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DEVELOPMENT OF NON-REFLECTIVE, WETTABLE, FIBROUS, FABRIC ASSEMBLIES FOR FIREFIGHTERS' CLOTHING

NAVY CLOTHING AND TEXTILE RESEARCH UNIT
NATICK, MASSACHUSETTS

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DEVELOPMENT OF NON-REFLECTIVE, WETTABLE, FIBROUS, FABRIC ASSEMBLIES FOR FIREFIGHTERS' CLOTHING

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I. INTRODUCTION

A non-reflective, wettable, firefighters', proximity garment was developed for use during pilot crash rescue operations and for damage control purposes aboard ship. The protective garment derives its major heat protective properties by rapidly absorbing water from the foaming agent and using the water as a thermal shield to protect the garment from charring and the firefighter from burns. The Navy Clothing and Textile Research Unit developed the non-reflective, wettable garment concept as a possible replacement for the current, standard, aluminized, asbestos, proximity, firefighters' garment. The object of this study was to develop non-reflective, wettable, fibrous fabric combinations affording heat protection equal to or greater than the highly reflective, aluminized, 19-ounce, asbestos, herringbone, twill cloth and field testing experimental prototype garments made from this fabric combination in assembly with a 5.5-ounce, neoprene-coated, nylon taffeta (vapor barrier) and a 16-ounce wool fabric (insulation liner).

A preliminary study (reference 1) has reported that the approach of using non-reflective, wettable, fibrous material assemblies, for high intensity heat protection was feasible. Based on this reported study, new wettable fibrous materials and fabric constructions were developed and laboratory tested for heat transfer to the back of experimental assemblies by exposing them to a radiant heat flux of 1.815 $cal/cm^2/sec$. Laboratory test results on the non-reflective assemblies show that when "wetted-out" the level of heat protection afforded is far superior to the reflective assembly. An experimental non-reflective coat and trousers were field tested and found acceptable when worn during pilot crash rescue training demonstrations. Because wear and soiling has only limited effect on this garment's heat protection, it should have a significantly longer use-life and reduced cost as compared to the reflective garment.

This report deals with the laboratory evaluation of the heat protective properties of non-reflective, wettable, fibrous, fabric assemblies in combination with a vapor barrier fabric and insulation liner. The wettable fabric combinations were limited to eight outer shell fabric combinations and six inner lining felts. A garment made from an optimum fabric assembly was field tested and reported on.

II. BACKGROUND

Heat protective properties of the current, proximity, firefighters' clothing depends to a large extent on the aluminized surface of the outer shell 19-ounce asbestos herringbone twill fabric remaining highly reflective. The good protection afforded by the reflective fabric and ultimate use-life of the garment is significantly reduced by soiling, foaming agents and normal wear. Reference (1) reported that simulated mild wear and soiling seriously affected the heat reflectivity of the aluminized material with soiling appearing more serious. One drop of pure mineral oil showed no visible dulling, yet it resulted in a 31 percent reduction in the time to reach 150°F behind the assembly. When the oil is mixed with a small amount of graphite (1/2 percent) a reduction of 65 percent was recorded compared to the original exposure time. It should be noted that the visual appearance was only slightly affected by the contamination. This would indicate that the protection afforded by the reflective garments could be seriously compromised without the wearer knowing it.

The first type of protective garment used by the Navy for rescuing pilots from burning aircraft was the regular "bunker clothing" with additional insulation added to the upper portion of the coat. It consisted of an outer shell of tightly woven fire-retardant cotton duck backed up with an impermeable vapor barrier material, a glass fiber liner, a glass fiber batting and a wool insulating liner--assembly weighed approximately 50 oz/yd^2.

Subsequently, this ensemble has been replaced by one consisting of a neoprene-coated, aluminized, asbestos, glass, cotton fabric outer shell (Military Specification MIL-C-21890) and a 16-ounce wool liner. The aluminized surface, when new, provided good protection from radiant heat and allowed the firefighters to work in close to fuel fires, thus enabling him to extinguish the fire and effect a rescue--assembly weighed about 33 oz/yd^2. However, reports were received which indicated that improvement was desired in both durability of the basic fabric and abrasion resistance of the aluminized coating. Accordingly, Cloth, Coated, Asbestos and Cotton, Herringbone Twill, Aluminized (MIL-C-82249) was developed to overcome these shortcomings. The integral neoprene coating was removed from the back of the new aluminized cloth and replaced with a separate vapor barrier material and the wool lining was replaced with a quilted rayon/wool batt lining. This assembly is used in the current, standard, firefighters', proximity clothing--assembly weighed about 41 oz/yd^2.

Even with this improved aluminum surface and base fabric, serious questions remain about the continued efficacy of aluminized firefighting clothing when used under conditions of contamination and wear. (Justification for continued use of this aluminized fabric is based on its extreme thinness and comparative low weight.) This problem arises from the accepted practice of wearing the clothing during the performance of routine duties. It is further complicated during a rescue, because the aluminized surface becomes partially covered with foaming agent, used to both extinguish the fire and clear a safe rescue path to the pilot. It is known that soil and foam will adversely affect the heat reflective characteristics of the aluminized fabric.

III. MATERIALS

A. Outer Shell

Table I lists three outer shell fabric combinations made by the needle punched method. The wool fabric and rayon batt components, for all three needled fabric combinations, were chosen because the wool is fire resistant and the rayon is highly water absorptive. The wool fabric and rayon batt were simultaneously conveyed under the needle carrier which contains the specially designed needles in a certain number and arrangement to produce the desired thickness and density of material. As the needle carrier pushes the blades of the barbed needles into the rayon batt, each barb catches one or more fibers and pushes them into and through the wool fabric. When the motion of the needle is reversed and they start to withdraw from the rayon batt, the fibers which were pushed down came unhooked from the barbs. The cumulative effect of repeating this action many times in the same area is the mechanical interlocking of rayon fibers into the wool fabric and producing a finished material with useful flame resistance and rapid water absorption properties.

Physical properties and characteristics of the needle punched materials are controlled by: fiber types, mechanical fiber opener and carding equipment used, weight of material delivered to the needle carrier, speed at which the material is delivered to the needle carrier, type of needle used, depth of needle penetration through the materials and bed plate, number of needle penetrations per square inch of material and number of passes through the needling machine.

Table I also lists three single fabrics and five outer shell assembly combinations. The five face fabrics, used in the assembly combinations, were chosen because of their ability to resist flaming--asbestos and glass fabrics are flame-proof and the wool fabric is considered flame resistant. The separate backing material, 4.5 and 7 oz/yd^2 rayon batts, were chosen because they have a high percentage moisture regain and rapid water absorption and wicking characteristics. (The absorbed water acts as an effective thermal shield reducing the heat to the back of the assemblies.)

B. Wettable Inner Lining

Inner lining needle punched felts, listed in Table II, were employed directly behind the outer shell fabric combinations and assemblies. The felts were specifically made to retain an additional controlled quantity of water and provide a desired thickness to further help reduce the heat flux through the assembly. (The needle punched method allows for the construction of felts having good thickness to low weight ratios.) This wettable inner lining is necessary to allow the firefighter to work in close proximity to the fire for extended periods of time. It is also necessary as additional insulation if the initial "wetting-out" is inadequate or on special occasions when the firefighter has to perform his job in a dry garment.

The type and percentage of fibers used has a direct bearing on the physical properties of the finished felt. Wool was chosen because it is a flame-resistant fiber with good compressional recovery and rayon has a high percentage of moisture regain and rapid wicking action. It was found that an intimate blend of 50% wool/50% rayon fibers, in a needle punched construction, produced optimum inner lining materials.

C. Vapor Barrier

The vapor barrier fabric is utilized to keep the vaporized water (steam) from penetrating through the fabric assembly and "par-boiling" the firefighter. Two important physical properties are light weight and good hydrostatic resistance. The current, aluminized, proximity, firefighters' garment uses a 5.5-ounce, neoprene-coated, nylon taffeta, Military Specification MIL-C-19699, Type II, chloroprene-coated, flame-resistant and is acceptable for the purpose intended. Accordingly, the same fabric was also considered for this development work.

Table I. Description of Outer Shell Fabric Combinations

Identification Code No.	Thickness (1) (inches)	Weight (oz/yd^2)	Fabric Combinations (first listed fabric, in all cases, is considered the face)
S-19	0.044	19.0	Asbestos, UG(2), herringbone twill, FR(3)
S-19 Alum.	0.045	22.0	Aluminized asbestos, UG(2), herringbone twill, FR
S-9	0.038	8.7	Wool fabric (woven), 100%
N-9/4 (4)		13.2	8.7 oz. wool fabric needled to 4.5 oz. rayon batt
N-9/7 (4)		15.7	8.7 oz. wool fabric needled to 7.0 oz. rayon batt
N-6/4 (4)	0.098	10.0	5.9 oz. wool fabric needled to 4.1 oz. rayon batt
A-19/7 (5)	0.20	26.0	19 oz. asbestos, UG, herringbone twill/7 oz. rayon batt
A-19/4 (5)	0.156	23.5	19 oz. asbestos, UG, herringbone twill/4.5 oz. rayon batt
A-6/7 (5)	0.226	13.0	6 oz. glass, plain weave/7 oz. rayon batt
A-9/7 (5)	0.194	15.7	8.7 oz. wool fabric/7 oz. rayon batt
A-9/4 (5)	0.150	13.2	8.7 oz. wool fabric/4.5 oz. rayon batt

(1) Thickness measured at 0.1 psi foot pressure.

(2) UG - Underwriter's Grade: 80% asbestos (min.), 20% cotton.

(3) FR - Fire-resistant finish.

(4) Rayon batt needle punched to wool fabric.

(5) Fabrics in assembly with rayon batts are considered as one outer shell combination.

Table II. Description of Wettable Inner Lining Felts

Identification Code No.	Thickness (1) (inches)	Weight (oz/yd^2)	Test Felts
IL-17	0.218	17	Intimate blend (50% wool/50% rayon) needle punched felt; 1 oz. rayon scrim embedded in felt
IL-16	0.158	16	Intimate blend (45% wool/45% cotton/ 10% rayon) needle punched felt
IL-6	0.070	6	Intimate blend (50% wool/50% rayon) needle punched felt
IL-12	0.168	12	Intimate blend (50% wool/50% rayon) needle punched felt
IL-7B	0.156	7	100% rayon batt
IL-16F	0.105	16	100% wool fleece fabric

(1) Thickness measured at 0.1 psi foot pressure.

D. Insulation Liner

For laboratory study purposes, a 16 oz/yd^2 woven wool fleece fabric (Military Specification MIL-C-2049) was used in lieu of the quilted rayon/wool batt lining which is employed in the current, aluminized, proximity, firefighters', two-piece garment. The woven wool fabric has a more reliable type of construction for laboratory heat transfer studies, offering uniform weight and thickness between test specimens.

Reported laboratory investigation of both types of insulation linings has shown them to offer about the same degree of heat protection. The quilted lining was preferable for use in specification garments because it is lighter in weight and more comfortable to the wearer.

E. Fabric Assembly Employed in Garment for User Evaluation

The experimental garment, for user evaluation, contained the following materials which are listed in order of use. The first listed fabric is considered the outer shell.

1. 10-ounce wool/rayon fabric combination, made by needling a 4.1-ounce rayon batt to the back of a 5.9-ounce, 100 percent wool fabric, undyed.

2. 17-ounce needle punched felt consisting of an intimate blend of 50 percent wool and 50 percent rayon fibers, needled to a thickness of 0.218 inch, undyed.

3. 5.5-ounce neoprene-coated nylon taffeta, vapor barrier material used to protect the firefighter from steam burns.

4. 16-ounce, 100 percent wool fabric used as additional insulation liner.

Appendix A reports on a user evaluation of this garment by the Naval Damage Control Training Center, Philadelphia, Pennsylvania. The report covers two separate tests, using the same garment, conducted seven days apart and contains results, comments, and recommendations.

IV. APPARATUS AND PROCEDURE

A. Wetting-Out; Water

The "wetting-out" of laboratory test assemblies was performed by using the rain penetration tester as described in Test Method 5524 of Federal Standard CCC-T-191. A 6-foot hydrostatic heat and a "wetting-out" time of 4 seconds were used as standard test procedure. The water temperature was kept at 80°F and the spray was contained behind a plastic shield until the 4-second timing was ready to start.

Immediately after "wetting-out" the specimen was weighed on a gram scale and placed in the sample holder of the infrared quartz lamp for heat testing.

B. Radiant Heat Exposure Test

The prepared assemblies were heat tested using the quartz lamp infrared radiant heat source (reference 2). The assemblies were placed in the sample holder which was spaced 1-1/2 inches from the lamp surface at a heat flux of approximately 1.815 cal/cm^2/sec. The average temperature of the bank of five lamps was approximately 2990 $\pm$ 10^{o}F. The assemblies were backed with a 0.5 mil polyester film which was first attached to the sample holder back plate by taping all four sides. The outermost side of the film was coated with a 150^{o}F Tempilaq (reference 3) heat indicator applied to a thickness of less than 0.001 inch. This temperature was arbitrarily selected as one which approached the maximum temperature level which could be tolerated by the body for short periods of time. The test assemblies were exposed to the heat source until the change (melt) in the Tempilaq heat indicator was observed. The exposure time was noted from the moment the lamps were turned on until the power was shut off.

C. Wetting-Out; Protein Foam

Visual observations of "wetting-out" characteristics of selected experimental assemblies were made after being sprayed with protein foam. The foam consists of about 96 percent water. The assemblies were sprayed for 4 seconds from a 100 pound low pressure, wide angle nozzle, at six gallons per minute. Test panels (30" x 30") were taped to a flat metal surface and positioned about 12 feet from the nozzle--care was taken to completely tape all four sides to eliminate water leakage from around the edges to the back of the assemblies.

D. Wear and Soiling

To demonstrate the effect of wear and soiling on the heat-reflective outer shell fabric, an aluminized 1.2-pound asbestos fabric, in assembly with the vapor barrier and wool fleece liner, was tested under simulated conditions. Mild abrasion was effected by subjecting the aluminized sample to 300 wear cycles on the Wyzenbeek abrader as detailed in Military Specification MIL-C-82249. Oildag (a collodial suspension of graphite in petroleum oil) was used to simulate dirty-oil-type soiling. Both it and pure mineral oil were applied from a stirring rod and spread evenly over the exposed surface area (2-1/2" x 6") of the sample. Results are shown in Table III.

V. PROCEDURE FOR USER EVALUATION OF GARMENT

An experimental prototype garment was manufactured and user evaluated to demonstrate the concept that non-reflective, wettable, fibrous materials, used in assembly with a vapor barrier and insulation lining, will offer the necessary heat protection. This garment was worn by a professional Navy firefighter, at the Philadelphia Naval Training Center during normal pilot crash rescue training demonstrations.

Thirty to forty gallons of gasoline fuel were sprayed over an airplane and on the flight deck under the plane. The fuel was ignited and allowed to burn for about ten seconds. The firefighter, wearing the non-reflective garment, was wetted down with a two-second spray of protein foam, front and back. The foam is then turned on the fire and the firefighter approaches the flames with a ladder in hand. He walks toward the flames, while the foam was snuffing out the fire, climbs the ladder (placed against the airplane), removes a 100-pound dummy pilot from the cockpit and hands it down to his "back-up" man. The rescue is effected within two minutes, at which time the fire should be extinguished and the demonstration ended. The purpose for these demonstrations is to acquaint the sailors with proper techniques of putting out airplane fires under controlled, realistic field conditions.

VI. DISCUSSION OF FINDINGS: MATERIAL ASSEMBLIES

A. Wear and Soiling Effects on Standard Aluminized Asbestos Fabrics

Table III shows that simulated mild wear and soiling seriously affected the heat reflectivity of the aluminized material. Of the two, soiling appears to be more serious. The aluminized fabric in its original new condition, accepted a heat exposure time of 98 seconds. The pure mineral oil exhibited no visual dulling of the aluminized surface, yet one drop spread on the surface resulted in a 31 percent reduction in the time to reach 150°F behind the assembly. Mild abrasion alone affects the original exposure time by about 25 percent; however, after abrasion and one drop of mineral oil spread over the surface, a further reduction results in the time to reach 150°F behind the assembly. The addition of one drop of a 1/2 percent graphite suspension in oil results in a reduction of 65 percent when compared to the original exposure time even though the visual appearance of the aluminized surface was only slightly affected by the contaminant.

B. Comparing Heat Transfer Time of Non-Reflective Assemblies to Aluminized Assemblies

Table IV heat transfer results show that the dry non-reflective fabric assemblies are significantly better than mildly abraded and soiled aluminized fabric assemblies. This improvement by itself would not be enough to recommend the non-reflective assembly due to charring of the fabric layers. However, Table V shows that, after three of the test assemblies are "wetted-out," the "start-of-char" occurs at about 118 seconds for assembly A-9/7:IL-12 and at about 123 and 133 seconds for assemblies A-9/7:IL-17 and A-9/4:IL-17, respectively, as compared to the original aluminized fabric assembly which took 98 seconds to exhibit a heat transfer of 150°F. Continued heat exposure of the three non-reflective fabrics shows exposure times of 180 seconds without reaching 150°F behind the assemblies.

C. Dry Fabric Assemblies Exposed to Radiant Heat

Table IV shows the deleterious effect radiant heat has on dry non-reflective fibrous material assemblies prior to reaching a heat rise of 150°F behind the assemblies. The outer shell fabrics, wettable inner linings and vapor barrier fabrics exhibited various degrees of heat degradation for the exposure times indicated while the insulation liners showed no charring. The following visual observations were recorded after exposure to the radiant heat:

1. The wool/rayon outer shell fabrics intumesced forming a "puffed-up" brittle char which contributed to the heat protection afforded.

2. The wettable inner linings formed a hard char which showed brittleness through to the back of the material.

3. The vapor barrier fabric showed the neoprene coating charred and the nylon taffeta fabric melted.

4. The asbestos and glass outer shell fabrics retained their integrity; however, their tensile and tear strengths were reduced.

5. The heat transfer through the asbestos and glass fabrics affected the assembly's remaining three material layers in the same manner as indicated for the wool/rayon outer shell.

It can be seen that the heat flux through the successive layers of material is continually reduced so that by the time it reaches the back insulation liner the heat flux has been significantly lowered. This does not assume that continued exposure would not affect the liner. Upon continued exposure the temperature within the wool liner should slowly increase to a level where upon it will start to exhibit degradation. However, this heat increase within the wool liner should be relatively slow and for the time the firefighter needs to remain in close proximity to a hot fire the insulation liner should show no char.

All the outer shell fabrics appear to react to the heat flux in the same manner--rapid blackening and char-through. It can be assumed that between the tested fabrics there is no significant difference in slowing the heat through to the wettable inner lining. The wool/rayon fabric combinations intumesced, forming a friable char. The asbestos and glass fabrics retained their integrity; however, they offer distinct disadvantages. The 19-ounce asbestos fabric needle punched to a rayon batt will produce an excessively heavy, bulky and stiff fabric while glass fabrics show poor durability to flexing.

It is of interest to note the dry exposure times for various wettable inner linings. The 16-ounce and 17-ounce linings afforded about the same protection time when tested in assembly. The 12-ounce lining shows a reduced time to reach 150°F behind the assemblies while the 6-ounce and 7-ounce linings exhibited significantly lower times.

It appears that by retaining the same density inner linings and increasing their thickness, the heat exposure time can be adjusted to a predetermined level for the amount of protection time desired. To accomplish this extended protection time, however, it appears that the fabric would become overly bulky and heavy and might be rejected by the firefighter. Maximum thickness and weight appear to have been reached by the 16-ounce and 17-ounce inner linings. Based on garment design, comfort and dexterity factors, however, the thinner 12-ounce inner lining appears to be more desirable--heat protection time still remains a primary characteristic to be considered.

Table III. Effect of Wear and Soiling on Heat Protective Characteristics of Aluminized Fabric, Tested in Assembly (1)

S-19 Alum. (2) Test Specimens; No.	Condition of Aluminized Surface	Time to Failure; ΔT - 150°F (3) (sec.)
1	Original	98
2	Abraded	75
3	One drop mineral oil	67
4	Abraded plus 1 drop mineral oil	48
5	One drop 1/2% Oildag	35
6	Abraded plus 1 drop 1/2% Oildag	35

(1) Assemblies exposed to a radiant heat flux of 1.815 $cal/cm^2/sec$ contained a 5.5-oz. neoprene-coated nylon taffeta (vapor barrier) and 16-oz. wool fleece liner.

(2) 19 oz/yd^2 asbestos (U.G.) herringbone twill fabric, aluminized.

(3) ΔT = heat rise at back of assemblies.

Table IV. Dry Test: Time (sec.) for Tempilaq Heat Indicator Temperature Increase (ΔT); Assemblies Exposed to a Radiant Heat Flux of 1.815 cal/cm²/sec

Experimental Assemblies Code No.	Assemblies (1) Weight oz/yd²	Assemblies (1) Thickness (2) (inches)	ΔT - 150°F Time (sec.)	Appearance of Tested Fabrics: Outer Shell	Inner Lining	Vapor Barrier	Insulation Liner
A-19/7-IL-17	64	0.529	80	Blackened	Char Through	Char	No Change
A-19/4-IL-17	63	0.485	71	Blackened	Char Through	Char	No Change
A-6/7-IL-17	50	0.493	68	Blackened	Char Through	Char	No Change
A-9/7-IL-17	53	0.568	76	Char Through	Char Through	Char	No Change
A-9/4-IL-17	50	0.524	71	Char Through	Char Through	Char	No Change
N-6/4-IL-17	47	0.427	54	Char Through	Char Through	Char	No Change
S-19-IL-17	58	0.373	57	Char Through	Char Through	Char	Singed
S-9-IL-17	48	0.367	54	Char Through	Char Through	Char	No Change
A-19/7-IL-16	63	0.358	83	Blackened	Char Through	Char	No Change
A-19/4-IL-16	62	0.425	73	Blackened	Char Through	Char	No Change
A-6/7-IL-16	49	0.433	70	Blackened	Char Through	Char	No Change
A-9/7-IL-16	52	0.508	78	Char Through	Char Through	Char	No Change
A-9/4-IL-16	49	0.464	75	Char Through	Char Through	Char	No Change
N-6/4-IL-16	46	0.367	65	Char Through	Char Through	Char	No Change

Table IV. Dry Test: Time (sec.) for Tempilaq Heat Indicator Temperature Increase (ΔT); Assemblies Exposed to a Radiant Heat Flux of 1.815 cal/cm^2/sec (cont'd)

Experimental Assemblies Code No.	Assemblies (1) Weight oz/yd^2	Assemblies (1) Thickness (2) (inches)	ΔT - 150°F Time (sec.)	Appearance of Tested Fabrics: Outer Shell	Inner Lining	Vapor Barrier	Insulation Liner
A-19/7-IL-6	52	0.381	58	Blackened	Char Through	Char	No Change
A-19/4-IL-6	52	0.337	51	Blackened	Char Through	Char	No Change
A-6/7-IL-6	39	0.345	47	Blackened	Char Through	Char	No Change
A-9/7-IL-6	42	0.420	52	Char Through	Char Through	Char	No Change
A-9/4-IL-6	51	0.376	51	Char Through	Char Through	Char	No Change
A-9/7-IL-12	50	0.473	64	Char Through	Char Through	Char	No Change
A-19/7-IL-7B	54	0.467	61	Blackened	After Glow	Char	Singed
A-6/7-IL-7B	40	0.431	45	Blackened	After Glow	Char	No Change
A-9/7-IL-7B	43	0.506	50	Char Through	After Glow	Char	No Change
A-9/4-IL-7B	34	0.462	34	Char Through	Flamed	No Change	No Change

(1) Assemblies contain, in addition to listed fabric combinations, a neoprene-coated nylon vapor barrier and a wool fleece insulation lining; first listed fabric, in all cases, is considered the face.

(2) Thickness measured at 0.1 psi foot pressure.

D. "Wetted-Out" Fabric Assemblies Exposed to Radiant Heat

Table V shows the time for the heat to reach 150°F behind fabric assemblies after a 4-second "wet-out" and exposure to radiant heat. All Table V listed assemblies were exposed for 180 seconds without the Tempilaq heat indicator showing a heat rise behind the assemblies of 150°F, except for the glass/rayon outer shell assemblies. Glass fabrics are poor absorbers of water and this was the reason for the low recorded exposure times. Once again, for the extended exposure time of 180 seconds, the outer shell fabrics showed char, except for one; fabric combination A-9/7:IL-7B showed no char after 180-second exposure. Further testing will be necessary before a conclusion can be made for this one excellent result. In general, the higher the water pick-up the better heat protection can be anticipated for the individual fabric layers in the assembly.

E. Percentage Water Absorption Between Outer Shell and Inner Lining

This percentage water absorption between outer shell and inner lining is extremely important and needs to be closely controlled. Excessive water pick-up would make the garment overly heavy, while too little water may not provide the heat protection required. If the majority of water remained in the outer shell, the heat would rapidly evaporate it and the reserve water in the inner lining would not be enough to continue to protect the outer shell from charring. On the other hand, if the outer shell allowed too rapid water absorption to the inner lining, the final garment would be extremely heavy and place the water where it would not be instantaneously available.

Table VI shows four candidate fabric assemblies as to their water absorption characteristics. Assembly N-9/7:IL-12 exhibited the lowest amount of water absorbed with 64.5% in the outer shell and only 35.5% in the wettable inner lining. The other three assemblies have significantly higher amounts of water with a reverse percentage distribution between outer shell and inner lining. Table VI results also show that the needle punched 7-ounce rayon batt to a 7.8-ounce wool outer shell fabric in assembly with an intimate blend 50% wool/50% rayon, needle punched 12-ounce batt (0.168 inch thick) inner lining, approaches the optimum type of fabric combinations required.

F. "Wetting-Out" Characteristics Using Protein Foam

Table VII shows "wetting-out," wicking and water absorption characteristics of five fabric assembly combinations when sprayed with protein foam under controlled conditions. Assembly "A" exhibited the highest weight of water absorbed with a 135% increase in overall weight of the assembly as compared with its dry weight. Assemblies "D" and "E," containing wool fabric outer shells, exhibited the lowest weight of water absorbed. Wool is not considered a good water absorber. Table VII results show the need of needling the rayon batt to the back of the wool fabric for rapid and maximum water absorption to the back of the outer shell a wettable inner lining.

Table V. Wet Test: Time (sec.) for Tempilaq Heat Indicator Temperature Increase (ΔT); Assemblies Exposed to a Radiant Heat Flux of 1.815 $cal/cm^2/sec$

Experimental Assemblies Code No.	Assemblies (1)		Avg. H_2O Pick-up (3) (gms.)	ΔT - 150°F Time (sec.)	Start of Char Outer Shell (sec.)	Wetting Charact. of Inner Lining	Appearance of Tested Fabrics			
	Weight Dry oz/yd^2	Thickness (2) (inches)					Outer Shell	Inner Lining	Vapor Barrier	Insulation Liner
A-19/7-IL-17	64	0.529	55	180+		Poor	Burnt	Surface Charred	No Change	No Change
A-19/4-IL-17	63	0.485	54	180+		Fair	Burnt	Surface Charred	No Change	No Change
A-6/7-IL-17	50	0.493	12	94		None	Blackened	Char Through	Charred	No Change
A-9/7-IL-17	53	0.568	55	180+	133	Poor	Char Through	Singed	No Change	No Change
A-9/4-IL-17	50	0.524	66	180+	123	Good	Char Through	Singed	No Change	No Change
N-6/4-IL-17	47	0.427	70	180+		Good	Char Through	Singed	No Change	No Change
S-19-IL-17	58	0.373	71	180+		Good	Burnt	Slight Singe	No Change	No Change
S-9-IL-17	48	0.367	53	180+		Good	Charred	Singed	No Change	No Change
A-19/7-IL-16	63	0.358	47	180+		Poor	Burnt	Char Through	Charred	No Change
A-19/4-IL-16	62	0.425	38	180+		Poor	Burnt	Char Througn	Char Spot	No Change

Table V. Wet Test: Time (sec.) for Tempilaq Heat Indicator Temperature Increase (ΔT); Assemblies Exposed to a Radiant Heat Flux of 1.815 cal/cm^2/sec (cont'd)

Experimental Assemblies Code No.	Assemblies (1) Weight Dry oz/yd^2	Assemblies (1) Thickness (2) (inches)	Avg. H_2O Pick-up (3) (gms.)	ΔT - 150°F Time (sec.)	Start of Char Outer Shell (sec.)	Wetting Charact. of Inner Lining	Appearance of Tested Fabrics: Outer Shell	Inner Lining	Vapor Barrier	Insulation Liner
A-6/7-IL-16	49	0.433	18	131		None	Blackened	Char Through	Charred	Singed
A-9/7-IL-16	52	0.508	48	180+		Fair	Char Through	Singed	No Change	No Change
A-9/4-IL-16	49	0.464	27	180+		Poor	Char Through	Char Through	Charred	No Change
N-6/4-IL-16	46	0.367	42	180+		Fair	Char Through	Surface Char	No Change	No Change
A-19/7-IL-6	52	0.381	39	180+		Poor	Burnt	Singed	No Change	No Change
A-19/4-IL-6	52	0.337	61	180+		<Good	Burnt	No Change	No Change	No Change
A-6/7-IL-6	39	0.345	22	77		None	Blackened	Char Through	Charred	No Change
A-9/7-IL-6	42	0.420	36	180+		>Good	Char Through	Singed	No Change	No Change
A-9/4-IL-6	51	0.376	40	180+		<Good	Char Through	Slight Singe	No Change	No Change

Table V. Wet Test: Time (sec.) for Tempilaq Heat Indicator Temperature Increase (ΔT); Assemblies Exposed to a Radiant Heat Flux of 1.815 cal/cm^2/sec (cont'd)

Experimental Assemblies Code No.	Assemblies (1) Weight Dry oz/yd^2	Assemblies (1) Thickness (2) (inches)	Avg. H_2O Pick-up (3) (gms.)	ΔT - 150°F Time (sec.)	Start of Char Outer Shell (sec.)	Wetting Charact. of Inner Lining	Appearance of Tested Fabrics: Outer Shell	Appearance of Tested Fabrics: Inner Lining	Appearance of Tested Fabrics: Vapor Barrier	Appearance of Tested Fabrics: Insulation Liner
A-9/7-IL-12	50	0.473	36	180+	118	Poor	Char Through	Char Through	Charred	No Change
A-19/7-IL-7B	54	0.467	31	180+		Poor	Burnt	Char After Glow	Charred	No Change
A-6/7-IL-7B	40	0.431	5	59		None	Blackened	Char After Glow	Charred	No Change
A-9/7-IL-7B	43	0.506	42	180+		Fair	No Change	No Change	No Change	No Change
A-9/4-IL-7B	34	0.462	40	180+		Good	Char Through	Singed	No Change	No Change

(1) Assemblies contain, in addition to listed assemblies, a neoprene-coated nylon vapor barrier and a wool fleece insulation material; first listed fabric, in all cases, is considered the face.

(2) Thickness measured at 0.1 psi foot pressure.

(3) Water penetration tester using 4" x 8" test specimens.

Table VI. Percentage Water Absorption (1) of Outer Shell to Wettable Inner Lining, in Assembly

Assemblies (2) Code No.	Total Water Absorbed (gms.)	Outer Shell Water Absorbed (gms.)	Outer Shell % Water Absorbed	Inner Lining Water Absorbed (gms.)	Inner Lining % Water Absorbed
N-9/4-IL-17	51.4	12.9	23.5	38.3	74.5
N-9/7-IL-17	56.1	18.7	33.0	37.5	67.0
N-6/4-IL-17	77.0	19.8	26.0	57.2	74.0
N-9/7-IL-12	36.8	23.6	64.5	13.2	35.5

(1) Apparatus used for water absorption study was the rain penetration tester with a 6-foot head, and a "wetting-out" time of 4 seconds on a 4" x 8" specimen.

(2) Assembly Nos. beginning with "N" refer to needle punched outer shell fabrics; "IL" refers to inner lining felts.

Table VII. "Wetting-Out" Characteristics of 30" x 30" Assembly Panels, Using Protein Foam

Assembly Code No.	Component Materials in Assembly (1)	Weight of Water Absorbed (oz.)	% Weight Increase of Wet Assembly	Visual Observations
A	1. N-6/4 2. IL-6	31	135	1. Total wet-out 2. Large wet spot
B	1. N-6/4 2. IL-16	27	90	1. Total wet-out 2. Small wet spot
C	1. S-19 2. IL-17	18	75	1. Total wet-out 2. Good absorption of water by inner lining
D	1. 5 oz. 100% wool fabric (unfulled) 2. IL-7	15	58	1. Back of shell fabric only damp 2. Inner lining dry
E	1. 8.7 oz. 100% wool fabric (unfulled) 2. IL-17	10	55	1. Slight wet-out 2. Inner lining dry

(1) Standard vapor barrier and insulation lining, respectively, were added to the back of component materials to complete test assembly panels.

VII. DISCUSSION OF FINDINGS: GARMENT EVALUATION

The experimental prototype garment (coat and trousers) was field tested and reported on, Appendix "A." This garment contained the 10-ounce wool/rayon needle punched outer shell, 17-ounce wool/rayon wettable inner lining, neoprene-coated nylon taffeta vapor barrier and 16-ounce wool fleece insulation liner. The total assembly weighed about 47 oz/yd^2 with a thickness of 0.427 inch. The garment was worn during regular pilot crash-rescue demonstrations.

It was visualized that this garment would be unacceptable because it was too bulky, uncomfortable and extremely heavy after "wetted-out." The dry weight of the medium size coat and trousers was about 13 pounds, as compared to about 14 pounds 8 ounces for a standard medium size aluminized garment. The "wetted-out" non-reflective garment exhibited a final wet weight, taken after the completion of the first test, of about 21 pounds, and after the second test of about 31 pounds. Appendix "A" reported that the increased weight did not appear critical.

Overall comments by the firefighter, as reported in Appendix "A," was that the garment afforded excellent protection during pilot crash-rescue operations and the increased wet weight did not hinder his ability to perform his primary mission. The garment was found acceptable for the purpose intended. A visual inspection of the worn garment showed a large friable char area on the right sleeve below the elbow which occurred during the first test. The firefighter noted that the charred area would not by itself render the garment unusable.

VIII. CONCLUSIONS AND RECOMMENDATIONS

Appendix "A" field evaluation reported that the firefighter considers, "this type of garment was the most comfortable one that he has worn." The report also concludes that, "this suit, with the suggested improvements, would have all the favorable characteristics required for a fire fighting suit and would render maximum protection and safety features to the firefighter."

After analysis of results, it can be concluded that any number of fabric combinations can be used for the outer shell and wettable inner lining. Some of the more important physical characteristics for each fabric layer within the assembly can be stated as follows:

1. A single needlepunched outer shell fabric in lieu of a two-layer system.

2. The outer shell should be fire resistant and highly water absorbent.

3. Rapid 2-second wicking of the water from the outside to the back of the outer shell will be required.

4. The outer shell should be lightweight (8 to 13 oz/yd^2), flexible and easy to sew into garments.

5. The wettable inner lining should be an intimate blend of 50% fire-resistant fiber and 50% highly water absorbent fiber in a needle punched construction.

6. The inner lining should weigh about 10 to 12 oz/yd^2.

7. The density and percentage fiber content of the inner lining will depend on the total water pick-up from the outer shell fabric. The water pick-up is critical and has to be closely controlled.

Based on the favorable report received from the Naval Damage Control Center, Appendix "A," the non-reflective wettable concept could be used to make heat-protective garments. Emphasis would be placed on reducing the bulkiness and weight of the garment by using newly developed fire-resistant lightweight fabrics and redesigning the garment. The bulk and weight of the candidate experimental assemblies could be further reduced with a better understanding of the fire environment, reference 4, and use of newly developed laboratory test equipment which more closely reproduces the heat flux of airplane fuel fires and accurately measures the heat transfer to the back of the assembly.

However, it is not recommended to continue to pursue this work at this time. The firefighters persist in their need for a very lightweight garment that is not bulky. At this point in the development work of a non-reflective garment, bulk and weight cannot be reduced sufficiently to satisfy the user. The concept of this non-reflective garment is solid and, if required, the development work can be reopened with the emphasis placed on reducing bulkiness and weight.

APPENDIX "A"

FF/WT:311
9800
Ser: 451
20 Sep 1966

From: Commanding Officer, U.S. Naval Damage Control Training Center, U.S. Naval Base, Philadelphia, Pennsylvania 19112
To : Officer in Charge, U.S. Naval Supply Research and Development Facility, Naval Supply Center, Bayonne, New Jersey 07002

Subj: Fire Fighting Suit; evaluation of

1. Two tests using the new type fire fighting suit were conducted at this command at 0930, 18 and 25 August 1966. Results, comments and recommendations are listed below.

DESCRIPTION OF THE SUIT — Two piece suit with bunker type coat and shoulder strap trousers. Aluminized hood with chin strap and extra brace attached to helmet. Made of wool with nylon insulation inserted. Coat has corduroy collar with asbestos sewed around the open end of each sleeve. Trousers have asbestos sewed around bottom of each leg.

TYPE OF FIRE BOTH TESTS — 30 to 40 gallons of gasoline sprayed over airplane and on the flight deck under the airplane.

PROCEDURE FOR FIRST TEST — The gasoline was ignited and allowed to burn for ten seconds. During this pre-burn time, the suited fire fighter was thoroughly wetted down with standard protein foam. He then proceeded toward the plane and climbed the ladder to rescue the dummy pilot. The fire fighter then descended the ladder and left the flight deck area. "Stay time" was approximately 2 minutes.

RESULTS OF FIRST TEST — The right sleeve of the fire fighting suit coat was charred. The fire fighter experienced no heat from the burning gasoline except that, as he stated, he felt some heat on the back of his hands; especially the right hand.

The suit weighed approximately 13 pounds dry and approximately 21 pounds after the test. The fire fighter did not notice the added weight.

PROCEDURE FOR SECOND TEST — The suited fire fighter was wetted down thoroughly with standard protein foam. The gasoline was then ignited. The fire fighter proceeded toward the plane through the burning gasoline. The fire was very hot and it was noted that the fire fighter hesitated for an instant. The reason for the hesitation will be explained later. He then proceeded up the ladder and rescued the dummy pilot from the cockpit. Next, he handed the dummy pilot to his assistant and descended the ladder. He then left the flight deck area. His "Stay time" in the hottest part of the fire was timed at 10 seconds, the amount of time that he hesitated, because he said that he had difficulty in breathing. Total "Stay time" in the burning area was approximately 1 minute and 30 seconds.

RESULTS OF SECOND TEST

The fire fighter felt some heat under his hood. This was probably at the same time that he had trouble in breathing. He also felt some heat from the bottom of the coat at the front. Further, the heat was quite noticeable by the fire fighter on the backs of his hands. No fogging of the face shield occ red.

EVALUATION BOTH TESTS

The fire fighter wearing the suit, a Navy man who has worn many different types of fire fighting suits, commented that this type was the most comfortable one that he has worn.

This suit is of a good weight; it is not bulky and it is easy to maneuver in.

The gloves are bulky and stiff and allow some heat penetration.

The hood is much improved over the last type tested. The chin strap and extra brace held it firmly in place.

On the coat, the wrist openings of the sleeves are too small. A wearer with large hands would have difficulty in sliding his hands through the openings.

Approximate weight of the suit before being thoroughly wetted down was 13 pounds. The approximate weight after being wetted down is 31 pounds. This final weight was taken at the completion of the test.

Water seeped through the bottoms of the trouser legs below the points at which the insulation ended.

COMMENTS AND RECOMMENDATIONS

The material used in this suit has excellent heat resistant properties. However, if the suit is not thoroughly wetted down before being subjected to severe heat, the material will weaken and break-down, as was noted from the charred sleeves of the suit in the first test. Alteration or elimination of the collar, since it is quite bulky around the wearer's neck, would be advantageous.

Widen the sleeves at the wrist openings. Continue the insulation to the bottoms of the trouser legs.

Insert anklets in the trouser leg openings and make a similar addition in the coat sleeves. Improve the flexibility of the gloves so that objects may be firmly grasped and also improve the heat resisting properties of the gloves. The suit dried thoroughly in 24 hours, but the foam odor remained.

This suit, with the suggested improvements would have all the favorable characteristics required for a fire fighting suit and would render maximum protection and safety features to the fire fighter.

M. V. MARTINI

Copy to:
BuPers (Pers-C21)
CO NAVSCOLCOM T.I.

APPENDIX B. REFERENCES

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3. Tempilaq (dries to dull finish), Manufactured by Tempil Corporation, New York, New York.

4. Graves, K. W., "Fire Fighters' Exposure Study," Cornell Aeronautical Laboratory, Inc. Report, dated December 1970.