ARMORED MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

PROJECT NO. 20 - STUDIES OF COLD WEATHER CLOTHING

Report On

Sub-Project No. 20-2, The Insulation Provided by Windbreaks
(OQMG Test No. 57 - II)

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Project No. 20-2 1 June 1944

ARMORED MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

Project No. 20-2
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1 June 1944

1. PROJECT NO. 20 - Studies of Cold Weather Clothing. Report on Sub-Project No. 20-2 - The Insulation Provided by Windbreaks. (OQMG Test No. 57-II).

a. Authority - 2nd Ind. C/G AGF, 450 (21 Jan 44) GNRQT 11/69428.

b. Purpose - To determine the relative influence upon overall insulation of windproof overgarments made of materials having different wind permeabilities.

2. DISCUSSION

a. The contribution made by outer garments of low air permeability to the overall insulative value of cold weather garments and to the comfort of the wearer is uncertain, although no one doubts either the value or the necessity of an outer windproof layer. It has been suggested that the degree of windproofing necessary depends upon the relative permeability of the underlying layers. The thicker and the more permeable the under garments, the greater is the necessity for a good windproof since the increased heat losses which occur with wind arise primarily from air exchange within the clothing. If the layer most immediate to the windproof outer garment offers some resistance to air movement, the possible increase in heat loss by convection and air exchange with wind is consequently diminished. This can be illustrated by comparing thermal experiences under the two conditions of use of the alpaca-mohair pile garments of the Arctic issue. If the pile is placed outside, next to the windproof garment, greater heat losses occur with wind than if the backing of the pile is worn adjacent to the outer garment.

b. Since the prescribed manner of use of the pile garment in the Arctic zone issue is to wear the backing next to the windproof layer, the extent to which the insulation value of the assembly can be improved by altering the permeability characteristics of the windproof outer cloth is perhaps questionable.

c. Tests have been conducted on both men and on a copper cylinder dressed in Arctic issue clothing altered only by the substitution of outer windbreak garments, the air permeability of which varied from zero (0) to twenty (20) cubic feet per square foot per minute. Results are presented in Appendix A. Lists of clothing and comments thereon are given in Appendix B and C.

3. CONCLUSIONS

a. No differences were apparent between the four types of wind-

break materials at zero (0) wind velocity.

b. The herringbone twill assembly broke down when tested in wind velocities of five (5.0) and nine and six tenths (9.6) miles per hour.

c. The remaining three windproof garments proved essentially satisfactory under conditions of rapid air movement and only minor differences were observed between them.

4. RECOMMENDATIONS:

a. That windproof garments be made from fabrics having an air permeability of at least 10 cu. ft./sq.ft./min., which provides satisfactory protection from winds up to nine and six tenths (9.6) miles per hour.

Submitted by:

Steven M. Horvath, Captain, SnC

APPROVED Willard Machle
WILLARD MACHLE
Colonel, Medical Corps
Commanding

Incls.
#1 Appendix A
#2 Tables 1 to 4
#3 Figures 1 to 5
#4 Appendix B
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APPENDIX A

I. PROCEDURES

These experiments were conducted in the cold room for the most part at an environmental temperature of -10°F (-23.3°C). Other temperatures were 0°F (-17.8°C) and -33°F (-36°C). Previous experience with the Arctic issue at 0°F had demonstrated that men sitting quietly can remain in comfort for periods of four to five (4 to 5) hours. However, exposure at an ambient temperature of 0°F would necessitate rather long experimental periods and other factors such as hunger, boredom, etc. might become the deciding elements of the tests. It was also known that the Arctic issue offered adequate protection for two to three (2 to 3) hours at -20°F. Therefore it was felt that an intermediate temperature of -10°F would enable differences to be detected without any of the disadvantages of the lower or higher temperatures.

A tunnel 18 feet long, 7 feet high and 5 feet wide was constructed in the cold room. Six fans were so placed that in blowing air through the tunnel turbulence was reduced to a minimum. The tests were conducted at three wind velocities; 0 mph, 5 mph, and 9.6 mph. By placing two subjects on tables, four men could be exposed simultaneously to an uninterrupted air stream. In all of the tests a copper cylinder, clothed in the four layers of the complete Arctic issue, was suspended in the midst of the subjects from the roof of the tunnel and the rate of cooling of the contained water was measured.

Ten (10) representative subjects were selected from a group of fifty (50) men whose subjective responses to cold had been previously determined. Originally we had selected as the four (4) subjects for detailed study, two (2) men who were classified as resistant and two (2) as susceptible to cold. Unfortunately, considerable difficulty was experienced in outfitting the men, owing to discrepancies between the stated and actual sizes of the garments, so that we finally had to employ three (3) men who had been tentatively classified susceptible and only one (1) resistant. During the progress of the test, however, it became evident that the classification of relative resistance is somewhat uncertain and was subject in the majority of cases to considerable daily variation so that the failure to have equality at the outset in number of resistants and susceptibles was not very important.

A standardized procedure was followed prior to each day's test. The men arrived at 0645 hours, ate a standard breakfast, and then rested until they dressed for the test which began at 0830 hours. Tests were conducted both morning and afternoon but only those data obtained during the morning runs are presented here since the subjects' reactions differed somewhat from morning to afternoon.

Skin temperatures were obtained on chest, upper arm, thigh, calf and dorsal surface of the foot; in some cases ten (10) thermocouples were worn. On two subjects, continuous measurements of oxygen consumption were made, one

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with an open circuit and the other with a closed circuit apparatus. Rectal temperatures were obtained by clinical thermometer.

The clothing worn by the subjects is listed in Appendix B. For convenience, the clothing worn and the basic layer principle of the Arctic zone issue are illustrated in Figure 1. Owing to improper fit in certain garments and the availability of only a single nylon windproof suit of small size, a complete set of tests on all subjects in each of the windbreaks was impossible. Nevertheless, a sufficient number of tests were made on all four of these clothing items (Figure 2), with at least two subjects wearing each of the items, so that general conclusions may be drawn.

II. RESULTS

a. Effect of wind upon insulation.

In table 1 are presented data on the insulation value of the standard Arctic assembly, including the sateen outer garments having an air permeability of 5 cu. ft./sq.ft./min. Hourly clo values, determined by the standard procedure, are presented in the table together with the average clo values for the second and third hours. The clo values as determined from the third hour metabolic rate and the predicted equilibrium temperature, θ_e are also given for the five subjects. All values are corrected for the insulation of the surrounding air. During the three (3) hour exposure, the apparent insulation of the Arctic issue was changing. It appears to have increased with time under still air conditions. This was true to a lesser extent at 5 mph wind but not at all with a velocity of 9.6 mph. After the first hour there was a fairly consistent decrease in insulation value with increasing wind velocity.

The insulation afforded by the Arctic assembly with outer garments of four degrees of air permeability is shown in Table 2. At zero wind velocity no material differences were observed between these garments. This was not unexpected since the insulation values obtained with and without any windbreak garments are almost identical. For example, tests on two individuals at zero wind velocity gave the following clo values for the Arctic assembly with and without the sateen windbreaker; 5.3 and 5.2 and 4.0 and 4.4, respectively.

When the wind velocity was increased to 5.0 and 9.6 mph, the clo values decreased in all cases except with the nylon outer garment. The high average insulation at 9.6 mph in this case, however, resulted from an extreme value (7.0) on one of the two subjects, while in the other the insulation value was lower than at 5.0 or 0 miles per hour. The greatest loss of insulation with wind occurred with herringbone twill, the clo value dropping from 5.3 to 3.6.

The decrease in the apparent insulation value of the clothing assembly with increasing air movement results no doubt from the interference with the stability of the bound air layer. Insulation of clothing is essentially determined by the thickness and stability of the air bound between fabric layers and within the fabrics themselves. There is a possible three-fold variation

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in the insulation from a completely static air layer to one within which there is free convection. At high wind velocities two factors may be operating to alter the insulation; circulation within the clothing and internal circulation plus air exchange with the outside; both may result in real increases in heat transfer.

b. Effect of wind on cooling rate.

Neither the values of the cooling constant, K, the mean skin temperature at the end of the exposure period nor the predicted equilibrium temperature θ_e, exhibited great change with the type of outer garment being worn. However, slight trends in the average data relative to wind velocity were observed. The median values for the last mean skin temperatures recorded were 26.0°C, 25.2°C and 24.8°C at wind velocities of zero (0), 5.0 and 9.6 miles per hour, respectively. The predicted equilibrium mean skin temperatures followed this same pattern but were approximately 1.2°C lower. The median values for K, the cooling constant, were 0.720, 0.755 and 0.835 for the three wind velocities. These differences are not significant.

c. Relation of permeability of outer garments to metabolic rate.

Of greatest interest in showing the effect of wind permeability of the outer garment was the changes in metabolic rate with continued exposure. Table 3 presents such data for the sateen outer garment. The metabolic response of the subject under these experimental conditions is approximately the same for the first hour at all wind velocities. During the second and third hours, however, a marked stimulus for extra heat production is evident. The higher the wind velocity, the sooner developed is the stimulus to extra heat production and the greater the response. In this connection it is interesting to note that as a rule the greatest changes in stored heat occur during the first hour. Variable but generally much smaller demands on this heat supply were made during the next two hours. Neither the absolute amount nor the rate of the heat loss from storage appears to be correlated with the stimulus to extra heat production.

Men dressed in the nylon, sateen, or khaki twill windproof garments had similar metabolic responses to increased air movement and duration of exposure. The herringbone twill garments offered less protection against wind, however, and the extra heat production of subjects dressed in this garment was greater than with the others, the hourly metabolic rates being: 42,93 and 79 cal/M²/hr.

d. Subjective responses.

The subjective responses of men are significantly altered when they are exposed to cold and wind (Figures 3,4 and 5). Subject He., Figure 3, was the most resistant subject in this study. When he wore adequate outer windproof garments (sateen or nylon) he did not become uncomfortable even at the highest wind velocity. The herringbone twill outers, however, failed to maintain comfort at 5.0 mph and with a wind velocity of 9.6 mph it was definitely inadequate. For less resistant subjects the herringbone twill

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was equally inadequate at 5.0 mph wind. In Figure 4 are recorded the subjective sensations for Subject Gr. in the two best windproof outer garments, sateen and nylon. He remained relatively comfortable at zero wind velocities but with air movement his subjective sense of discomfort increased. He appeared to be less comfortable when wearing the nylon than with the sateen outer garment. This is in striking contrast to the subjective experiences of subject He shown in Figure 3. Comparisons of subjective experiences of subject Va dressed in sateen and khaki twill outers are presented in Figure 5. Slightly better protection appears to be offered by the sateen garments.

Exposure of men to rapid air movements diminishes the time from initial exposure to the appearance of sensations of discomfort. Although general body comfort, as evidenced by time of onset of shivering, appears to be most readily influenced by wind, the onset of discomfort in the extremities does not lag very far behind. Shivering, continued for any length of time, is a distressing experience, fatiguing and distracting. Fine muscular control is almost impossible and concentration is difficult, one thought dominating - the desire for termination of shivering. Under such conditions the general overall efficiency of a soldier is impaired and the necessity for good windproof garments is quite clear.

III. SUMMARY

No differences were apparent between any of the windbreakers at zero (0) wind velocity. When the wind velocity was increased to five (5.0) and to nine and six tenths (9.6) miles per hour, evidences of some breakdown were apparent in all of the garments. Only one, the herringbone twill, could be considered to have failed completely. The differences between the other windproof garments was of such small magnitude as to make impossible the drawing of any conclusions as to their respective superiority. On the basis of present information it would appear that garments made of any material having an air permeability of 10 cu. ft./sq.ft./ min. or less would offer adequate protection.* Because of the factor of high heat losses from the extremities in present clothing the relative importance of permeability of windproof garments cannot be fully demonstrated.

The need for adequate protection for mechanized troops is clearly indicated by this study. Such personnel are continually exposed to local air streams or general wind and subjectively and objectively they may be in more strigent straits than their fellow soldiers walking along the road. The necessity for providing them with the best windproof protection is obvious.

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* Men dressed in these four windproofs have walked for periods of from one half hour to two hours prior to quiet sitting. No appreciable differences were noted in either the thermal insulation of the garment assembly or the subjective sensations experienced by the subjects whether their sitting exposures were or were not preceded by activity.

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TABLE 1

INSULATION VALUE ON THE STANDARD ARCTIC ASSEMBLY

IN RELATION TO WIND VELOCITY

Subject	Wind Velocity mph	Insulation				
		Clo Units, by standard method				Clo Units, by θ_e
		First Hour	Second Hour	Third Hour	Average of 2nd and 3rd hours	
Go.	0	3.1	3.4	—	3.4	5.2
	5	4.3	3.9	5.5	4.7	5.0
	9.6	2.7	3.1	4.1	3.6	4.0
He.	0	3.5	5.7	3.8	4.7	5.3
	5	2.9	4.3	3.2	3.8	4.5
	9.6	2.7	3.8	2.8	3.3	3.7
Gr.	0	4.8	4.1	4.3	4.2	4.9
	0	3.4	4.4	5.9	5.1	4.9
	5	3.6	4.2	4.4	4.3	4.2
	9.6	3.3	3.5	2.8	3.2	3.7
Va.	0	3.8	5.0	4.8	4.9	5.0
	5	3.2	5.0	3.8	4.4	5.2
	9.6	3.5	4.5	4.3	4.4	5.5
Ba.	0	2.5	4.3	3.0	3.7	3.9
	5	2.3	4.8	4.2	4.5	4.1
	9.6	5.2	2.9	3.7	3.3	4.1
Average for all subjects	0	3.5	4.5	4.5	4.5	4.9
	5	3.4	4.4	4.2	4.3	4.6
	9.6	3.5	3.5	3.5	3.5	4.2

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TABLE 2

INSULATION VALUE OF STANDARD ARCTIC ISSUE IN

RELATION TO THE AIR PERMEABILITY OF THE OUTER GARMENT LAYER

Average Values From Two to Six Subjects
In Clo Units, Calculated from θ_e

Arctic Issue with outer garments of the following windproof materials	Wind Velocity, Miles Per Hour		
	0	5.0	9.6
Nylon*	5.3	4.3	5.8
Sateen-9 oz.	4.9	4.6	4.2
Khaki Twill	5.4	5.2	4.7
Herringbone Twill	5.4	4.3	3.6

* Two Subjects

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TABLE 3

HOURLY METABOLIC RATES* IN RELATION TO WIND VELOCITY

STANDARD ARCTIC ASSEMBLY WITH SATEEN OUTERS

AVERAGES FOR SIX SUBJECTS

	0 M. P. H.		5.0 M. P. H.		9.6 M.P. H	
	Cals/M^2/ Hr.	Per Cent Increase	Cals/M^2/Hr.	Per Cent Increase	Cals/M^2/Hr.	Per Cent Increase
First Hour	38.3		39.0		39.4	
Second Hour	42.7	11	45.2	16	63.6	61
Third Hour	51.3	34	60.1	54	67.8	73

* M-(E+A)

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TABLE 4

WEIGHT AND WATER RETENTION OF VARIOUS TYPES OF WINDBREAKS

Type Windbreak		Weight (grams)		% Water Removed after	
		Before Drying*	After Drying	24 hr. drying	141 hrs drying
Sateen	Parka	950	907	2.9	4.4
	Trousers	737	695	3.8	5.7
Nylon	Parka	468	425	3.0	9.0
	Trousers	400	340	0.0	14.2
Herringbone Twill	Parka	933	908	3.0	3.0
	Trousers	7.0	634	8.0	10.0
Twill (8.2 oz.)	Parka	933	850	4.5	9.0
	Trousers	680	634	6.2	6.2

* All clothing was left for 72 hours at 75°F and 50% relative humidity prior to being placed in oven to dry.

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The Arctic Zone Issue As Worn, Illustrating The Layer Principle

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Project No. 20-2 FORT KNOX, KY. Figure 1

Incl. #3

Four Types of Windbreaks Tested (From Left To Right
Nylon, Sateen 9 oz., Twill 8.2 oz, and Herringbone Twill)

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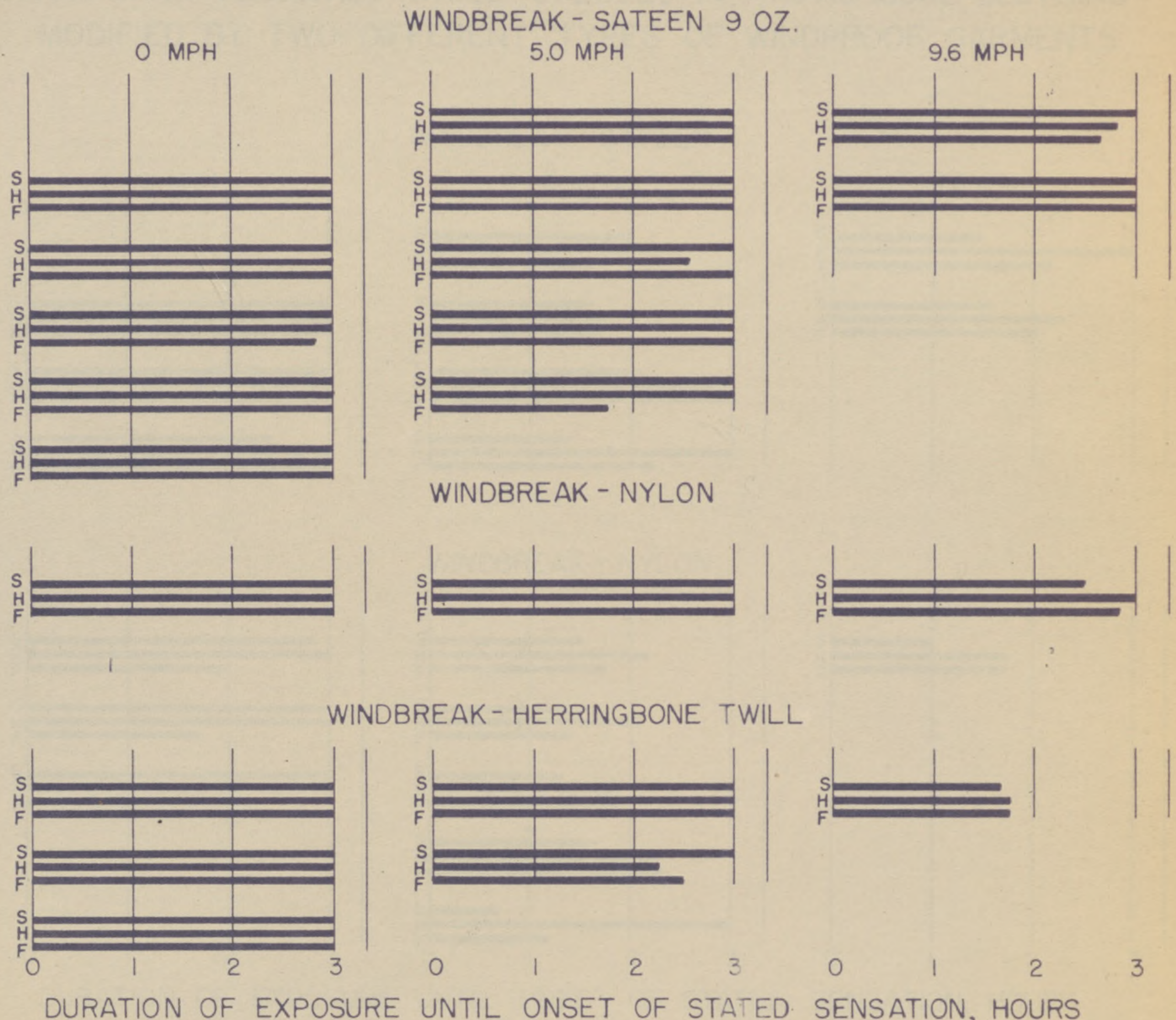
Project No. 20-2 — FORT KNOX, KY. — Figure 2

Incl. #3

FIG. 3

SUBJECTIVE REACTIONS OF SUBJECT HE. EXPOSED AT -10° F TO VARYING WIND VELOCITIES WHILE DRESSED IN ARCTIC ISSUE AND DIFFERENT WINDBREAKERS



-KEY-

F = ONSET OF PAIN IN FEET
H = ONSET OF PAIN IN HANDS
S = ONSET OF SHIVERING

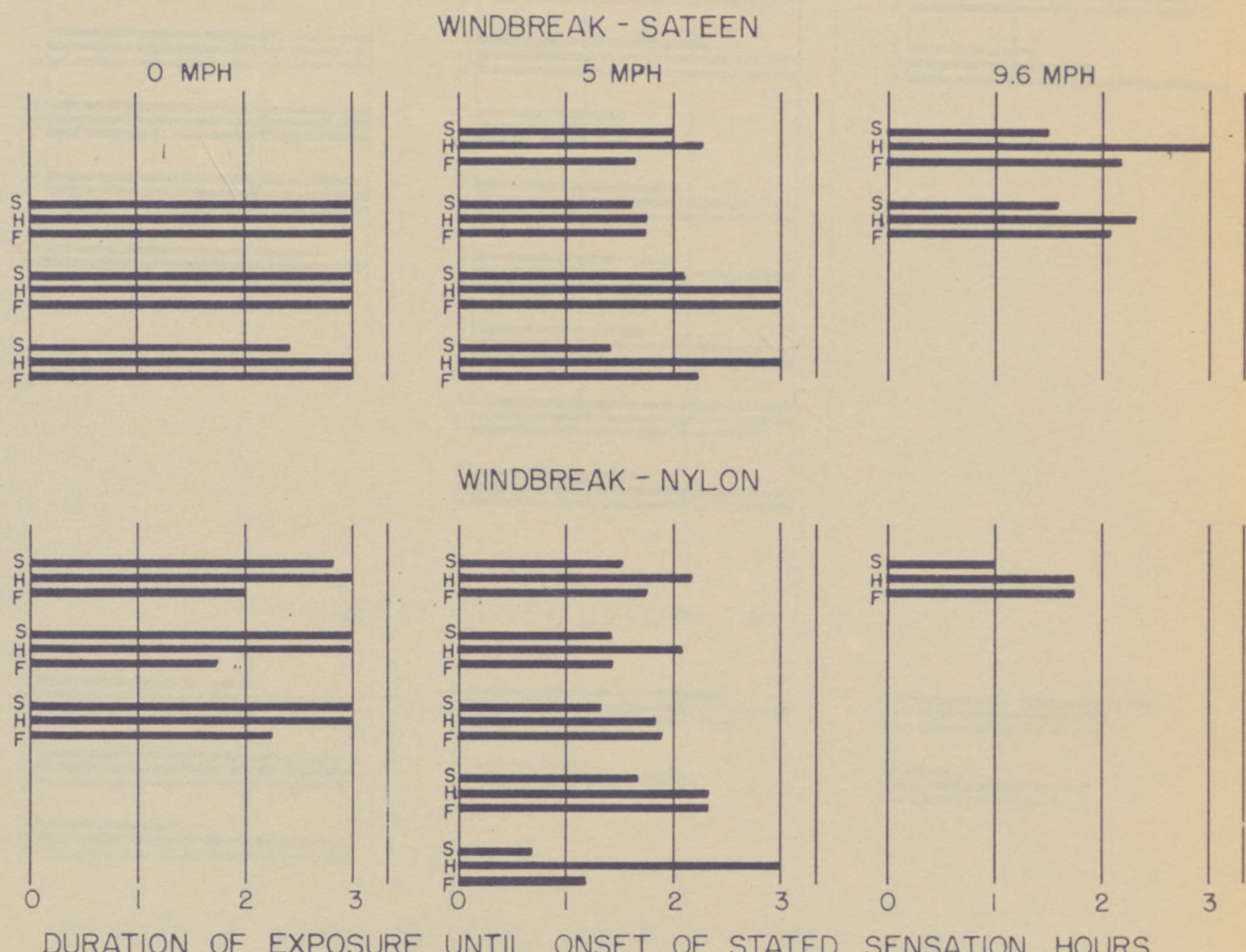
EXTENSION OF LINE TO 3 HRS. INDICATES NO STATED SENSATION DURING EXPOSURE

Incl # 3

FIG. 3

FIG. 4

SUBJECTIVE REACTIONS OF SUBJECT GR. EXPOSED AT -10° F TO VARYING WIND VELOCITIES WHILE DRESSED IN ARCTIC ISSUE CLOTHING MODIFIED BY TWO DIFFERENT TYPES OF WINDPROOF GARMENTS



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Incl #3

FIG. 4

FIG. 5

SUBJECTIVE REACTIONS OF SUBJECT VA. EXPOSED AT -10°F TO VARYING WIND VELOCITIES WHILE DRESSED IN ARCTIC ISSUE CLOTHING MODIFIED BY TWO DIFFERENT TYPES OF WINDPROOF GARMENTS

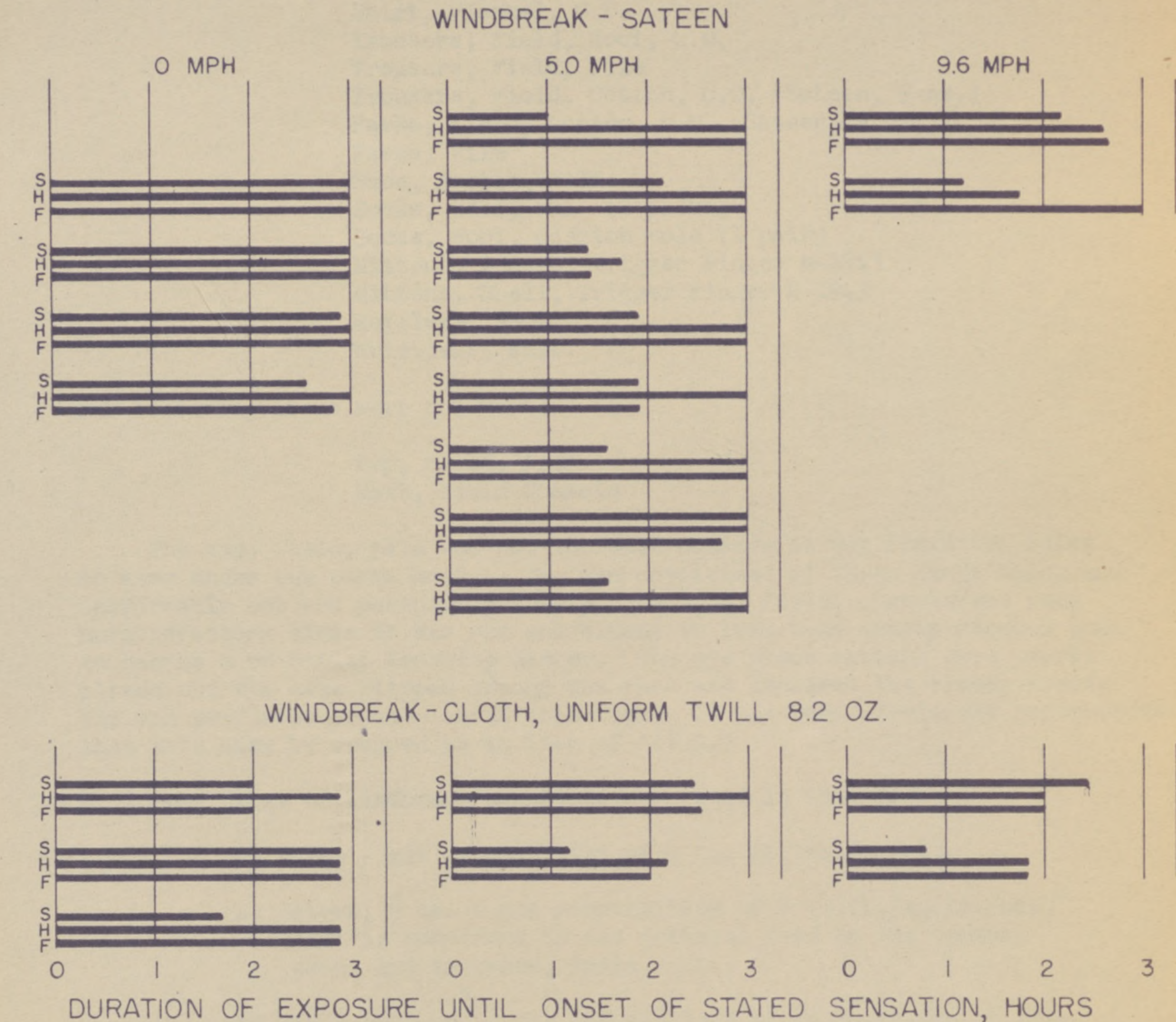

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FIG. 5

APPENDIX B

Control clothing worn by subjects in this test was as follows:

Drawers, Wool, 50/50
Undershirts, Wool, 50/50
Shirt, Flannel, O.D.
Trousers, Field, Wool, O.D.
Trousers, Field, Pile
Trousers, Field, Cotton, O.D. (Sateen, 9 oz.)
Parka, Field, Cotton, O.D. (Sateen, 9 oz.)
Parka, Pile
Shoe, Arctic, Felt
Socks, Wool, ski (2 pairs)
Socks, Wool, cushion sole (1 pair)
Mittens, Insert, Trigger Finger M-1943
Mittens, Shell, Trigger Finger M-1943
Mufflers, Wool
Wristlets, Knit.

The following items were not worn:

Cap, Field, Pile
Mask, Field Chamois

The cap, field, pile was not included because it was found too bulky to wear under the parka hoods. The men complained of their heads being uncomfortably hot and perspiring freely. The mask, field, chamois was very unsatisfactory since it was wet and clammy in less than thirty minutes and so became a potential frosting danger. The eye piece cutouts were poorly placed and the mask slipped around the face and impaired the visual field. The men preferred to do without this item. It has been previously recommended that this mask be dropped as an item of issue.*

Four types of windbreak materials were used in this test:

(a) Nylon - air permeability of 0 cu. ft./sq.ft./min.

(b) Sateen, 9 oz. - air permeability of 5 cu.ft./sq.ft./min. (This is identical to the material used in the control parka and trousers, field, O.D.)

(c) Twill, 8.2 oz. - Air permeability of 10 cu.ft./sq.ft./min.

(d) Herringbone Twill - Air permeability of 20 cu.ft./sq.ft./min.

Some physical characteristics of these garments are presented in Table 4.

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* Project No. 11 - Test of Clothing, Battle, Four Zone, Cold and Arctic Issues - September 30, 1943.

Incl #4

APPENDIX C

During the progress of tests on the Arctic assembly a number of minor defects in the garments of this issue were observed. It is believed that attention to these defects would materially increase the usefulness of the assembly.

1. The fur trim of the pile parka does not appear to serve any useful purpose in its present form. The inferior quality, poor cut and haphazard attachment of the fur piece to the garment may be seen in several of the illustrations in this and other reports. The guard hairs protrude in every direction - primarily into the eyes and face. In addition to being annoying, there is considerable interference with vision. Irritation of the skin from rubbing by wet fur frequently occurs.

2. The mask, field, chamois is definitely an inferior item. Comments have been made previously.

3. Knee protection is still a source of difficulty. Knees frequently have become unbearably cold in our sitting subjects. The fabrics over the patellar area are compressed with consequent loss of protection over an area having poor circulation. A number of methods can be used to eliminate this difficulty. The Canadian procedure of inserting a diamond shaped piece into the garment at the popliteal area may offer a solution.

4. Draw strings on the outer parka, due to breakage of wooden balls on the cords, are frequently lost or one end is pulled within the channel and cannot be recovered. Tacking the cords in the center of the back would solve this problem.

5. The shoes, felt, Arctic should be made two or three inches higher. There is often a gap between the top of the shoe and the pile trousers. The suggested modification would not only provide increased insulation above the ankle but would prevent snow from getting into the boots.

6. Fly opening of the Pile Trousers needs attention. At present when a man stoops over, a decided gap appears in the fly. It continues to stay open or bunches up when the erect position is resumed.

7. Fit of the pile parka around the body has been a frequent source of complaint. The coolness in the small of the back has been attributed to the loose fit of the inner parka. A possible solution for seated men may be the insertion of a draw string so that the bottom of the garment can be tied down when required.

8. Constriction and binding of the pile jacket across the back and under the arms has been mentioned in a previous memorandum from this laboratory. This may be due to the pile having been added as a liner in a jacket pattern designed to be made without a lining.

9. Creeping of pile garments is still a serious defect. When men are

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4. Draw strings on the outer parka, due to breakage of wooden bolls on the cords, are frequently lost or one end is pulled within the channel and cannot be recovered. Tacking the cords in the center of the bars would solve this problem.

5. The shoe, felt, Arctic should be made two or three inches higher. There is often a gap between the top of the shoe and the pile trousers. The suggested modification would not only provide increased insulation above the ankle but would prevent snow from getting into the boots.

6. The crotch of the pile trousers needs attention. At present when a man sits or squats, a [illegible] gap appears in the fly. It continues to stay open or [illegible] up when the erect position is resumed.

7. Fit of the pile parka around the body has been a frequent source of complaint. The coolness of the small of the back has been attributed to the loose fit of the inner parka. A possible solution for seated men may be the insertion of a draw string so that the bottom of the garment can be tied down when required.

8. Constriction and binding of the pile jacket across the back and under the arm has been mentioned in a previous memorandum from this laboratory. This may be due to the pile having been added as a liner in a jacket pattern designed to be made without a lining.

9. Leakage of pile garments is still a serious defect. When men are

working the resulting bunching of the pile and underlying garments is decidedly uncomfortable and interferes with the performance of the job at hand.

10. Incorrect size labeling was a major problem with the garments sent to the laboratory. Generally, garments one or two sizes larger than those usually worn by the men had to be issued. However, in a few cases smaller sizes than those required fitted the men very well. The importance of proper sizing in fitting out large number of men should not be underestimated. A good deal of the present difficulty with garments issued is a size problem and to increase the supply sergeants difficulty by improper sizing of garments will make the proper fitting of troops just that much more unlikely. The problem here appears to be a simple case of carelessness in marking since the same size mark was found on a wide range of actual sizes.

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