.

Polarguard®

Polarguard® is a continuous filament polyester batting insulation developed by Hoechst-Celanese Corporation and manufactured by the Reliance Products Company. It conforms to MIL-B-41826 Type VII Continuous Filament Batting[6]. Polarguard® 's water-repellent fiber finish and spray adhesive are similar to those used for the A.I. Continuous Filament insulation. However, the Polarguard® fiber, with a diameter of approximately 5 denier (20 μm), is much larger than the A.I. Continuous Filament fiber, which has a diameter of 1.2 denier (11.5 μm).

Polarguard® is used in the U.S. Army's sleeping bag for the Extreme Cold Weather Sleep System (ECWSS) (Mil-44309). This sleeping bag is of shingle construction design, which takes advantage of the characteristics of Polarguard® 's durable continuous filament batting. Note that the ECWSS bag is not the same as the extreme cold sleeping bag, which was described above in the waterfowl down section.

Thus, a total of four high-performance insulation materials were evaluated. Earlier versions of Primaloft®, which had a slightly different fiber size distribution, a heavier scrim, and different areal densities, were also evaluated during this test series. However, the test data on these earlier versions of Primaloft® are omitted from this report for the purposes of clarity.

All testing of the Primaloft® insulation included the nonwoven scrim on both sides. The scrim enhances handling and sewing Primaloft® into clothing items. The scrim was included as an integral part of the Primaloft® system, since it would most likely be included in any sleeping bag or clothing item which incorporates Primaloft®. The scrim weight contributed 0.35 oz/yd² to the weight of the Primaloft® samples.

TEST METHODOLOGY

The Primaloft® and A.I. Continuous Filament insulation materials were evaluated by a range of different test methods to fully characterize the materials' thermal properties, mechanical/compressive properties, and laundering durability.

Thermal Properties

The thermal properties of the four insulations were measured by two methods: 1) Guarded Hot Plate, and 2) Heat Flow Meter (Rapid "K" Thermal Conductivity Instrument).

The Guarded Hot Plate tests were conducted according to ASTM D1518 - Thermal Resistance of Textiles Between Guarded Hot Plate and Cool Atmosphere[7]. This test gives the thermal resistance (reported in units of clo) of an uncompressed sample lying on a heated plate and surrounded by a cooler atmosphere. The clo value reported is the intrinsic clo value for the material, with the thermal resistance of the plate and boundary air layer subtracted out. One unit of clo is equivalent to 0.88 hr-ft^2-°F/BTU. The surface temperature of the guarded hot plate was maintained at 92°F and the air temperature at 50°F.

The Heat Flow Meter tests were conducted according to ASTM C518-85, Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter[8]. The Heat Flow Meter tests use a heated upper plate and a refrigerated lower plate in contact with the upper and lower surfaces of the test sample. The distance between the upper and lower plate can be adjusted to determine the thermal resistance of the sample under varying degrees of compression and at various bulk densities. The thermal conductivity of samples tested in the Heat Flow Meter apparatus are reported in units of (Btu-inch)/(hour-ft^2-°F). The upper plate temperature was 95°F and the lower plate temperature was 55°F. The two methods differ in their heat flow direction, which also affects heat transfer characteristics. In the guarded hot plate tests, since the direction of heat flow is upwards, the importance of convection through the fibrous batting structure is included in the thermal resistance measurements. The Heat Flow Meter testing eliminates this convective heat flow since in this case the direction of heat flow is downwards. The Heat Flow Meter testing also eliminates the layer of insulating air over the sample which is present in the guarded hot plate tests. The use of both of these test methods thus permits a more complete characterization of the insulating properties of the test materials.

Compressive Properties

The compressive properties of the four insulators were determined using a compression load cell mounted in an Instron automated testing machine. The measured values include: 1) work to compress from .002 psi to 5 psi, 2) work of recovery from 5 psi to .002 psi, 3) compressive strain at 5 psi, 4) strain recovery from 5 psi to .002 psi.

The gauge lengths of each sample were all different, and were measured at the "touch density" of .002 psi. Since the sample thicknesses are different, the values of work of compression and work of recovery are not directly comparable. In this report the work of compression values are "normalized" to the values for a one-inch thick sample. This at least provides a means of comparison for the work of compression values for the four insulations, although it is probably not as accurate as using the actual work of compression values measured at identical gauge lengths.

On the other hand, the reported resilience values do use the actual work to compress and work of recovery values measured during the Instron tests. Resilience is defined as the work to compress to 5 psi divided by the work of recovery back to .002 psi.

Water Repellent Properties

The water repellent properties of the four insulators were determined by immersing insulator samples in water. Two different immersion times were used. The first trial immersed the samples for a 20 minute period, and the second trial immersed the samples for six hours. Each sample was completely submerged for the specified amount of time. The samples were not compressed or agitated while submerged. After removal from the water, the samples were gently shaken to remove excess water from the surface and were then allowed to drain for about two minutes on a wire rack before being weighed and measured.

The weight gain due to water pickup and the associated thickness loss were used to report the percentage loft retention, the percentage density increase, and the absorptive capacity of each sample.

Wet Thermal Conductivity

The thermal conductivity values of the four insulation materials were measured after they had been soaked in water. For these tests the insulation samples were submerged for 20 minutes. The samples were compressed while under water to soak up as much water as possible. The samples were then allowed to drain for 10 minutes, gently compressed and shaken to remove excess water, and measured for thickness and weight. Each sample was then tested with the Heat Flow Meter to determine its wet thermal conductivity.

Laundering Durability

Laundering samples were fabricated from each of the three synthetic insulators. Waterfowl down was not included in the laundering durability evaluation, but laundering data on down was available from a previous study[9]. The laundering samples consisted of batting covered with a nylon taffeta fabric[10] (MIL-C-21852 Type III). The samples were channel-quilted with 6 inch wide channels. Each sample was a square approximately 24 inch on a side (about the size of a guarded hot plate thermal test sample). The samples were marked for dimensional stability to determine if the batting shrank significantly during laundering.

The thermal properties of each quilted sample were measured before laundering. After laundering, the thermal properties were again measured, and the quilted sample was dissected. The laundered batting was examined for evidence of fiber migration and shrinkage. The thermal properties of the dissected laundered batting were measured once more for comparison with the unlaundered batting. Compression testing and water repellency tests were also conducted on many of the laundered batting samples to determine how laundering affected these properties of the synthetic insulators.

Laundering Conditions

Several laundering conditions were used during the laboratory evaluation of these synthetic insulation materials. Three laundering methods were used: 1) Laundry and Dry Cleaning Decontamination System (LADDS), 2) Army Field Laundering Procedure[11], DA FM 10-280, Formula II, 3) Method 5556 - Cotton Procedure - Federal Test Method Standard 191[12]. A brief description of each laundering method is given below.

The Laundry and Dry Cleaning Decontamination System (LADDS) laundering procedure is an experimental procedure under development for the U.S. Army. Since LADDS uses Freon® solvent it will probably not be approved due to environmental reasons, but a similar method based on a different solvent will probably be in use soon.

A commercial dry cleaning unit was used to clean the samples. The unit used Freon®113 solvent. No detergents were added to the solvent. Solvent at ambiant temperature (60°F) was continuously applied to the wash load at 60 gallons per minute for eight minutes. Solvent was extracted from the samples at 350 rpm for three minutes. The samples were then dried with hot air at 130°F for 16 minutes. The LADDS procedure is the least harsh of the three laundering methods.

The Army Field Laundering Procedure is the standard military laundering procedure used for soldiers' clothing and equipment. It is referred to hereafter in the text and tables as FM 10-280. Formula II of FM 10-280 is used to launder woolen items, sleeping bags, and winter clothing. It consists of wash and rinse cycles using water at 90°F and a dryer temperature of 130°F.

Method 5556 - Cotton Procedure - Federal Test Method Standard 191 is referred to hereafter as CTN 5556. It is the harshest of the three laundering methods in terms of the water temperature used. The wash temperature is 140°F and the drying temperature is 135°F.

The number of laundering cycles was also varied, as well as the ballast included with the samples. Ballast is extra material included in the wash load to make sure that a standard load weight or volume is included in each wash cycle. Two different types of ballast were used. The first type was normal cotton cloth ballast. This ballast tended to beat the quilted insulation samples quite severely during the washing and drying cycles and caused a large decrease in sample thickness. A quilted batting ballast was used for other laundry trials. The quilted ballast caused less of a thickness decrease for the insulation upon laundering.

The various laundering conditions are given in Table I., in order of increasing severity. This nomenclature is also used in the various tables and plots given later in this report.

Table I. Laundering Conditions

Laundering Method	*Number of Cycles*	*Ballast Type*
LADDS	3	Batting
FM-10-280	3	Batting
FM-10-280	3	Cloth
CTN 5556	3	Batting
CTN 5556	3	Cloth
FM-10-280	10	Cloth
CTN 5556	10	Cloth

3. RESULTS AND DISCUSSION

UNLAUNDERED BATTING SAMPLES (NO COVER FABRIC)

Thermal Properties

The results of testing all four insulation materials in the Heat Flow Meter Testing Instrument are presented in Figure 1. The data for the unlaundered batting materials are contained in Table A-1 in Appendix A.

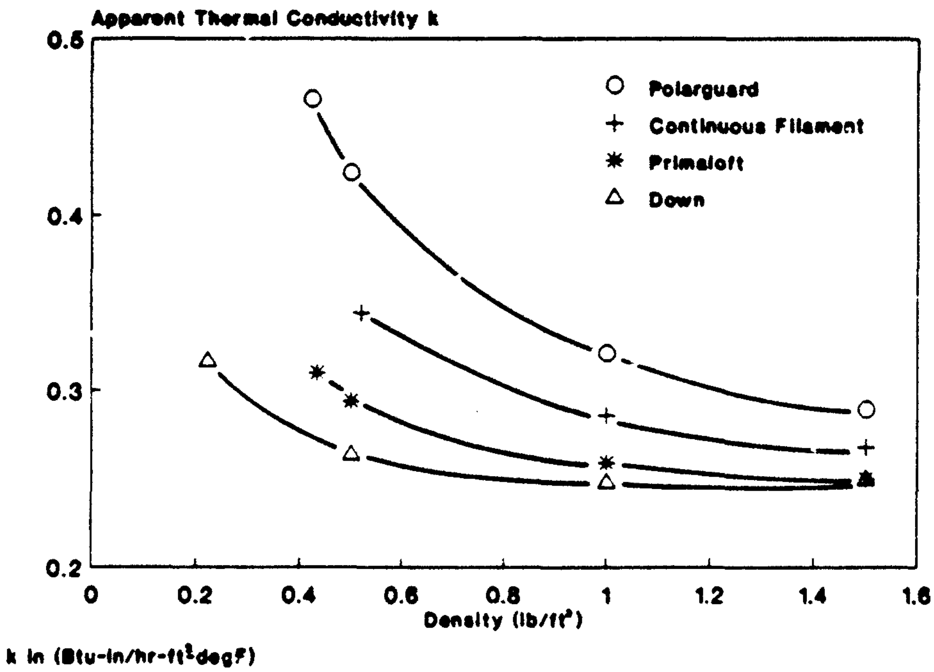

Figure 1. Apparent thermal conductivity K versus bulk density for four insulation materials.

Primaloft® outperforms both Polarguard® and the A.I. Continuous Filament insulation over a wide range of bulk densities. Primaloft® is not quite as good an insulator as down at very low bulk densities (below 0.5 lb/ft³) but at higher densities, which are closer to the densities used in clothing and sleeping bags, Primaloft® is essentially as good an insulator as down.

The Heat Flow Meter apparatus compresses the insulation between parallel plates, with the hot plate at the top. Convection through the batting is minimized and the presence of a quiescent insulating air layer at the top surface of the insulation is eliminated.

Guarded Hot Plate tests allow the importance of convection and the insulating air layer to be included in the thermal resistance measurements. The next series of plots, Figures 2-4, show the thermal properties (from the Guarded Hot Plate) of the three synthetic insulators. The data for these plots are given in Table A-2, Appendix A. Guarded Hot Plate test data for waterfowl down are not included in these plots, since loose waterfowl down is difficult to evaluate in the apparatus. A comparison between down and the three synthetic insulation materials is available in the quilted samples section, which follows later in this report.

Figure 2 shows the intrinsic thermal resistance, in units of clo, for the three synthetic insulations. The insulation values obtained with the guarded hot plate apparatus are comparable with the values obtained from the Heat Flow Meter apparatus. Primaloft®'s intrinsic clo value is still more than twice as high as that of Polarguard® .

Figure 3 presents intrinsic clo values divided by the batting thickness. This is a measure of insulating efficiency based on minimizing the bulk of insulation required to provide a given degree of thermal insulation. Primaloft® is again seen to give high values in both intrinsic thermal resistance and insulating efficiency per unit of thickness.

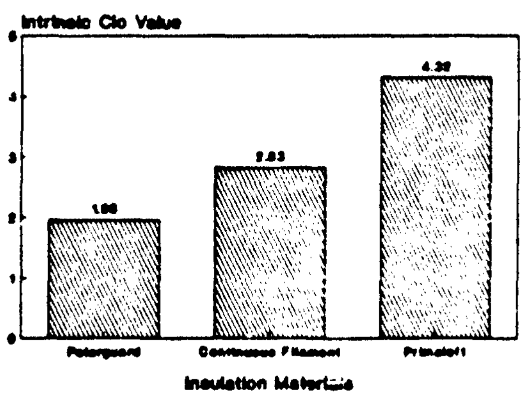

Figure 2. Intrinsic Clo Values, Batting Samples.

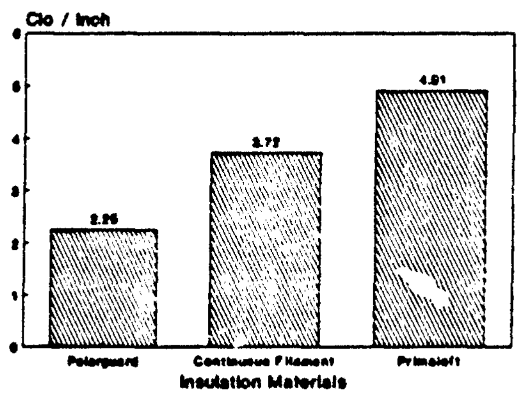

Figure 3. Clo/Inch Values, Batting Samples.

Another measure of insulating efficiency is the thermal resistance given per unit areal density. This provides a measure of the insulation provided per unit weight, which is important when one is trying to reduce the load carried by soldiers. Figure 4 shows that the relative insulating efficiency of Primaloft® is again much higher than Polarguard®.

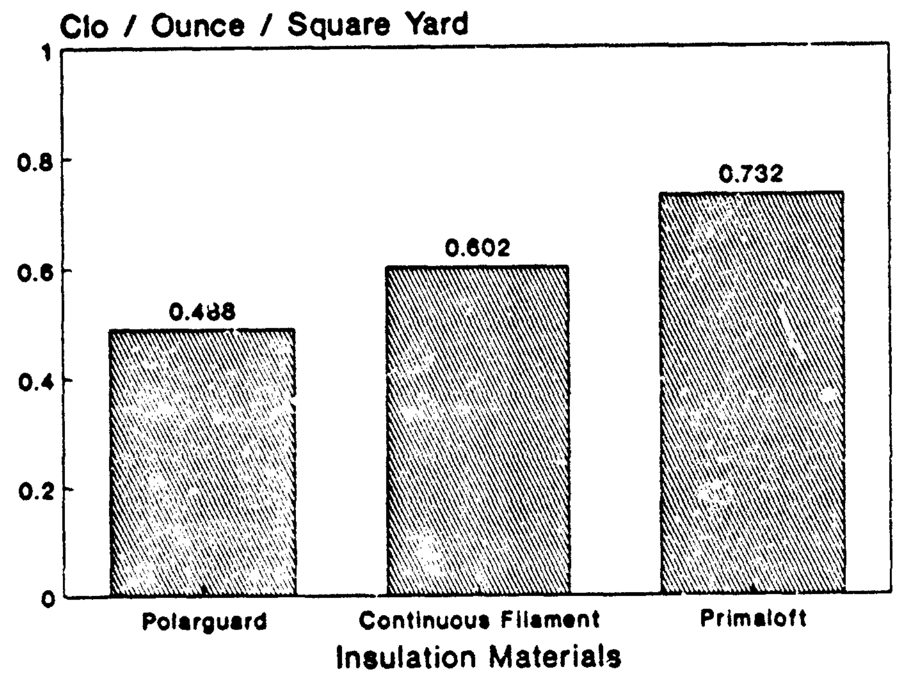

Figure 4. Relative insulating efficiency, Clo/Ounce/Yard², for three batting materials.

Compressive Properties

The compressive properties of the three synthetic insulation materials, along with waterfowl down, are given in Figures 5-8. The data comes from Table A-3 in Appendix A.

Figures 5 and 6 show compressional strain and compressional recovery from a stress level of 5 psi. Five psi is a bit higher than the highest level of stress experienced by the bottom layer of a sleeping bag from the compression due to a person lying on top of it (nominally 3 psi)[13]. The compressional strains for the three synthetic insulation materials are approximately the same. The down shows a higher resistance to compression, which means it would provide slightly more insulation due to its greater thickness.

In terms of compressional recovery (Figure 6), Primaloft® outperforms the other insulation materials, including waterfowl down. However, this recovery is measured back to the stress level of .002 psi, and does not include any "fluffing," which would undoubtedly restore all the insulating materials to a greater thickness, especially down.

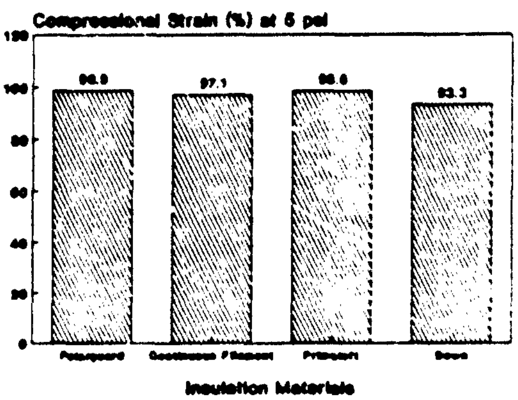

Figure 5. Compressional Strain at 5 psi for four materials.

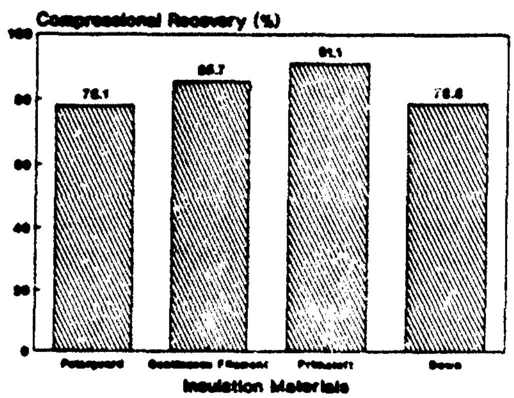

Figure 6. Compressional Recovery from 5 psi for four materials

Figure 7 shows the work to compress values for the four materials. Work to compress is the area under the load-displacement curve between the limits of .002 psi and 5 psi. It gives an idea of the work required to compress insulation down to a given volume. Generally, the lower the value of work to compress, the better. A low work of compression value should mean that a sleeping bag material can be more easily stuffed into its storage sack, and that garments offer less resistance to arm and leg movements. Primaloft® has the lowest work to compress values of any of the insulations tested. The work to compress values in Figure 7 are normalized to a standard 1 inch sample thickness.

Resilience is a measure of the ability of an insulation material to store energy upon compression and release it when the stress is removed. An insulation shouldn't become permanently compressed when it's squeezed down for storage. Primaloft® also had the highest resilience of the four insulation materials tested, as shown in Figure 8. The resilience values are derived from the measured work to compress and work of recovery values, not the normalized values in Figure 7.

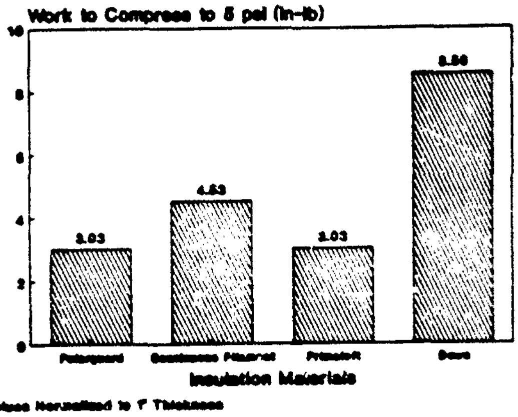

Figure 7. Work to Compress to 5 psi for four materials.

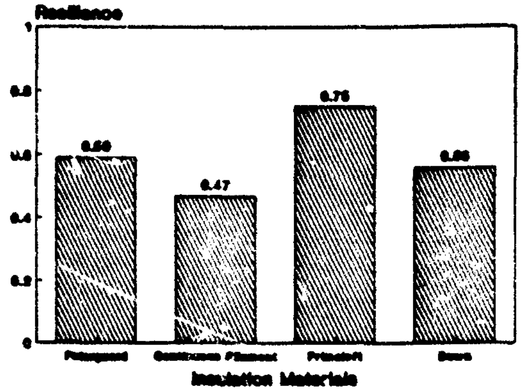

Figure 8. Resilience (work to compress divided by work of recovery) for four materials.

It should be noted that several of these measurements contradict hands-on experience. For example, down sleeping bags and jackets are much easier to compress and stuff into storage sacks than comparable items made with polyester insulation. Yet Figure 7 shows that down has a much higher work to compress value than the synthetic insulation. The reason for this discrepancy lies in the way the materials were tested.

The test direction for the synthetic insulation materials was through the batt thickness. In the synthetic insulation materials most of the batt fibers are aligned parallel to the surface of the insulation. There are comparatively few fibers perpendicular to the insulation surface which would provide much resistance to compression. Therefore, the measurements of work to compress values of synthetic insulation materials were very low. If one were to measure compression properties along the batt machine direction, where the fibers are in line with the test direction, the work to compress values would be much greater.

In contrast to the anisotropic mechanical properties of synthetic insulation materials, waterfowl down is isotropic. The work to compress values are independent of the test direction.

The compression values presented in this report are valid only for comparing insulation under conditions such as the compression of insulation in a sleeping bag under the weight of a person, or the resistance of insulating clothing items to leg and arm movement. In these cases the compression properties through the thickness are the most important properties.

These measurements are not valid for evaluating the "stuffability" of insulation materials. The anisotropic nature of synthetic insulation becomes much more important during the compression of these materials into storage sacks. Measurements of the compressive properties of synthetic insulation in all three orthogonal directions would be necessary for a valid comparison between these materials and waterfowl down.

Water Repellency

The water repellency of the four insulation materials varied quite a bit. The two continuous filament insulations (Polarguard® and the A.I. Continuous Filament) both soaked up much more water than the Primaloft® and waterfowl down. AIRC[4] has attributed this increased water absorbency to the spray adhesive used to stabilize both types of continuous filament insulation.

The water repellency test results for the unlaundered insulation materials are contained in Figures 9-11. The tests were conducted for both a 20 minute immersion time and a six hour immersion time. The data for these figures are contained in Table A-4 (20 minutes immersion) and Table A-5 (six hours immersion) in Appendix A.

Figure 9 shows the absorptive capacity of all four materials. Absorptive capacity is defined as the wet weight divided by the dry weight. Both the Primaloft® and the down performed similarly in water absorption, and there wasn't much difference between being immersed for 20 minutes or six hours. Both the Polarguard® and the A.I. Continuous Filament insulation picked up a lot of water, which is attributed to the presence of a hygroscopic adhesive sprayed on the batt.

Figure 10 shows the loft retention of the materials. Loft retention is defined as the wet thickness divided by the dry thickness. All the synthetic insulation materials out-performed down in this regard. Loft retention when wet is an important property of an insulator, since the thicker the material the more insulation it will provide. Primaloft® out-performed all three other materials, including waterfowl down, in this area.

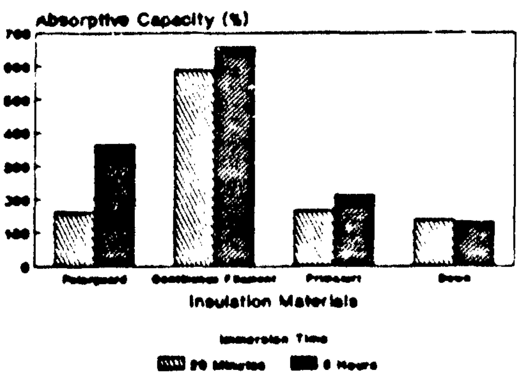

Figure 9. Absorptive capacity after immersion of four insulating materials.

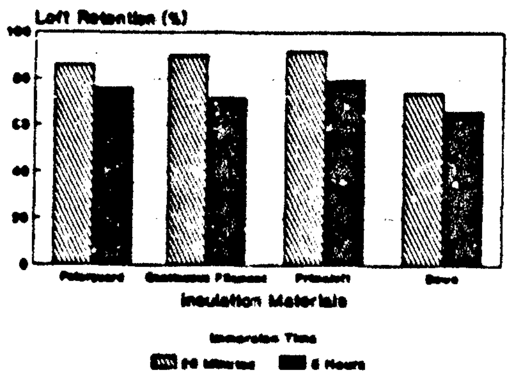

Figure 10. Loft retention after immersion of four insulating materials.

Figure 11 shows the density increase of all four insulating materials for the two different immersion times. The percent density increase is defined as the difference in the wet bulk density and the dry bulk density divided by the dry bulk density. The percent density increase combines both the decrease in thickness due to loss of loft and the increase in weight due to water absorption. Materials which have a high density increase would put an increased work load on someone who had to carry items containing them as well as providing less insulation. Primaloft® and waterfowl down are comparable in this performance measure, while the two continuous filament insulations are deficient due to the high amount of water pick-up.

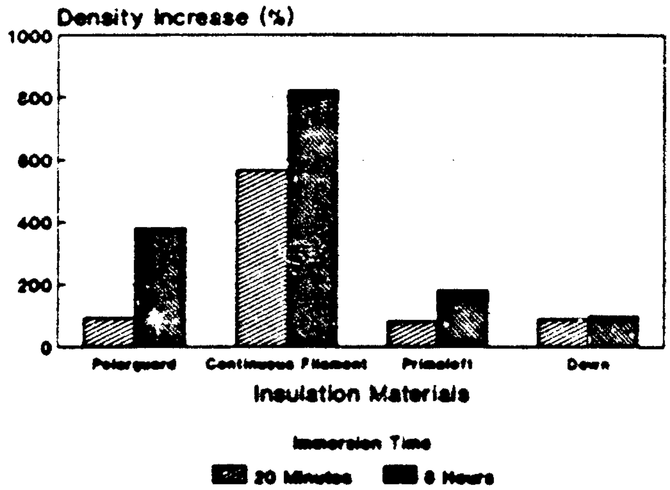

Figure 11. Percent density increase due to water absorption for four unlaundered insulating materials.

The water repellency test results presented here can be misleading. There was no agitation of the test samples while they were submerged. Using this test method, waterfowl down did not soak up much water compared to the other insulations. After the non-agitated tests were completed the test samples were squeezed under water to make them soak up as much water as possible. It was apparent that the water soaked up by the synthetic insulation materials could be removed by a vigorous shaking of the samples, but the waterfowl down remained a sodden lump of feathers that took much longer to dry out. No reliable method for testing for the "agitated" immersion of insulation could be developed, but these observations should be kept in mind when reviewing the water repellency data contained in this report.

Wet Thermal Conductivity

The thermal conductivities of the three synthetic insulation materials and down were tested after being exposed to water as described in the Test Methods section. Figure 12 shows data for the two continuous filament insulations and Figure 13 shows data for Primaloft® and waterfowl down.

The thermal conductivities were determined at various thicknesses for both the wet and dry insulation materials. The wet thermal conductivity data is plotted against the equivalent dry density to allow a direct comparison between the wet and dry materials. The data for Figures 12 and 13 are contained in Table A-7 in the Appendix.

Both Primaloft® and the waterfowl down were encased in an identical polyester scrim material on both sides. The scrim added about 0.4 oz/yd² to the weight of each sample.

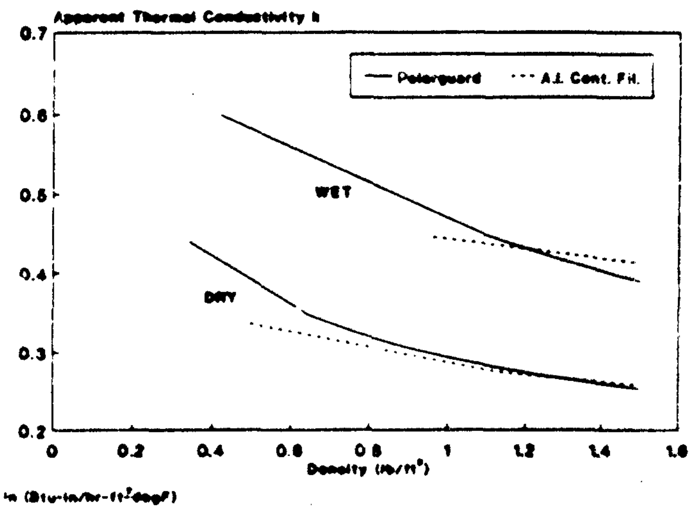

Figure 12. Wet thermal conductivity for Polarguard® and A.I. Continuous Filament insulation.

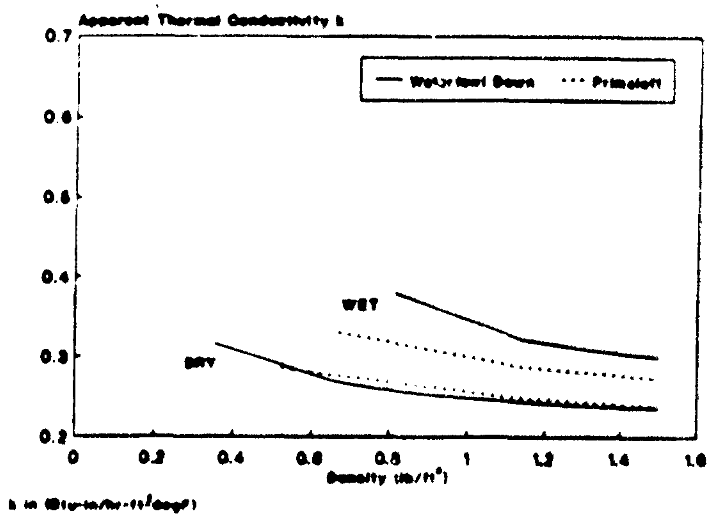

Figure 13. Wet thermal conductivity for Primaloft® and waterfowl down.

Both continuous filament insulations behave approximately the same when exposed to water. Their thermal conductivities increased by a large amount over a range of different thicknesses. The average increase in thermal conductivity for both insulations was about .15 Btu-in/hr-ft^2-°F.

Primaloft®'s thermal conductivity increased by a much smaller amount (.04 Btu-in/hr-ft^2-°F). Primaloft® retained much more insulating value when wet than the two continuous filament insulation materials. Primaloft® also lost less insulation than waterfowl down (down's thermal conductivity increased .07 Btu-in/hr-ft^2-°F).

UNLAUNDERED QUILTED SAMPLES

Thermal Properties

The initial properties of the unlaundered quilted samples are given in Figures 14-16. The addition of the nylon taffeta cover fabric and the channel quilting did not change the relative ranking of the insulations. The quilted down sample was constructed to have an areal density midway between the Polarguard® and Primaloft® samples. The data for these figures are contained in Table A-6, Appendix A.

Figure 14 shows that Primaloft® actually has a higher intrinsic clo value than waterfowl down when both are sewn into the channel-quilted configuration. Both Primaloft® and the A.I. Continuous Filament insulation also perform well in terms of clo per unit thickness as shown in Figure 15.

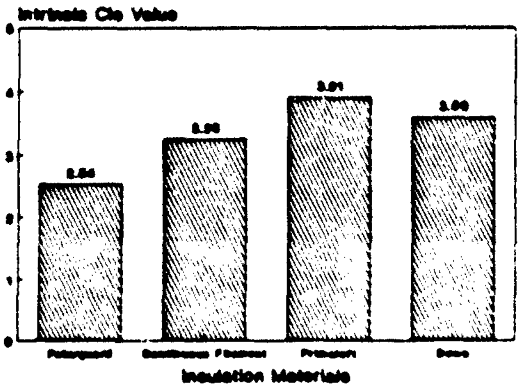

Figure 14. Intrinsic clo values for channel-quilted samples before laundering.

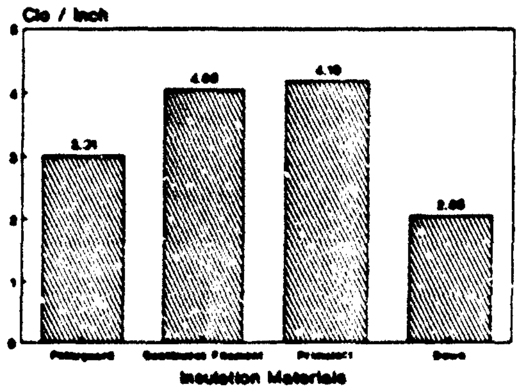

Figure 15. Clo per inch values for channel-quilted samples before laundering.

Figure 16 shows the relative insulating efficiency of each insulation on a weight basis. Down has a slight advantage over the other insulating materials due to its inherent high loft and light weight. In this channel-quilted configuration the advantage down holds over the synthetic materials is very slight.

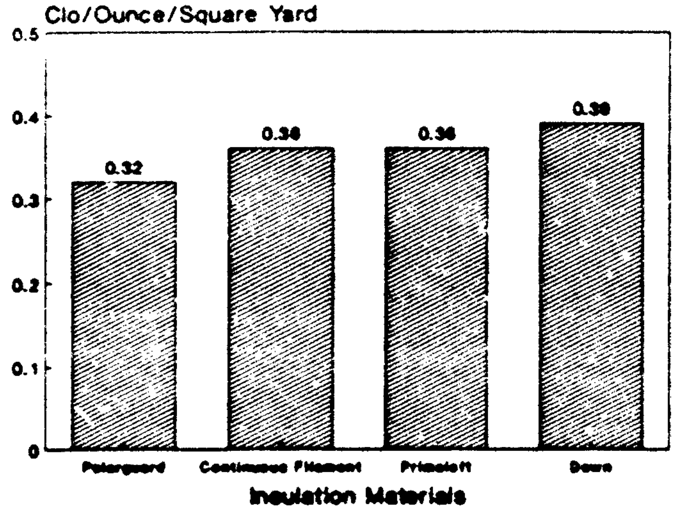

Figure 16. Relative insulating efficiency per unit areal density for four unlaundered insulating materials in the channel-quilted configuration.

LAUNDERED SAMPLES - GENERAL

All three synthetic insulation materials suffered a relatively large thickness loss and insulating loss when subjected to severe laundering conditions. Figure 17 shows sections cut from quilted samples after being subjected to 3 and 10 wash/dry cycles of the Field Laundering Procedure FM 10-280, Formula II. The 3-cycle samples were washed with batting ballast and the 10-cycle samples were washed with cotton cloth ballast.

10 Cycles 3 Cycles Unlaundered

Polarguard®

A.I. Continuous Filament

Primaloft®

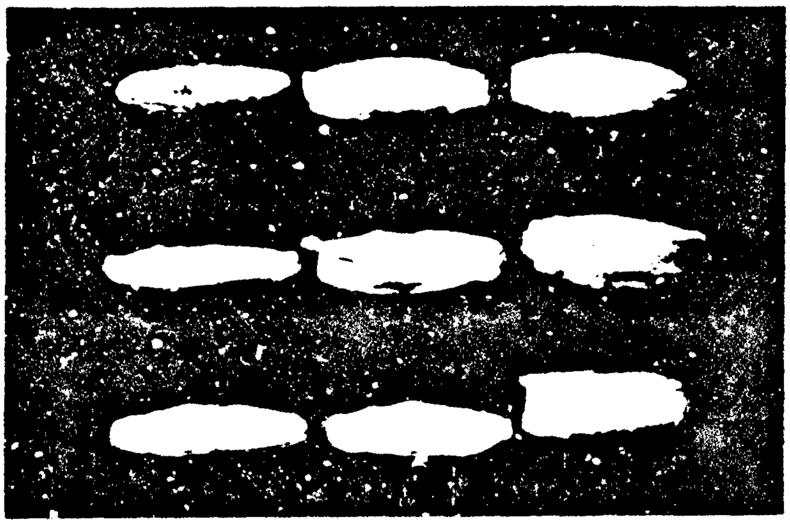

Figure 17. Three synthetic insulation materials after 3 and 10 wash/dry cycles of Field Laundering Procedure FM 10-280, Formula II (refer to Figure 21 for actual thickness reduction values).

Although the synthetic insulation materials suffered a relatively large thickness decrease after a few cycles of military laundering, there was no discernible fiber migration or shrinkage. No thick or thin spots developed in any of the laundered samples. There was no roping together or consolidation of batting fibers. Aside from the thickness decrease, the dimensional stability of all three of these batting materials is excellent.

The results of the laundering durability tests will be presented in two sections. The thermal properties of the laundered channel-quilted samples will be presented first. All these properties were measured using the guarded hot plate apparatus. The second section presents test results on the dissected laundered samples which have had the channel quilting and the nylon cover fabric removed. This allowed the properties of the batting to be remeasured to see how laundering affected the insulation itself. Thermal properties were measured with both the guarded hot plate and the Heat Flow Meter testing instrument. The compressional properties and water absorption properties of the laundered batting materials were also measured and are compared to the original measurements performed on the unlaundered batting.

For the purpose of clarity, most of the plots of laundered batting properties only show the data for field laundering conditions (FM 10-280, Formula II). Most of the plots show: 1) unlaundered sample properties, 2) properties after 3 wash/dry cycles, 3) properties after 10 wash/dry cycles. The 3-cycle field laundering test condition shown on the plots used quilted batting as the laundry ballast. The 10-cycle test condition used a heavier load utilizing cloth ballast and is thus a very severe laundering procedure. The data for all the other laundering conditions are included in the appropriate tables in Appendix A.

LAUNDERED SAMPLES - QUILTED

Thermal Properties

The thermal properties for the quilted samples subjected to 3 and 10 cycles of the field laundering procedure are shown in Figures 18-22. The data are contained in Table A-6 in Appendix A.

Figures 18-20 show that upon laundering there is quite a reduction in insulating value (due to thickness loss) for all of these insulation materials. Figure 18 shows that most of the insulation reduction takes place after the first three launderings, especially for Primaloft®, and that further laundering has less of an effect on the insulating value and thickness of these insulations. Primaloft® remains a much better insulator than Polarguard® through all the various laundering conditions, but the set of samples which were washed 10 times in the field laundering procedure showed little difference in intrinsic clo values between the three types of synthetic insulation. Figure 19 shows an increase in insulating value per unit thickness for all these materials. This is due to the large thickness reduction and the increased bulk density, which tends to increase the insulating value of fibrous battings. Figure 20 shows that the insulating efficiency in terms of clo per unit areal density also decreases dramatically for all of these insulations. Since the Primaloft® is inherently heavier than the other materials it suffers the greatest decrement in insulating performance in terms of insulating power per areal density.

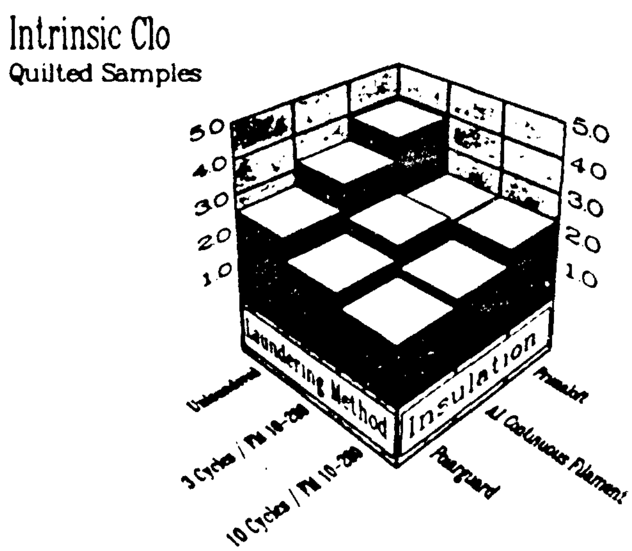

Figure 18. Intrinsic clo measurements for laundered channel-quilted insulation samples covered with nylon taffeta fabric.

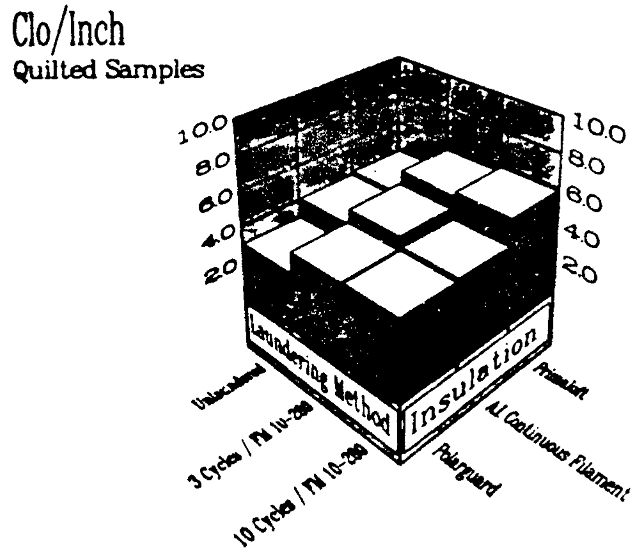

Figure 19. Intrinsic clo/unit thickness measurements for laundered channel-quilted samples covered with nylon taffeta fabric.

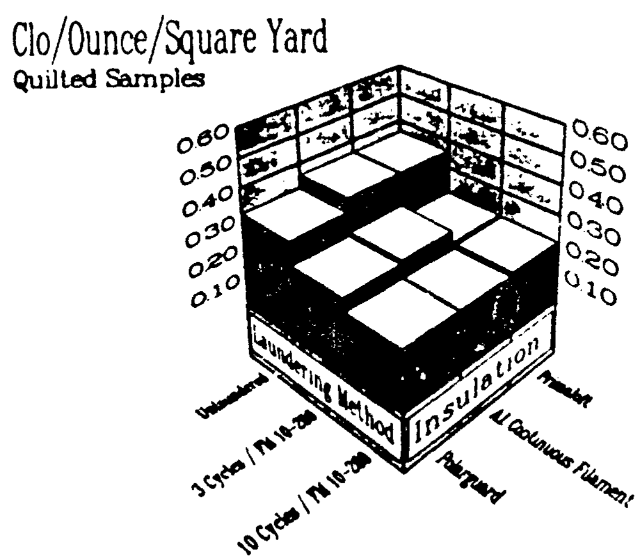

Figure 20. Intrinsic clo per unit areal density for laundered channel-quilted samples covered with nylon taffeta fabric.

Figure 21 shows the thickness loss of the quilted samples after laundering. Primaloft® showed the greatest thickness loss due to laundering. Primaloft® lost about 60% of its thickness for most laundering conditions. The A.I. Continuous Filament insulation performed best in this regard, losing approximately 40% of its thickness under most conditions. The Polarguard® was midway between the two Albany International insulation materials; it lost 40% to 50% of its insulation value after laundering. This thickness loss translates into a loss of insulating value for all these insulation materials. The amount of air trapped in the air spaces between fibers is what accounts for the insulating power of fibrous insulation, so a reduction in thickness means less dead air space is available in a clothing item or sleeping bag.

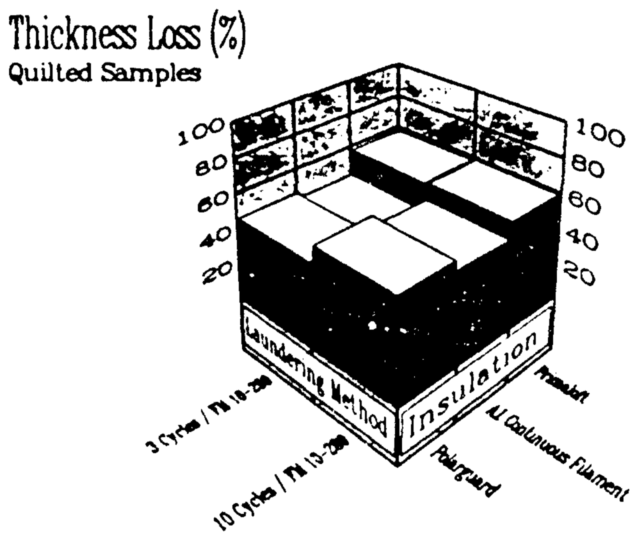

Figure 21. Thickness loss after laundering for channel-quilted samples covered with nylon taffeta fabric.

The intrinsic clo loss for each laundering condition is shown in Figure 22. After only three cycles of the military field laundering procedure, Primaloft® loses 40% of its insulating value. Polarguard® loses about 25% of its thermal resistance after three cycles of military field laundering and the A.I. Continuous Filament insulation loses 30% to 40% after three cycles. Primaloft® loses up to 50% of its intrinsic thermal resistance to heat flow after the most severe laundering condition (ten cycles of the CTN 5556 method with cloth ballast, data from Table A-6, Appendix A).

Even though Primaloft® has a relatively large decrease in both thickness and insulation value after laundering, because its initial thermal insulation value is so high, it still provides more thermal insulation after 10 laundering cycles than Polarguard®.

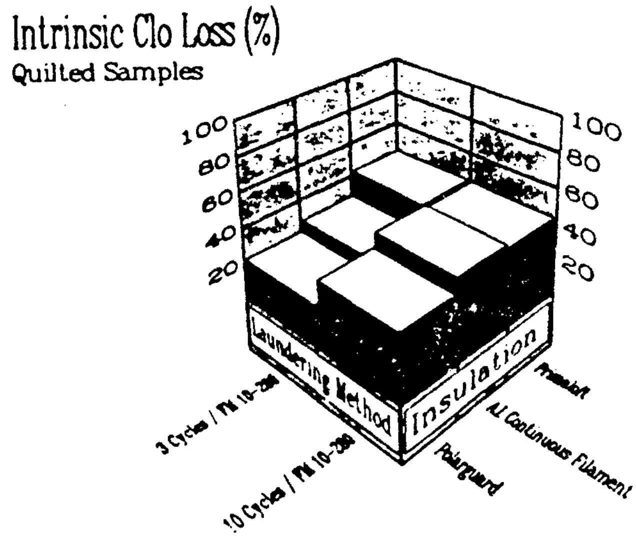

Figure 22. Intrinsic clo loss after laundering for channel-quilted samples covered with nylon taffeta fabric.

Direct Laundering Comparison of Waterfowl Down with Synthetic Insulation

Primaloft® is comparable to down in all its performance properties, with the exception of laundering durability. Although quilted down samples were not tested as part of this present study, laundering durability data (CTN 5556 method) on water-repellent treated down are available from previous studies[9]. The waterfowl down samples in this previous study were channel-quilted, laundered, and tested on the guarded hot plate in an identical manner to the methods used in this report. The quilted down samples had an areal density of 4 oz/yd^2, while the synthetic samples ranged from 4 to 6 oz/yd^2. Figures 23 and 24 show that all of the synthetic insulation materials perform very poorly (in terms of retention of insulating value and thickness) when compared directly with waterfowl down.

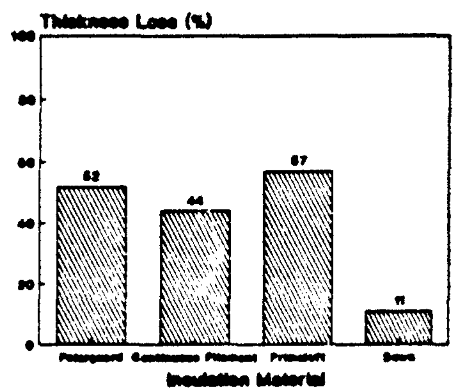

Figure 23. Thickness loss of laundered quilted down and synthetic insulation samples after 10 cycles of laundering procedure CTN 5556.

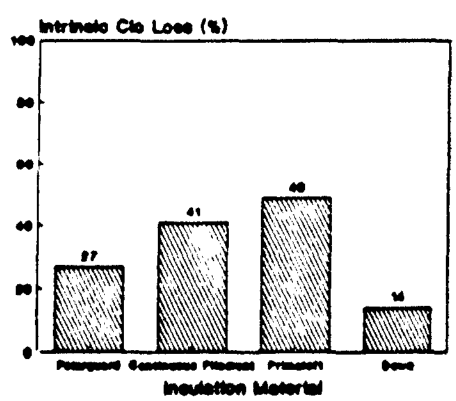

Figure 24. Intrinsic clo loss of laundered quilted down and synthetic insulation samples after 10 cycles of laundering procedure CTN 5556.

LAUNDERED SAMPLES - BATTING

After the channel-quilted samples were laundered and tested, the nylon taffeta cover fabric and quilt stitching were removed. The laundered batting was re-tested on the Guarded Hot Plate, the Heat Flow Meter instrument, the compressional properties were determined, and the water repellency tests were performed.

Thermal Properties

The results of retesting the laundered batting in the Heat Flow Meter instrument are presented in Figures 25-27 for each of these materials. The data for these figures are contained in Table A-1.

Since laundering increases the bulk density of these insulations, the testing did not produce any surprises. For the most part, the laundered batting materials, with their increased density, fall on the appropriate portion of the unlaundered batting curve.

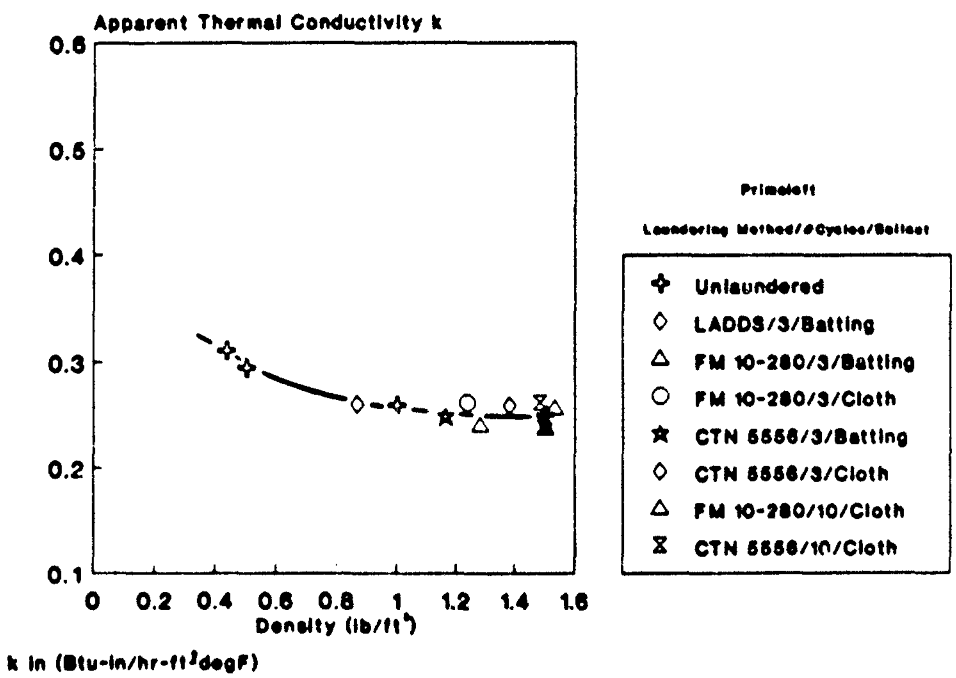

Figure 25. Thermal conductivity versus density for laundered Primaloft®.

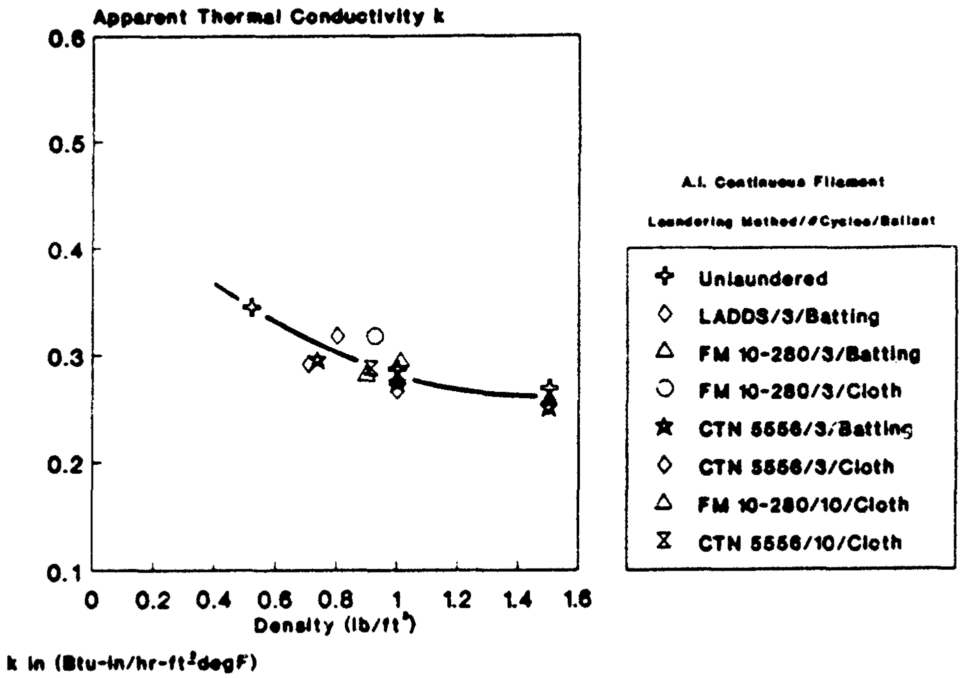

Figure 26. Thermal conductivity versus density for laundered A.I. Continuous Filament insulation.

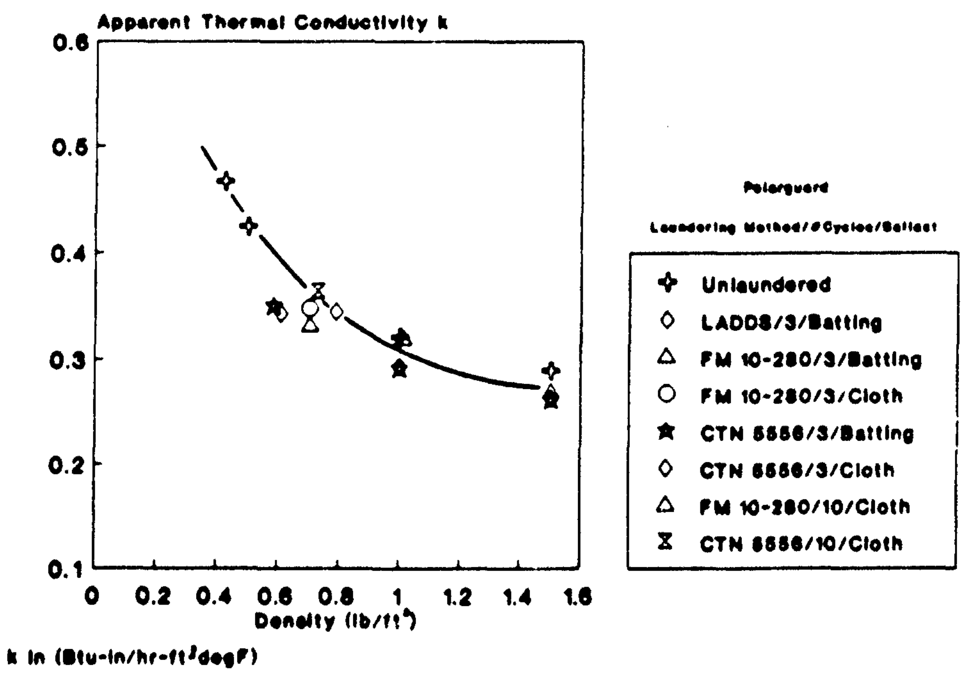

Figure 27. Thermal conductivity versus density for laundered Polarguard®.

The thermal properties of the laundered batting as determined by Guarded Hot Plate testing are contained in Table A-2 in Appendix A. The Guarded Hot Plate thermal properties of the laundered batting are consistent with the thermal properties of the laundered quilted samples. The nylon taffeta cover fabric does not make any difference in the relative ranking of each insulation. The cover fabric does add some insulating value to the batting, as expected, but the trends remain the same. The Primaloft® still shows a relatively high thickness loss and insulating value loss compared to the Polarguard® and A.I. Continuous Filament materials.

Compressive Properties

Selected compressional properties for the laundered batting materials are presented in Figures 28 and 29. The complete data set for these figures is contained in Table A-3, in Appendix A.

The compressional properties of the laundered batting materials do not change much as a result of laundering. The reduced thickness of the samples is the main reason for any changes in compressive properties.

Since the samples are thinner and more consolidated to begin with, the values for compressional strain at 5 psi decrease. The samples don't have to be squeezed as much as before to reach this stress level.

Similarly, as shown in Figure 28, the compressional recovery from 5 psi to .002 psi remains approximately the same, or improves slightly, since the samples don't have to recover the high loft portion of their thickness that the unlaundered samples do.

The normalized work of compression, for 1 inch thick samples, rises for all three materials (Figure 29). The normalized work of compression doubles for Primaloft® and Polarguard®, but is still below the value for unlaundered waterfowl down.

Finally, the resilience retained by the batting materials after laundering doesn't change much for any of these materials. Primaloft® still remains the most resilient of the three insulations, even after 10 wash/dry cycles of Method CTN 5556. This suggests that the large diameter fibers are still doing their job of providing elasticity and loft retention in the fibrous structure.

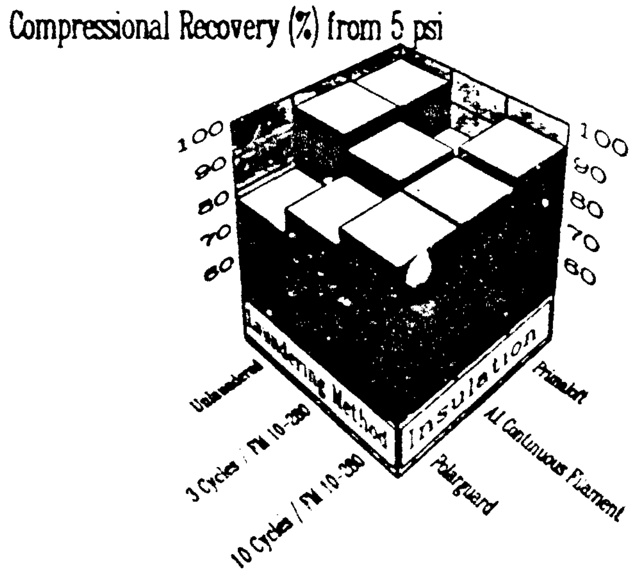

Figure 28. Compressional recovery (%) from 5 psi to .002 psi for three materials after laundering.

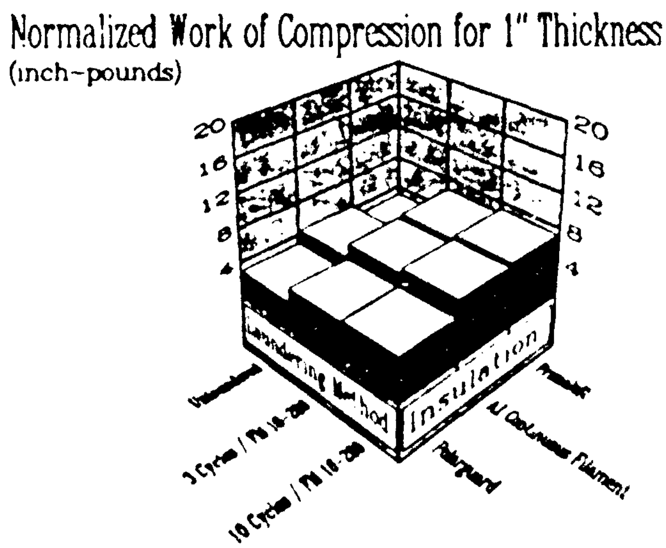

Figure 29. Normalized work of compression (1inch thickness) for three materials after laundering.

Water Repellency

The water repellent properties of the three synthetic insulation materials are presented in Figures 30-31. The data for these figures are contained in Table A-4 and A-5 in Appendix A. Only data for 20-minute immersion time are shown in Figures 30-31.

Aqueous laundering did not affect the water repellent properties of Primaloft® after 10 laundering cycles. Primaloft® retained its loft when wet, did not pick up much water, and quickly dried out. The Primaloft® samples were tested with the nonwoven polyester scrim fabric on both sides. The scrim seemed to be responsible for most of the water absorption of the Primaloft® insulation. Elimination of the nonwoven scrim would probably increase the water repellency of Primaloft® insulation.

Laundering did change the water repellent characteristics of both Polarguard® and the A.I. Continuous Filament insulation materials. This is not surprising since they both used similar fiber finishes and spray adhesives. The water repellency of both materials, which wasn't high to begin with, degraded significantly after 10 wash/dry cycles. Both materials picked up large amounts of water, with a consequent increase in weight. It was fairly easy to rid the Polarguard® and A.I. Continuous Filament materials of water after they had been washed three times. A vigorous shaking could get rid of most of the water. But after they had been washed 10 times, they were much harder to rid of water. Even squeezing the samples couldn't get a lot of the water out of the severely laundered samples.

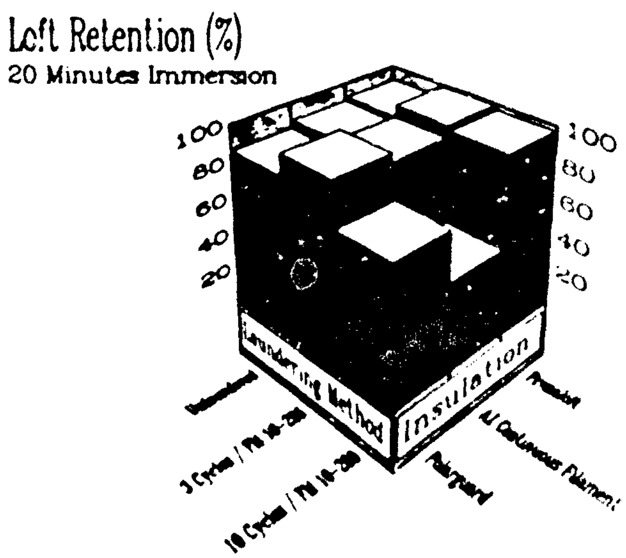

Figure 30. Loft retention of laundered batting after 20 minutes immersion time.

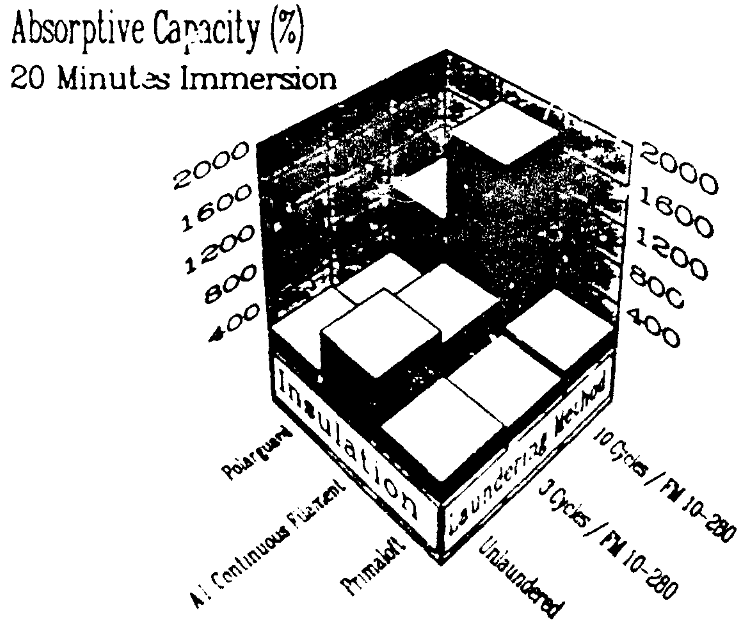

Figure 31. Absorptive capacity of laundered batting after 20 minutes immersion time (axes modified for clarity).

This document reports research undertaken at the US Army Natick Research, Development and Engineering Center and has been assigned No. NATICK/TR-[illegible] in the series of reports approved for publication.

4. CONCLUSIONS

Primaloft® exhibited excellent thermal, mechanical, and water repellent properties in this laboratory evaluation. The A.I. Continuous Filament insulation also exhibits excellent thermal and mechanical properties, but did not perform well in water repellency tests. The A.I. Continuous Filament insulation is not as good as Primaloft®, but performs better than Polarguard® overall.

Both Primaloft® and the A.I. Continuous Filament insulation suffered significant reductions in insulating value and thickness after several cycles of military field laundering. This loss of properties after laundering was not any more significant than that experienced by other high-loft, high-performance batting materials. Primaloft® still provides more thermal insulation after 10 cycles of military field laundering than Polarguard®, which happens to be one of the most durable high-loft batting insulations available. In addition, none of these synthetic materials performed as well as water-repellent treated waterfowl down in laundering durability tests. The synthetic materials were especially deficient, compared to down, in terms of retention of insulating value and thickness.

The A.I. Continuous Filament insulation performed better than Primaloft® in laundering durability testing, in terms of retention of thermal resistance. However, both the A.I. Continuous Filament and Polarguard®, which have a similar finish and spray adhesive, suffered a major decrement in water repellency after a few cycles of military field laundering.

The inherent water-repellent properties of polyester batting insulation is the great advantage of using such materials rather than waterfowl down. Down is still unsurpassed for most applications as long as it can be kept dry. Primaloft®'s outstanding resistance to water absorption, and its wet loft retention, make it preferable over down in any application where insulation is exposed to moisture.

All three synthetic polyester batting insulation materials exhibited excellent dimensional stability during laundering. Aside from the thickness decrease, there was no lateral shrinkage of the laundered samples. There was no evidence of fiber migration in any of these three insulations.

5. RECOMMENDATIONS

1). Primaloft® is a very promising insulation material; evaluation in terms of mannikin testing and field trials should proceed.

2). The laundering durability of Primaloft® should be improved. This may be achieved with minor changes to the fiber finish, according to Albany International. Primaloft® is being produced commercially on a production line at the present time, so the manufacturing process is largely set in place and difficult to modify. The laundering durability of Primaloft® is sufficient for normal civilian home washing machines. If the military laundering durability of Primaloft® is improved, then there should be no question that Primaloft® offers a significant advantage over current MIL-B-41826 polyester batting in all military applications.

3). The A.I. Continuous Filament insulation is also very promising. It should be inherently more stable and rugged than cut staple insulation materials since its fibers are continuous. It should also be competitive in price with other polyester insulation materials since it uses the same manufacturing process as Polarguard®. The major drawback of the A.I. Continuous Filament is its poor water repellency. If the problem is the spray adhesive used to stabilize the batt, then the water repellency problem should be easily solvable. The results of manikin testing and field trials should determine whether the A.I. Continuous Filament insulation is worth pursuing, in addition to Primaloft®, for use in military clothing and equipment items.

6. REFERENCES

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10. Military Specification MIL-C-21852, Cloth, Taffeta, Nylon, Type III, (1986).

11. Department of the Army Field Manual, FM 10-280, Appendix B, Formulla II.

12. Method 5556, Mobile Laundry Evaluation for Textile Materials of Federal Test Method Standard No. 191A, Federal Standard for Textile Test Methods (1978).

13. Roberts, N., Edelman, N., *Quartermaster Research on Down and Feathers and Other Filling Materials for Sleeping Bags*, Textile Series Report 43, Quartermaster Research and Engineering Command, Reprinted October 1957, p. 45.

APPENDIX A

PROPERTY TABLES

Table A-1
Thermal Conductivity versus Density
Upper Plate Temperature 95°F
Lower Plate Temperature 55°F

note: blank entries indicate samples were already too dense from thickness reductions due to laundering to be tested at the lower densities

Laundering Method/ Number of Cycles/ Ballast Type	Weight (g)	Density (lb/ft^3)	Thickness (in)	K Value	0.5 lb/ft^3 Thickness (in)	0.5 lb/ft^3 K Value	1.0 lb/ft^3 Thickness (in)	1.0 lb/ft^3 K Value	1.5 lb/ft^3 Thickness (in)	1.5 lb/ft^3 K Value
Polarguard										
Unlaundered	13.3	.424	.83	.466	.70	.424	.36	.321	.24	.289
LADDS/3/Batting	11.5	.608	.50	.343	----	----	.30	.293	.20	.263
FM 10-280/3/Batting	12.8	.703	.48	.332	----	----	.34	.592	.23	.269
FM 10-280/3/Cloth	11.7	.702	.44	.348	----	----	----	----	----	----
CTM 5556/3/Batting	10.9	.585	.49	.350	----	----	.29	.291	.19	.261
CTM 5556/3/Cloth	11.9	.789	.40	.345	----	----	----	----	----	----
FM 10-280/10/Cloth	12.8	1.012	.33	.319	----	----	----	----	----	----
CTM 5556/10/Cloth	11.7	.729	.42	.364	----	----	----	----	----	----
A.I. Continuous Filament										
Unlaundered	16.5	.521	.84	.344	----	----	.43	.286	.29	.268
LADDS/3/Batting	15.0	.708	.56	.291	----	----	.40	.267	.26	.252
FM 10-280/3/Batting	15.6	.898	.46	.281	----	----	.42	.277	.28	.258
FM 10-280/3/Cloth	16.8	.927	.48	.317	----	----	----	----	----	----
CTM 5556/3/Cloth	14.9	.736	.54	.295	----	----	.39	.273	.26	.250
CTM 5556/3/Cloth	17.1	.802	.56	.317	----	----	----	----	----	----
FM 10-280/10/Batting	14.7	1.010	.38	.294	----	----	----	----	----	----
CTM 5556/10/Cloth	15.4	.915	.44	.287	----	----	----	----	----	----
Primaloft										
Unlaundered	13.6	.435	.83	.310	.72	.294	.36	.259	.24	.250
LADDS/3/Batting	18.0	.866	.55	.260	----	----	----	----	.32	.241
FM 10-280/3/Batting	17.9	1.280	.37	.240	----	----	----	----	.32	.237
FM 10-280/3/Cloth	16.8	1.236	.36	.261	----	----	----	----	----	----
CTM 5556/3/Batting	21.6	1.165	.49	.248	----	----	----	----	.38	.242
CTM 5556/3/Cloth	19.8	1.379	.38	.259	----	----	----	----	----	----
FM 10-280/10/Cloth	20.0	1.532	.34	.256	----	----	----	----	----	----
CTM 5556/10/Cloth	19.0	1.483	.34	.262	----	----	----	----	----	----
Down										
Unlaundered	14.0	.223	1.66	.317	.74	.264	.37	.248	.25	.250

Units of Thermal Conductivity K are (Btu-in)/(hr-ft^2-°F)

Values given above are averages of 6 samples for unlaundered conditions, 2 or 3 samples per laundered condition.

Table A-2
Guarded Hot Plate Tests
Batting Samples
Air Temperature 50°F, Plate Temperature 92°F

Laundering Method/ Number of Cycles/ Ballast Type	Weight (g)	Thickness (in)	Density (lb/ft^3)	Areal Density (oz/yd^2)	K Value	Intrinsic Clo	Clo/Inch	Clo/ Ounce/ $Yard^2$	Thickness Loss (%)	Clo Loss (%)
Polarguard										
Unlaundered	23.0	.87	.392	4.0	.555	1.95	2.24	.488	----	----
LADOS/3/Batting	46.0	.46	.690	3.8	.303	1.73	3.76	.454	47	11
FM 10-280/3/Batting	46.9	.47	.700	4.0	.309	1.74	3.69	.437	46	11
FM 10-280/3/Cloth	43.5	.45	.710	3.9	.321	1.61	3.58	.413	48	17
CTM 5556/3/Batting	44.3	.52	.630	4.0	.368	1.61	3.09	.435	40	17
CTM 5556/3/Cloth	45.2	.42	.812	4.1	.320	1.50	3.57	.365	52	23
FM 10-280/10/Cloth	41.1	.33	1.012	4.1	.323	1.18	3.52	.288	61	39
CTM 5556/10/Cloth	44.9	.42	.729	3.7	.346	1.40	3.29	.378	51	28
Continuous Filament										
Unlaundered	50.0	.76	.521	4.7	.304	2.83	3.72	.602	----	----
LADOS/3/Batting	55.0	.56	.739	5.0	.284	2.25	4.01	.452	26	20
FM 10-280/3/Batting	52.0	.46	.874	4.8	.244	2.14	4.66	.451	39	24
FM 10-280/3/Cloth	59.1	.48	.879	5.0	.278	1.99	4.15	.398	37	30
CTM 5556/3/Batting	53.7	.54	.769	5.0	.250	2.46	4.59	.497	29	13
CTM 5556/3/Cloth	57.4	.51	.847	5.2	.262	2.23	4.37	.429	33	21
FM 10-280/10/Cloth	58.8	.38	1.010	4.7	.260	1.69	4.39	.360	49	40
CTM 5556/10/Cloth	54.1	.44	.915	4.9	.246	2.06	4.63	.420	41	27
Primaloft										
Unlaundered	62.5	.88	.560	5.9	.233	4.32	4.91	.732	----	----
LADOS/3/Batting	65.0	.54	.906	5.9	.235	2.61	4.84	.445	39	40
FM 10-280/3/Batting	77.0	.36	1.370	5.9	.205	2.00	5.56	.339	59	54
FM 10-280/3/Cloth	67.8	.35	1.350	5.6	.223	1.78	5.09	.318	60	59
CTM 5556/3/Batting	71.7	.50	1.110	6.6	.207	2.77	5.51	.416	43	36
CTM 5556/3/Cloth	66.7	.37	1.440	6.3	.216	1.95	5.27	.305	58	55
FM 10-280/10/Cloth	73.4	.34	1.530	6.3	.227	1.73	5.01	.275	61	60
CTM 5556/10/Cloth	70.0	.34	1.480	6.1	.215	1.80	5.29	.295	61	58

Values given above are averages of 6 samples for unlaundered condition, 2 or 3 samples per laundered condition.

Table A-3

Compressional Properties

Laundering Method/ Number of Cycles/ Ballast Type	Compressional Recovery from 5 psi (%)	Compressional Strain at 5 psi (%)	Normalized Work of Compression (1" Thickness)	Resilience
<u>Polarguard</u>				
Unlaundered	78.1	98.9	3.03	.59
LADOS/3/Batting	91.4	98.6	4.72	.53
FM 10-280/3/Batting	96.5	97.5	4.63	.76
CTN 5556/3/Batting	83.5	98.5	4.07	.62
FM 10-280/10/Cloth	95.9	97.3	4.89	.66
CTN 5556/10/Cloth	91.4	97.8	6.18	.62
<u>A.I. Continuous Filament</u>				
Unlaundered	85.7	97.1	4.53	.47
LADOS/3/Batting	84.8	97.6	5.13	.47
FM 10-280/3/Batting	92.6	96.1	6.19	.50
CTN 5556/3/Batting	97.8	96.9	5.44	.51
FM 10-280/10/Cloth	82.0	96.3	6.89	.52
CTN 5556/10/Cloth	95.8	94.1	6.40	.57
<u>Primaloft</u>				
Unlaundered	91.1	98.6	3.03	.75
LADOS/3/Batting	93.9	96.3	4.08	.69
FM 10-280/3/Batting	91.3	94.0	6.56	.60
CTN 5556/3/Batting	96.0	94.2	5.42	.76
FM 10-280/10/Cloth	93.6	91.5	7.18	.69
CTN 5556/10/Cloth	95.7	91.5	7.00	.68
<u>Down</u>				
Unlaundered	78.8	93.3	8.56	.56

Values given above are averages for 2 to 3 samples.

Table A-4

Water Absorption
20 Minutes Immersion

Laundering Method/ Number of Cycles/ Ballast Type	Loft Retention (%)	Density Increase (%)	Absorptive Capacity (%)
Polarguard			
Unlaundered	86	93	163
LADDS/3/Batting	99	79	177
FM 10-280/3/Batting	98	44	140
CTN 5556/3/Batting	91	77	162
FM 10-280/10/Cloth	74	1077	862
CTN 5556/10/Cloth	68	1805	1286
A.I. Continuous Filament			
Unlaundered	90	566	589
LADDS/3/Batting	98	280	367
10-280/3/Batting	93	371	445
CTN 5556/3/Batting	92	71	157
FM 10-280/10/Cloth	47	3751	1791
CTN 5556/10/Cloth	45	3340	1521
Primaloft			
Unlaundered	92	81	166
LADDS/3/Batting	88	80	161
FM 10-280/3/Batting	99	15	113
CTN 5556/3/Batting	97	32	127
FM 10-280/10/Cloth	97	65	160
CTN 5556/10/Cloth	93	49	139
Down			
Unlaundered	74	88	138

Values given above are averages for two samples

Table A-5

Water Absorption
6 Hours Immersion

Laundering Method/ Number of Cycles/ Ballast Type	Loft Retention (%)	Density Increase (%)	Absorptive Capacity (%)
Polarguard			
Unlaundered	76	380	363
LADDS/3/Batting	91	207	279
FM 10-280/3/Batting	92	270	338
CTN 5556/3/Batting	82	293	320
FM 10-280/10/Cloth	77	575	378
CTN 5556/10/Cloth	75	539	477
A.I. Continuous Filament			
Unlaundered	72	821	659
LADDS/3/Batting	51	2122	1125
FM 10-280/3/Batting	67	1041	759
CTN 5556/3/Batting	47	2862	1375
FM 10-280/10/Cloth	58	1797	1089
CTN 5556/10/Cloth	46	1911	914
Primaloft			
Unlaundered	79	181	212
LADDS/3/Batting	87	196	257
FM 10-280/3/Batting	92	237	274
CTN 5556/3/Batting	93	173	252
FM 10-280/10/Cloth	66	1246	994
CTN 5556/10/Cloth	87	294	334
Down			
Unlaundered	66	99	131

Values given above are averages for two samples

Table A-6

Guarded Hot Plate Tests

Quilted Samples

Air Temperature 50°F, Plate Temperature 92°F

Laundering Method/ Number of Cycles/ Ballast Type	Weight (g)	Thickness (in)	Density (lb/ft^3)	Areal Density (oz/yd^2)	K Value	Intrinsic Clo	Clo/Inch	Clo/ Ounce/ $Yard^2$	Thickness Loss (%)	Clo Loss (%)
Polarguard										
Unlaundered	99.8	.85	.80	8.0	.378	2.54	3.01	.315	----	----
LADOS/3/Batting	101.0	.50	1.36	8.2	.287	1.98	3.97	.242	41	22
FM 10-280/3/Batting	102.0	.46	1.48	8.2	.267	1.97	4.27	.241	44	22
FM 10-280/3/Cloth	97.3	.46	1.45	8.0	.274	1.91	4.36	.239	46	25
CTM 5556/3/Batting	98.0	.56	1.18	7.9	.316	2.02	3.61	.256	34	20
CTM 5556/3/Cloth	101.3	.44	1.52	8.0	.284	1.75	4.00	.219	48	31
FM 10-280/10/Cloth	95.0	.37	1.80	8.0	.262	1.60	4.34	.200	56	37
CTM 5556/10/Cloth	104.5	.41	1.63	8.0	.252	1.85	4.51	.231	52	27
Continuous Filament										
Unlaundered	109.8	.80	.93	9.0	.281	3.26	4.05	.362	----	----
LADOS/3/Batting	108.0	.55	1.40	9.5	.270	2.32	4.21	.243	32	29
FM 10-280/3/Batting	106.0	.46	1.70	9.0	.231	2.35	4.93	.250	43	28
FM 10-280/3/Cloth	118.0	.48	1.56	9.0	.279	1.98	4.10	.217	40	39
CTM 5556/3/Batting	109.5	.63	1.19	9.0	.274	2.61	4.15	.290	22	20
CTM 5556/3/Cloth	113.8	.46	1.63	9.0	.238	2.16	4.81	.240	43	34
FM 10-280/10/Cloth	120.5	.40	1.88	9.0	.256	1.78	4.44	.198	50	45
CTM 5556/10/Cloth	111.5	.45	1.67	9.0	.267	1.91	4.25	.212	44	41
Primaloft										
Unlaundered	129.2	.93	.97	10.9	.272	3.91	4.19	.360	----	----
LADOS/3/Batting	120.0	.61	1.51	11.1	.258	2.69	4.41	.242	34	31
FM 10-280/3/Batting	125.0	.39	2.26	10.6	.203	2.21	5.61	.208	58	43
FM 10-280/3/Cloth	125.4	.41	2.19	10.8	.228	2.05	4.99	.190	56	48
CTM 5556/3/Batting	127.0	.60	1.48	10.7	.237	2.90	4.83	.271	35	26
CTM 5556/3/Cloth	125.0	.41	2.20	10.8	.232	2.02	4.92	.187	56	48
FM 10-280/10/Cloth	134.0	.38	2.36	10.8	.194	2.23	5.87	.206	59	43
CTM 5556/10/Cloth	129.0	.40	2.25	10.8	.229	1.98	4.95	.183	57	49
Down										
Unlaundered	110.5	1.75	.44	9.2	.554	3.59	2.05	.392	----	----

Values given above are averages of 6 samples for unlaundered conditions, 2 or 3 samples per laundered condition.

Table A-7
Wet Thermal Conductivity versus Density
Upper Plate Temperature-95°F
Lower Plate Temperature 55°F

note: blank entries indicate samples were already too dense to be tested at the lower densities

Insulation Material	Weight (g)	Dry Density (lb/ft^3)	Thickness (in)	K Value	0.5 lb/ft^3 Thickness (in)	0.5 lb/ft^3 K Value	1.0 lb/ft^3 Thickness (in)	1.0 lb/ft^3 K Value	1.5 lb/ft^3 Thickness (in)	1.5 lb/ft^3 K Value
Polarguard										
Dry	11.5	.342	.89	.440	.608	.368	.30	.281	.20	.254
Wet	59.0	.422	.72	.599	----	----	.30	.450	.20	.310
A.I. Continuous Filament										
Dry	15.0	.496	.80	.337	----	----	.40	.275	.27	.259
Wet	74.0	.945	.42	.447	----	----	----	----	.27	.413
Primaloft										
Dry	16.5	.519	.84	.286	----	----	.44	.251	.29	.238
Wet	67.0	.661	.66	.332	----	----	.44	.288	.29	.274
Down										
Dry	16.0	.353	1.20	.317	.85	.278	.42	.242	.28	.235
Wet	66.5	.813	0.52	.381	----	----	.42	.321	.28	.300

Units of Thermal Conductivity K are (Btu-in)/(hr-ft^2-°F)
Values given above are for one sample.

APPENDIX B

COMPARISON OF THERMAL CONDUCTIVITY VALUES AT DIFFERENT PLATE TEMPERATURES

The thermal conductivity tests conducted during the laboratory evaluation of Primaloft® were performed with the Heat Flow Meter apparatus. The plate temperatures used were 95°F for the hot upper plate, and 55°F for the lower plate. The original test report on the Primaloft® insulation, written by Albany International[3], quoted values of thermal conductivity determined using plate temperatures of 100°F and 50°F. Thermal conductivity measurements using Albany International's temperature settings were performed on the insulations to see if there was any significant difference in the thermal conductivity values obtained. Figure B-1 shows that there is some difference in values for the two different sets of plate temperatures, but the difference doesn't look significant. All Heat Flow Meter test results quoted in the body of this report were conducted at plate temperatures of 95°F and 55°F.

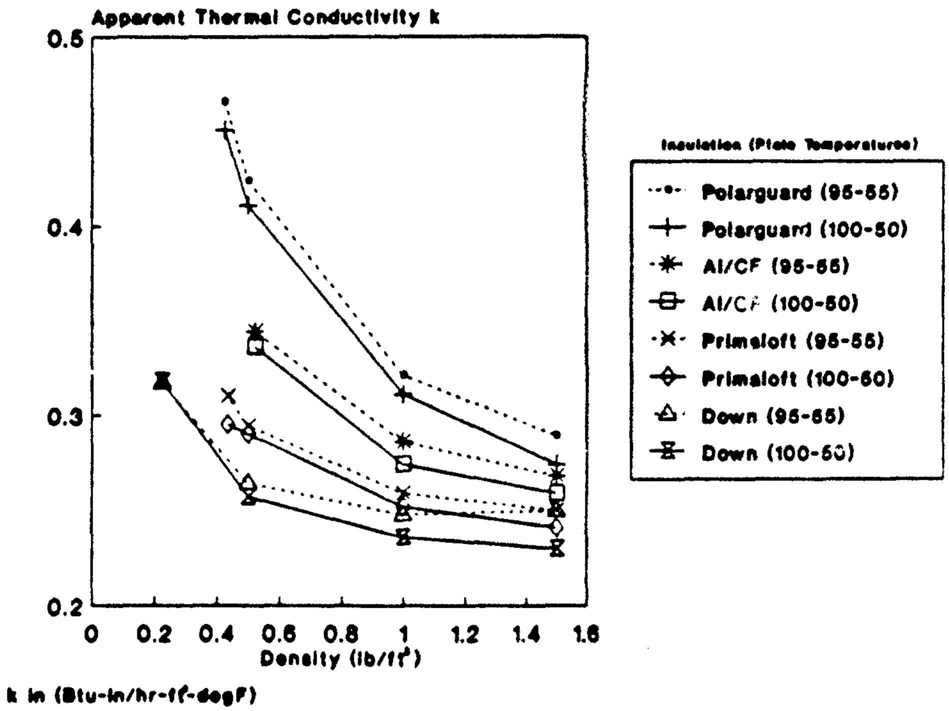

Figure B-1. Thermal conductivity values determined under two different plate temperature conditions.